CLINICAL ANATOMY
(A Problem Solving Approach)
Neeta V Kulkarni

2nd Edition
Forward
BR Kato

JAYPEE
CLINICAL ANATOMY

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Second Edition

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Foreword
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Dedicated to

The memory of my husband Dr VP Kulkarni
who was a pillar of strength during the making of first edition
I am extremely happy to write a foreword for the second edition of the book entitled Clinical Anatomy (A Problem Solving Approach) by Dr Neeta V Kulkarni. Generally, we observe that most books of anatomy and embryology are mainly based on description of structures. Like a born teacher, she has not only described structure but has shown her talent and maturity of thought by stressing the main purpose of knowing gross anatomy and embryology.

In the book, the author has given considerable justice to the living anatomy by inclusion of images of plain radiographs, computed tomography (CT), magnetic resonance imaging (MRI), digital subtraction angiography (DSA) and three dimensional reconstruction images using multidetector CT. Added to this, there are intraoperative photographic views of various internal organs in the body. She has shown how technology can be harnessed to convert this so-called static subject into a dynamic entity. She has been an anatomy teacher throughout her career and has assimilated the subject well. Knowledge when it becomes ripe gives wisdom and she has used her experienced wisdom to innovate the presentation according to the need of the day. This edition covers general embryology, genetics, special embryology, gross anatomy and basic knowledge of the tissues of the body with emphasis on application.

The reduction in the time of teaching anatomy at preclinical level is a very unfortunate step. This exhaustive subject deserves ample time to learn and understand. Clinical anatomy for students with its problem-solving approach will minimize the hardships of learning to understand anatomy.

I often used to wonder, if we should have separate anatomy texts catering to the needs of undergraduate curriculum, clinical postgraduate curriculum (as per the specialty chosen) and separate books for anatomists. But now I feel that books like Clinical Anatomy can build the bridges and provide a refreshing anatomical elixir to all involved in providing health care.

Let me wish a wholesome response to the new edition.

BR Kate MS, FAMS, FSAMS
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Preface to the Second Edition

Anatomy is the basis of medical profession as human body is the focus of examination, investigation and intervention for diagnosis and treatment of diseases. There is a re-awakening of the importance of anatomy with the realization that sound knowledge of anatomy is the backbone of safe medical practice. A doctor with sound anatomical knowledge is well-equipped to perform safe procedure or surgery, than the one who makes mistakes by cutting normal anatomical relations of the structure or organ, operated upon (for which the doctor is sued in the court of law for negligence). One must appreciate that application of anatomical knowledge is the ongoing process throughout the medical career. Therefore, clinical anatomy occupies the center stage right from the outset of medical training. There are intentional efforts by health educationists over the world to bridge the gray zone between preclinical anatomy and clinical anatomy. Learning anatomy (which includes gross anatomy, microscopic anatomy, embryology and genetics) in a short span of time is a Herculean task. Therefore, though it is not conceptually difficult, its sheer bulk makes anatomy overwhelming. In this context, a shift towards teaching/learning basic anatomy alongside clinical anatomy is a progressive step. The key to successful and enjoyable learning lies in consciously integrating the basic and the clinical anatomy right from the entry point by initiating the trainees to identify normal anatomical structures in plain radiographs, CT scans, ultrasound scans, MRI, etc. Added to this, they may be exposed to patients presenting with typical deformities due to nerve injury, patients with hemiplegia, paraplegia, etc., patients with obvious congenital defects, patients with thyroid swelling, parotid swelling, etc. This is bound to arouse their interest in learning. Another very interesting approach is to train the trainee in clinical problem solving by using anatomical knowledge. This approach not only convinces the trainees that preclinical anatomy is an integral part of bedside medicine but also expands their thinking capacity (brain power). This approach is indispensable for concept clarity and retention (rather than rote learning).

Giving due regard to the constructive suggestions and comments from readers (both students and teachers) and bowing down to the request of M/s Jaypee Brothers Medical Publishers (P) Ltd, New Delhi, India the work on second edition of Clinical Anatomy (A Problem Solving Approach) was undertaken. The basic theme of the first edition developing skills in anatomical thinking for solving clinical problems has been retained. New chapters have been added on general anatomy (for giving conceptual background about basic tissues), general embryology and genetics besides osteology. All chapters on regional anatomy have been extensively revised and enriched with plenty of new figures including photographs of clinical material (collected from various clinicians) and radiological images (collected from radiologists) to emphasize relevance of anatomy in the practice of medicine. The solved examples on clincanoatomi- cal problems and multiple choice questions (MCQs) (given at the end of each section) not only aid in revising but also lend credence to the theme of the book. Clinical insight, embryologic insight and know more are displayed in boxes.

I am sure that this edition too will spread positive vibes towards this tough subject and will reiterate the fact that the subject is interesting only, if looked through the mirror of its clinical relevance. Moreover, this text can be a good resource material in problem-based learning (PBL) curriculum in graduate medical education.

Neeta V Kulkarni
It is a well-known fact that is documented right from the Greek era that anatomy provides a firm foundation to the edifice of medical education. However, in the new paradigm, the clinical anatomy provides the keystone to this foundation. It must be appreciated that no part of the human body can be learnt in isolation and that relations of the same structure change from region-to-region. These anatomical relations may be the basis of the symptoms of a particular disease or of the signs of the disease or of a clinical test (used for diagnosis of a disease) or of a surgical procedure (used to diagnose and/or treat the disease). Traditionally, we are conditioned to equate anatomy to the science of muscles and bones, which gives the beginner an incorrect impression about the potential of the subject. The key to successful and enjoyable learning lies in consciously correlating the basic and clinical anatomy (like for example, understanding anatomical basis of the symptoms and signs of diseases, surgical procedures, contraceptive measures, understanding embryological basis of congenital anomalies, identifying normal structures in radiographs and comparing them with changes in the disease state, etc.). Medical Council of India (MCI) in its stipulations of 1997 has reduced the duration of the first MBBS course and has recommended problem-based learning in preclinical subjects. This situation demands a fresh approach in which the students are trained to solve clinical problems using the anatomical knowledge gained during the first professional course. To choose essentials of anatomy for first MBBS students from a vast body of anatomical facts posed a challenging task. Reading through the paraclinical and clinical texts besides special interactive sessions with clinical teachers gave an insight (to a certain extent) into how much of anatomy learnt at preclinical level is actually applied to gain sound clinical training. Accordingly, in a few instances, clinically-oriented concepts or interpretations are mentioned along with the conventional. The clinical testing of skeletal muscles is included to make the learning of muscles more meaningful. Thus, the problem-solving approach creates an imprint on the minds of the students that preclinical anatomy is an integral part of bedside medicine. The presentation of the subject matter throughout the text is logical and reader-friendly. Essentials of anatomy covering all regions of the body are encapsulated in a single volume in order to gain a holistic perception of the anatomical structures. The central theme of this text is, developing skills in anatomical thinking for solving clinical problems. It was indeed a Herculean task to give concrete shape to such a complex theme. Let us hope that students will enjoy learning anatomy when they are able to solve clinical problems given at the end of the sections.

Neeta V Kulkarni
Acknowledgments

What was uppermost in my mind while planning the second edition of *Clinical Anatomy (A Problem Solving Approach)* was the fear that without the backing of the living anatomy (portrayed through radiological images, intraoperative photographs of internal organs, photos of clinical examination of patients and of procedures done on the patients) it would be a futile effort. *How to procure the images of clinical material* was a big question mark. But soon lady luck smiled on me when Dr MA Elezy, Head of Department (Anatomy), Karuna Medical College, Palaghat, Palakkad, Kerala, India, began sending me almost on regular basis anatomically relevant images collected from her numerous contacts in clinical fraternity, with missionary zeal. I am immensely grateful to Dr Elezy, her family and friends for being so gracious. I would like to place on record the names of the clinicians who responded to Dr Elezy's call, Dr Sreekumar VK, Professor of Surgery, Medical College, Trichur, Kerala, India; Dr Raghushankar, Associate Professor of Surgery, Karuna Medical College, Palaghat, Palakkad; Dr Kesavan, Anesthesiologist, Medical College, Trichur; Dr NK Sanil Kumar, Kochi, Dr R Vijayakumar, Orthopedic Surgeon, Medical College, Trichur; Dr Bejohn JK, Pediatric Surgeon, Medical College, Trichur; Dr Shameer VK, Medical College, Trichur; Dr Santhosh Nambiar, Medical College, Trichur, and Dr Jamal Medical College, Calicut, Kerala, India.

It was a generous gesture of Dr Girijamony, Head of Department (Anatomy), Medical College, Trichur, Kerala, India to send the CD on laparoscopic anatomy of abdomen and pelvis.

I thank Dr Bertha for the Meckel's scan.

I am ever indebted to the clinical fraternity of Dr Somervell Memorial CSI Medical College, Karakonam, Kerala, India, for their cooperation. Special thanks are due to Dr R Varma, Head of Department (Pediatric Surgery); Dr Vimala, Head of Department (Nephrology); Dr Punithen, Associate Professor of Surgery; Dr Jacob Thomas, Professor of Surgery, Dr Mariam Philip (Dermatology); Dr Regi Ebenezer (ENT); Dr Sara Ammu Chacko, Head of Department, Dr Nita H and Dr Sebastian (Radiodiagnosis); Dr Aneesh Elias and Dr Sara Varghese (Plastic Surgery) and Dr Adeline Thankam (Obstetrics and Gynecology). Special thanks are extended to Dr Paul Augustine, Surgeon from RCC Thiruvananthapuram for providing the image of peau d’ orange.

I am thankful to Dr Chandrakumari and Dr Vilasini Anatomy Department, Gokulam Medical College, Thiruvananthapuram, Kerala, India, for providing the image of sirenomelia—a rare congenital anomaly.

My joy knew no bounds when I received a CD from Dr Avijit Basu, Cardiothoracic Surgeon, Chennai, Tamil Nadu, India, who is my son’s friend, containing images of heart and blood vessels.

I found a multimedia expert, Dr Jeyachandran G (Associate Professor of Biochemistry), who willingly shared the major burden of designing the figures on the newly added topics like general anatomy, general embryology (including genetics) and osteology. He deserves many thanks.

I would like to appreciate the support and encouragement extended by all staff members of anatomy, physiology and biochemistry departments.

The availability of reference books in the college library was a great boon.

My heartfelt thanks are due to Dr Bennet Abraham (Director) and Dr Samson Nissiah (Principal) of Dr Somervell Memorial CSI Medical College, Karakonam, Thiruvananthapuram, Kerala, India for providing institutional and infrastructural support.
It is a great luck to be able to pay respects to one’s teachers of yesteryear from Medical College, Nagpur, Maharashtra, India. Dr BR Kate is a renowned anatomist. He has to his credit a number of research papers, a few of which have been cited in 38th edition of Gray’s Anatomy. He retired as Director of Medical Education, Maharashtra, India. I thank him profusely for the thoughtful foreword. I also thank Dr Kadasne who is a unique blend of a popular anatomy teacher, a practicing surgeon and an author. His recent book on embryology is deftly illustrated with line diagrams.

I will ever remain indebted to Shri Jitendar P Vij, (Chairman and Managing Director), Mr Tarun Duneja (Director-Publishing), Mr KK Raman (Production Manager) and the entire team of M/s Jaypee Brothers Medical Publishers (P) Ltd, New Delhi, India.

Mr SS Shine of DK Press, Neyyattinkara, Thiruvananthapuram, Kerala, India has been an efficient graphic artist and designer without whose help this edition would not have seen the light of the day. Mr Sivaraman was available to draw new diagrams on osteology. He provided the precious photograph of Vesalius, the Father of Modern Anatomy.

My son and daughter (and their respective spouses) are my inspirational strength. I place on record the technical help rendered by Technosys India, Pune, Maharashtra, India, headed by Mr Ujjwal Deshpande.

With all humility in my heart, I place this edition at the feet of Almighty and seek His blessings.
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INTRODUCTION
ANATOMY IN BRIEF

Anatomy is a branch of medical science that deals with understanding the structural organization of the human body so that the doctor knows (to quote few examples) which structure is affected in disease, which structure is examined by him/her and which structure is being cut during surgery. The deep interest in this branch of medical discipline is evident right from the dawn of civilization. The history of human anatomy occupies a prestigious place in 19th and 20th centuries as this science was even then thought of as one of the cornerstones of medical education. The term anatomy is Greek meaning to cut up. In older times anatomy and dissection were synonymous, so to do anatomy was considered to do dissection. However, now we know that dissection is one of the techniques to learn gross anatomy. The development of anatomy as a scientific discipline is a journey of ups and downs. It can be divided into various eras and centuries so that we get a glimpse of the chronology of the developmental landmarks and also about the trials and tribulations faced by the great scientists in the pursuit of the scientific knowledge of the subject.

Greek Era
Hippocrates of Greece (the father of medicine and founder of anatomy) is the first name in the period spanning 469 to 399 BC. He believed that illness has a physical cause and performed dissections on both animals and human. Herophilus (335 to 280 BC) from school of Alexandria in Egypt was the first to perform dissection of human body in public.

Roman Era
Claudius Galen described as prince of physicians ruled the medical science from 130 to 200 AD. He wrote extensively on human anatomy based on his dissections on monkeys and pigs. His authority on the subject remained unchallenged for several centuries.

Dark Ages
The period extending from 3rd to 13th centuries is called dark ages because there was no progress in science and arts in Europe.

Fourteenth Century
An Italian anatomist, Mondino (1276 to 1326) was credited as restorer of human anatomy as he taught anatomy by doing dissections on human bodies and wrote a book called Anathomia based on his observations.

Renaissance (15th and 16th Centuries)
This is a period when both arts and science were revived and flourished. Leonardo da Vinci (1452-1519) was an artist, painter, mathematician and anatomist, all rolled into one. Vitruvian man was his most famous anatomical drawing of a geometrically proportionate human male. He was the inventor of cross sectional and illustrative anatomy.

Andreas Vesalius, a German anatomist and surgeon performed extensive dissections on executed criminals after obtaining special permission from the Pope. He was the first to describe accurate anatomy in his treatise in Latin called de fabrica humani corporis. Vesalius truly
challenged Galenean dogmas. Vesalius is aptly called the father of modern anatomy (Fig. 1.1).

**Seventeenth Century**
William Harvey was credited with discovery of circulation of blood. It is reported that Harvey dissected his own freshly dead family members (father and sister) before burial to confirm his findings. Marcello Malpighi pioneered the use of microscope to understand the histological structure of human tissue (a beginning of microscopic anatomy).

**Eighteenth Century**
This is a very thrilling century as far as anatomy is concerned. Formalin as preservative was accepted world over. In England and Scotland, medical schools began to open and it became a tradition to rely on executed criminals for dissection. Anatomy museums came into being for which more cadavers were necessary. The shortage of cadavers led to crimes of grave robbing and resurrectionists flourished in 18th and 19th centuries. There are stories of medical students and professors indulging in grave robbing! The famous Hunter brothers, John Hunter and William Hunter were surgeons and self-learned anatomists. They built well known anatomy museums in London and Glasgow. Another epoch making event was the understanding of development of human organs. Von Baer was credited with the title of father of modern embryology based on his work in that field.

**Nineteenth Century**
In London and Scotland, it became a practice to obtain bodies for medical schools and for doctors interested in research, with the help of body snatchers. William Burke and William Hare in 1828 committed 15 murders of boarders who were late for paying rent in their boarding house (to sell their bodies to medical schools). To put a stop to this illegal trade, the Parliament in Great Britain passed Warburton Anatomy Act in 1832 under which only the unclaimed bodies were allowed for dissection apart from donated bodies. Dissection of human cadavers by medical
students was made compulsory. Another epoch making
discovery of the century was X-ray discovered by Rontgen
in 1895 (a beginning of radiological anatomy). Henry Gray
(1827 to 1861) was the English anatomist cum surgeon,
who published first edition of Gray’s anatomy in 1858 con-
taining 750 pages and 363 illustrations.

Twentieth Century
With the advent of electron microscope and other tech-
nological advances, newer approaches to learning struc-
ture along with function were discovered. With the help of
newer imaging techniques like CT scan, ultrasound, MRI,
PET, etc. more and more emphasis on radiological anato-
my was given. In late 20th century virtual reality was used
to perform dissection on cyber cadavers.

Twenty First Century
Visible Human Project (VHP) created by NLM-NIH
USA (National Library of Medicine in National Health
Institutes in USA) is an excellent digital image library
highly useful in orienting and associating the structures
(seen in cadaver) in the exact location in the cross sec-
tions of the body. The changes in medical curriculum
saw the onset of vertical and horizontal integrations
by which one learns to apply the anatomical knowledge
to understand functions and diagnosis and treatment of
diseases (a beginning of clinical anatomy). The objective
of learning anatomy (prescribed in medical curricula the
world over) is to use the anatomical knowledge in learning
clinical problem solving skills.
Man being a multicellular organism, shows five levels of structural organization in the body starting from the simplest to the most complex.

i. First level of organization consists of the cells, which are the structural and functional units of the body, e.g. muscle cells (myocytes), neurons (nerve cells), connective tissue cells (fibroblasts, chondrocytes, osteocytes, blood cells, etc.) and the epithelial cells.

ii. Second level of organization consists of basic tissues, which are the groups of cells with similar structure and functions, e.g. epithelial tissue, connective tissue, muscular tissue and neural tissue.

iii. Third level of organization consists of organs, which are made of different types of tissues, e.g. heart, kidney, lung and skin. The organs are invariably composed of two or more different tissues.

iv. Fourth level of organization comprises of organ system in which group of organs work in unison to perform a specific function.

v. Fifth level of organization is the entire human being, composed of various organ systems capable of carrying out the basic life processes and much more.

The knowledge of the histological structure and function of the basic tissues is necessary to understand the structure and functions of the organs. It is useful in understanding the pathological changes in the tissues in diseases (to give histopathological diagnosis from biopsy, which is a bit of the diseased tissue examined under the microscope after processing in the laboratory and staining).

### TYPES OF BASIC TISSUES

i. Epithelial tissue

ii. Connective tissue

iii. Muscular tissue

iv. Neural tissue

### EPITHELIAL TISSUE

The epithelium is a layer or layers of cells (resting on the basement membrane) and lining the internal and the external surfaces of the body and body cavities (with the exception of synovial cavity inside the joints).

**Characteristic Features of Epithelium**

The epithelial tissue is mainly composed of cells with minimal extracellular space. The epithelial cells show polarity and are connected by cell-to-cell contacts (to maintain cell harmony and cell to cell communications), rest on the basement membrane and show structural specializations in response to functions.
**Polarity**
The epithelial cells show polarity. It means that the cells have free apical surface and basal surface (directed towards basement membrane). The cells exhibit two domains, namely apical and basolateral. The chemical components of plasma membranes are different in the two domains as per the functional requirements.

**Cell Junctions**
Intercellular contact is served by means of intercellular junctions, which contain specific structural proteins with glue like properties.
1. On lateral surface of the cells, there are four junctions from above downwards.
   i. **Tight junction (zonula occludens)** is located close to the luminal surface of the epithelium. It encircles the entire cell like a belt. It forms an effective barrier of paracellular absorption in the absorptive epithelia and in transitional epithelium.
   ii. **Zonula adherens (adherens belt)** is below the tight junction. It also encircles the entire cell.
   iii. **Desmosome (macula adherens)** is punctate or spot-like in appearance on light microscopy.
   iv. **Gap junction (nexus)** is seen only by electron microscope. The gap junctions allow passage of small molecules between neighboring cells and thus allow cell to cell communication.
2. The hemidesmosomes (spot like in appearance) attach the epithelial cells to the basement membrane.

**Structural Specializations for Absorptive Functions**
   i. Microvilli are the infoldings of apical plasma membrane (to increase the surface area). They are visible under electron microscope. Under the light microscope, microvilli appear as brush border or striated border, which is distinct when stained with special stains. The microvilli are characteristic of epithelium of small intestine and of kidney tubules.
   ii. Stereocilia are found in sites where fluid secretion and resorption take place, e.g. vas deferens and epididymis. The stereocilia are long microvilli but are non-motile.

**Structural Specialization for Protection**
The cilia are present in epithelia, lining the air conducting respiratory passages so that the dust particles and mucus are driven upwards towards nasal cavity via nasopharynx by co-ordinated beating of the cilia (to protect the smaller air conducting tubes and the lung alveoli). The cilia project from the apical surface of the cells from the basal bodies, are composed of microtubules and are motile. The tail of sperm consists of a very long cilium called flagellum, which allows it to undergo wavy movement inside female genital tract.

**Clinical insight ...**

**Kartagener’s Syndrome**
This is a genetic disease, in which the person is born with immotile cilia. The patients suffer from respiratory symptoms caused by the accumulation of dust and other particulate matter (inhaled from atmospheric air), which are normally trapped by pseudostratified ciliated columnar epithelium.

**Basement Membrane**
The basement membrane is a structure that supports the epithelium. When examined under electron microscope it shows two distinct layers.
   i. The basal lamina is the layer in contact with the epithelial cells (which synthesize it). It is visible under the electron microscope. The basal lamina is composed of type IV collagen fibers, which are amorphous (or a fibrillar). Its ground substance consists mainly of laminin.
   ii. The reticular lamina is the deeper layer. It is composed of reticular tissue, collagen fibers and matrix. It merges with surrounding connective tissue. It is synthesized by fibroblasts. The reticular lamina is visible in sections prepared for light microscopy.

**Functions of Basement Membrane**
   i. The basal lamina of the basement membrane provides a barrier between the underlying connective tissue and the epithelial cells. In pathologic conditions, the barrier is broken. The cancer cells from adenocarcinoma (developing from epithelium) invade the basement membrane to spread outside the primary site.
   ii. The basal lamina can filter noncellular materials. In the kidneys, the basal laminae of visceral epithelium and of glomerular capillaries fuse to form filtration membrane, which filters the blood. In the lungs, basal laminae of alveoli and capillary endothelium fuse to form blood air barrier to allow the exchange of gases.

**Basement Membrane in Diseases**
   i. The basement membrane thickens in pathologic conditions like nephropathies (kidney diseases) and...
The epithelium is avascular, hence it is nourished by diffusion from the capillaries that are present in the connective tissue subjacent to the basement membrane.

**Embryologic insight ...**

The epithelium is derived from endoderm, mesoderm and ectoderm (depending on the location).

i. The endoderm gives origin to epithelium of gastrointestinal tract and of respiratory tract including lung alveoli.

ii. The mesoderm gives origin to endothelium lining the blood vessels, the mesothelium of serous membranes, epithelium of kidney tubules and epithelium of majority of reproductive ducts and germinal epithelium covering ovaries.

iii. The ectoderm gives origin to the epidermis, oral mucosa, lining of ear canal and external surface of tympanic membrane.

**Cell Turn Over**

The epithelial cells undergo mitosis to renew old cells. This is known as cell turn over. The cells of intestinal epithelium have very high rate of mitosis.

**Classification of Epithelium**

The epithelium is classified according to the number of cell layers into simple epithelium and compound or stratified epithelium.

i. The simple epithelium is composed of a single layer of cells resting on a basement membrane.

ii. The stratified (compound) epithelium is composed of more than one layer of cells stacked on each other, out of which only the basal cells rest on the basement membrane.

**Simple Epithelium**

i. Simple squamous epithelium lines the lung alveoli, blood vessels (endothelium), serous membranes (mesothelium) and loops of Henle in kidney. In this epithelium, a single layer of squamous shaped cells rests on the basement membrane. The function of this epithelium is diffusion of gases and fluids.

ii. Simple cuboidal epithelium lines the thyroid follicles, germinal epithelium of ovary, etc. It is composed of a row of cube shaped cells resting on the basement membrane.

iii. Simple columnar epithelium is composed of columnar cells. It lines the gall bladder, uterine tube, endocervix, stomach, proximal and distal convoluted tubules of kidney.

iv. Simple columnar epithelium with goblet cells is found in small and large intestines. At places, the columnar cells are modified to form goblet cells to secrete mucus.

v. Simple columnar ciliated epithelium is found in uterine tube and uterus.

vi. Pseudostratified ciliated columnar (with goblet cells) lines the respiratory tract from nasal cavity to intrapulmonary bronchi. All cells rest on basement membrane but the nuclei of the cells are at varying levels giving false impression of stratification. There are shorter and taller cells. The taller cells bear cilia. This epithelium (also known as respiratory epithelium) is suited for respiratory passages as the cilia dispel the foreign particles inhaled in the air and the mucus secreted by goblet cells traps the foreign particles not dispelled by cilia.

**Stratified Epithelium**

i. Stratified squamous non-keratinized epithelium is found in cornea, conjunctiva, oral cavity, tongue, oropharynx, laryngopharynx, esophagus, ectocervix, vagina, male urethra inside the glans penis, etc. It forms the moist surfaces that are protective in function. It consists of multiple layers of cells of which superficial cells are flat (squamous) and basal cells are cuboidal in shape. The intervening rows of cells are polyhedral. The basal cells are capable of mitosis to produce new cells. There is migration and gradual transformation of new cells into polyhedral cells and finally into flat cells, which are shed from the body periodically. Thus it is clear that young cell population is in the basal layers and the oldest cells are in the superficial layers. The cells in all layers have nuclei.

ii. Stratified squamous keratinized epithelium is found in epidermis of skin, lining of external acoustic meatus, vestibule of nasal cavity, lining the lowest part of anal canal, etc. It is characterized by keratinization of superficial cells, which are dead and shed from the body surface. Its function is to provide protection against abrasion, bacterial invasion and desiccation.
Basic Tissues of the Body

Chapter (drying). This epithelium in the thick or glabrous skin of palms and soles is composed of five layers. From the basal to the superficial aspect, the layers are stratum germinativum, stratum spinosum, stratum granulosum (showing keratohyalin granules), stratum lucidum (showing eliedin) and stratum corneum (which is thickest and composed of dead keratinized cells without nuclei).

iii. Stratified cuboidal epithelium lines the ducts of sweat glands. It consists of two layers of cuboidal cells. The seminiferous epithelium in the testis is also regarded as a special type of stratified cuboidal epithelium, as the series of germ cells (spermatogonia, primary spermatocytes, secondary spermatocytes and spermatids) are arranged in layers from the basement membrane inwards.

iv. Stratified columnar epithelium lines the spongy part of male urethra and the main ducts of large salivary glands and large ducts of mammary glands. There are several layers of columnar cells, which serve protective and secretory functions.

v. Transitional epithelium is a special type of epithelium lining the urinary passages. Hence, it is called as urothelium. It lines the renal calyces, renal pelvis, ureter, urinary bladder and proximal part of urethra. It is structurally adapted to provide a permeability barrier to water and solutes in urine. Under the light microscope it shows cuboidal basal cells, which are uninucleate and basophilic. The cells in middle layers are polygonal or rounded. The surface cells (which are exposed to the urine) are large and faceted (umbrella cells). Their luminal surface is covered with modified plasma membrane. The apical cytoplasm contains microfilaments and fusiform membrane bound vesicles enclosing uroplakin plaques. In the undistended state, the epithelium is relaxed and the surface cells are rounded and project into the lumen. In the distended state, the epithelium is stretched and the surface cells become flattened. The fusiform vesicles along with plaques merge into the surface plasma membrane providing a reserve membrane during stretching.

Glandular Epithelium

The glands may consist of a single cell or aggregations of epithelial cells specialized for secretory function. The endocrine glands release secretion (hormone) directly into blood capillaries. The exocrine glands consist of secretory units (which synthesize secretion) and ducts (by which they let out their secretion).

Classification of Exocrine Glands

According to number of cells

i. Unicellular (e.g. goblet cells)
ii. Multicellular (e.g. salivary glands, sweat glands, mammary glands, liver, pancreas, etc.)

Subtypes of Multicellular Exocrine Glands

1. Depending on duct pattern
   i. Simple, if one duct drains the gland
   ii. Compound, if there is branching pattern of the ducts
2. Depending on the shape of the secretory units
   i. Simple tubular or coiled tubular (when the secretory units are shaped like small tubes)
   ii. Alveolar or acinar (if secretory units are shaped like small bags)
   iii. Tubulo-alveolar (combination of the above two shapes)
3. Depending on the type of secretion
   i. Serous-watery fluid containing protein (example parotid and lacrimal glands)
   ii. Mucous-viscous secretion containing mucus (example, esophageal glands, pyloric glands, sublingual salivary glands)
   iii. Mixed (example- submandibular salivary glands)
4. Depending on the mode of their secretion
   i. Merocrine (eccrine) in which secretory product is expelled out by exocytosis(e.g. sweat glands involved in thermoregulation and receive cholinergic sympathetic innervation)
   ii. Apocrine in which the secretory product accumulates in apical cytoplasm and is expelled out by pinching of the apical plasma membrane (e.g. mammary gland and apocrine type of sweat glands (secreting viscid sweat) that are active after puberty and are found in skin of axilla and around genital organs.
   iii. Holocrine in which the cell after filling with secretory product dies and is expelled along with its contents (e.g. sebaceous gland). The death of the cells to produce secretion is called apoptosis (programmed cell death).

Clinical insight ...

Metaplasia
Transformation of one type of epithelial tissue into another type is known as metaplasia or metaplastic change.

i. In cigarette smokers, pseudostratified epithelium in bronchi may change into stratified squamous epithelium.
ii. In chronic vitamin A deficiency transitional epithelium of urinary bladder may change into stratified squamous variety.
iii. The stratified squamous epithelium of esophagus may change into simple columnar with goblet cells (intestinal type) in a condition called Berret esophagus (which may lead to cancer).
CONNECTIVE TISSUE

The connective tissue serves the function of connecting and supporting the tissues and organs of the body. It is widely distributed in the body. The impaired structure and function of the connective tissue result in some disorders of connective tissue. In inflammation of any organ it is the connective tissue that acts as a battle ground for the infecting agents and immune cells of the connective tissue.

Basic Components

The connective tissue consists of three basic components:

i. Connective tissue cells (both resident and wandering)
ii. Intercellular material (or ground substance or matrix)
iii. Fibers (collagen, elastic and reticular)

Resident Cells

i. The fibroblasts are the most common type. They develop from embryonic mesenchymal cells. They are stellate or spindle-shaped cells with little cytoplasm. The fibroblasts are metabolically very active cells as they synthesize the three types of fibers and the ground substance. The electron microscopic appearance of fibroblasts reveals characteristics of protein secreting cells, like well-developed rough endoplasmic reticulum, one or more Golgi zones and abundant mitochondria. The surfaces of active fibroblasts show characteristic scalloping (coves). It is here that collagen fibrils are polymerized to form collagen fibers in the extracellular compartment. A special type of fibroblast (known as myofibroblast) shows properties of both fibroblast and smooth muscle cell. The myofibroblasts play a significant role in wound contraction during healing.

ii. The macrophages are also known as histiocytes. These large cells have round nuclei and abundant acidophilic cytoplasm rich in lysosomes. They show irregular contours or ruffles of plasma membrane. They develop from monocytes of the circulating blood. Their main function is phagocytosis by ingestion of foreign substances, cancer cells and organisms. They belong to the Mononuclear Phagocytic System (MPS).

iii. The mast cells are usually found in close relation to the blood vessels. They are large in size. Their cytoplasm is filled with basophilic granules. The mast cell granules on staining show metachromasia, i.e. they take up different color than that of the color of the stain, e.g. if stained with toluidine blue the granules take up purple color. The granules contain histamine (vasoactive agent), heparin (anticoagulant) and eosinophilic chemotactic factor of anaphylaxis (ECF-A). The mast cells increase their number in allergic or hypersensitivity reactions.

iv. The pigment cells or melanocytes of connective tissue are found in iris and choroid layer of eyeball.

v. The adipocytes or lipocytes or fat cells are large in size (average size 50 microns). They store neutral fat (triacylglycerides) in the form of a single lipid droplet in their cytoplasm. The lipid droplet is so large that it pushes the cytoplasm and the nucleus to the periphery of the cell. Thus, the cytoplasm is reduced to a rim containing cell organelles and flattened nucleus. On routine staining, the lipid droplet is dissolved. Therefore, the cell gives an empty appearance with a peripheral rim of stained cytoplasm containing a nucleus. This appearance resembles a signet ring. The fat droplet stains orange on staining with Sudan III.

Migrant Cells

i. The plasma cells are derived from the B lymphocytes. They are characterized by well-developed rough endoplasmic reticulum (accounting for basophilic cytoplasm). The Golgi complex is pale on regular staining, which is described as perinuclear halo (negative image of Golgi or Golgi ghost). The eccentrically placed nucleus has characteristic cart wheel or clock face appearance due to distribution of the chromatin in the form of four or five clumps subjacent to nuclear envelope. The plasma cells produce antibodies, which maybe discharged locally or may enter circulation. Sometimes, the antibodies are stored in the cytoplasm of the cell itself in the form of Russel bodies.

ii. The white blood cells that are found in connective tissue are the lymphocytes, neutrophils, basophils, eosinophils and monocytes.

Ground Substance

The connective tissue is composed of abundant ground substance. The connective tissue cells and fibers are embedded into it. The ground substance is amorphous and transparent having the properties of a viscous solution or a highly hydrated thin gel. On light microscopy, it is difficult to visualize the ground substance.

Chemically the ground substance is mainly composed of glycosaminoglycans (GAG), proteoglycans and multiahesive glycoproteins (e.g. fibronectin, laminin, etc.). The ground substance allows free exchange of nutrients and gases between the cells of tissues and the blood in the capillaries. Water or tissue fluid might accumulate in the extracellular spaces in case of venous stasis or lymphatic stasis causing edema.

Connective Tissue Fibers

Collagen Fibers

The collagen fibers are the white fibers of connective tissue. They are firm and do not stretch. They provide
tensile strength to the tissues (their strength is comparable to that of steel cables). The collagen fibers are composed of a protein called collagen, which is the most abundant structural protein in the human body. The collagen fibers aggregate into wavy bundles. Individual fibers do not branch, though bundles may branch. The collagen fibers are visible on light microscopy, as they are eosinophilic. They appear pink on staining with eosin. However, the collagen fibrils (which make up the fibers) are visible only by electron microscopy.

Contd...

for which vitamin C is an essential cofactor. The deficiency of vitamin C (scurvy) with resultant defective collagen leads to widespread effects like bleeding gums, loose teeth, weak bones and poor wound healing.

ii. The polypeptide chains coil around each other to form a triple helix except at the terminals where the chain remains uncoiled. This forms the soluble procollagen molecules.

iii. The packaging of procollagen molecules takes place in Golgi apparatus for transportation out of the cells.

**Extracellular Synthesis of Collagen (Fig. 2.1)**

i. The soluble procollagen is converted into nonsoluble tropocollagen by cutting the uncoiled terminals.

ii. The tropocollagen molecules aggregate to form collagen fibrils, which are polymerized into collagen fibers on the surface coves.

**Clinical insight ...**

**Genetic Disorders of Collagen Synthesis**

Defective collagen encoding genes cause autoimmune disorders in which immune responses destroy the collagen fibers. Examples of autoimmune disorders are rheumatoid arthritis and osteogenesis imperfecta.

Contd...

**Know More ...**

**Biosynthesis and Secretion of Collagen**

The collagen is secreted by fibroblasts in connective tissue, by osteoblasts in bone, by chondroblasts in cartilage and by odontoblasts in tooth. The collagen is also secreted by non connective tissue cells like smooth muscle cells, Schwann cells and epithelial cells.

**Intracellular Synthesis of Procollagen (Fig. 2.1)**

i. The proline, glycine and lysine form the alpha polypeptide chains, which reach the rough endoplasmic reticulum. Here the lysine and proline are hydroxylated for which vitamin C is an essential cofactor. The deficiency of vitamin C (scurvy) with resultant defective collagen leads to widespread effects like bleeding gums, loose teeth, weak bones and poor wound healing.

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**Clinical insight ...**

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Types of Collagen Fibers
There are numerous types of collagen fibers that differ from each other genetically, immunologically and chemically. They are designated by Roman numerals according to their order of discovery. Type I to type IV fibers are very common. The type I are widely distributed in the body. Type I fibers are found in fascia, tendons, ligaments, aponeuroses, capsules of glands, sclera, fibrocartilage, bone and dentin. Type II fibers are found in hyaline and elastic cartilages and cornea. Type III fibers are reticular fibers. They occur in spleen, lymph nodes etc; and type IV fibers are seen in basement membrane.

Elastic Fibers
The elastic fibers impart elasticity to the tissues. They are composed of an amorphous core of elastin, which is surrounded by a glycoprotein named fibrillin. The elastic fibers do not form bundles. The individual fibers branch and anastomose. They are highly refractile. They stain poorly with ordinary hematoxylin and eosin stains. They are produced by fibroblasts, epithelial cells and smooth muscle cells. They occur in loose areolar tissue, ligaments of joints, dermis of skin, lung, as fenestrated membranes in large arteries, ligamentum nuchae, ligamanta flava, suspensory ligament of lens, elastic cartilage etc.

Reticular Fibers
The reticular fibers are type III collagen fibers. They are smallest and very delicate. They are mainly produced by fibroblast but other cells like reticular cells in bone marrow and lymphoid tissues, smooth muscle cells and Schwann cells are also capable of producing them. The reticular fibers give support to the nerve fibers, muscle fibers, blood vessels and form stroma in the glands. They are the main component of reticular lamina of basement membranes. Because of their affinity to silver salts the reticular fibres are called argyrophilic fibers. With silver stains they appear black.

Classification of Connective Tissue Proper
i. Loose or areolar connective tissue
ii. Dense connective tissue
iii. Yellow elastic tissue
iv. Reticular connective tissue
v. Adipose tissue
vi. Myxomatous connective tissue (embryonic connective tissue)

Loose Connective Tissue
This type is the most abundant connective as it forms stroma of the organs and tunica adventitia of blood vessels. It lies underneath the epithelia forming lamina propria of mucous membranes and in submucosa of hollow organs. This tissue is rich in ground substance and poor in fibers and connective tissue cells.

Dense Connective Tissue
This type is composed predominantly of collagen fibers, hence also called white fibrous tissue. It is subdivided into two types, dense irregular and dense regular.

i. The dense irregular connective tissue is characterized by many collagen and elastic fibers (running in irregular orientation), few cells and moderate amount of matrix. It is found in reticular layer of dermis, periosteum and perichondrium.

ii. The dense regular connective tissue is characterized by densely arranged fibers, fewer cells (mostly fibroblasts) and minimum matrix. The collagen fibers are regularly oriented and are arranged in bundles. The regular dense connective tissue is found in tendons, ligaments, capsules, fasciae and aponeuroses. The tendons attach the muscle belly to the bone or cartilage. A tendon consists of parallel collagen fibers and fibroblasts. A longitudinal section of tendon consists of bundles of collagen fibers and parallel rows of elongated nuclei of fibroblasts that are compressed between collagen fibers.

Yellow Elastic Tissue
This tissue is composed predominantly of elastic fibers. This is found in ligamenta flava (which connect the laminae of adjacent vertebrae), cricovocal membrane of laryngeal skeleton, vocal ligaments, lung alveoli and in tunica media of aorta.

Reticular Tissue
The reticular tissue is a network of reticular fibers and fibroblasts and reticular cells (subtype of fibroblasts). It
provides a soft structural framework to support the cells of lymph nodes, spleen and bone marrow.

**Adipose Tissue**

The adipose or fatty tissue contains a collection of fat cells (adipocytes). It provides warmth, cushioning effect and is also a storehouse of energy reserve of the body. The adipose tissue is of two types. The white adipose tissue is found in adult and the brown adipose tissue is found in fetus and newborn.

i. The **white adipose cells** (white adipocytes) are larger in size and are called unilocular because their cytoplasm is filled by a single large lipid droplet. The cell nucleus is flat and pushed by the lipid droplet to the periphery. The mitochondria are few in number and are dispersed in the peripheral rim of cytoplasm. The white fat is widely distributed in the subcutaneous tissue in the body, in adults. In addition, it is found in yellow bone marrow and in abdominal cavity inside the peritoneal folds and around kidneys. It functions as a storehouse of energy.

ii. The **brown adipose cells** (brown adipocytes) are small polygonal cells and are called multilocular because their cytoplasm is filled with multiple lipid droplets. The nucleus is in the cell center and cell organelles are spread out in the cytoplasm. There are numerous mitochondria, which contain large quantities of iron-containing pigments cytochromes (which impart brown color to adipocytes). The brown adipose tissue is more widely distributed in fetuses and newborn. In adult, it is seen in the interscapular region and in the lumbar region behind the kidneys.

**Myxomatous (mucoid) Connective Tissue**

It is characterized by abundant ground substance, few cells and fewer fibers. In the fetus, it occurs as Wharton's jelly in the umbilical cord. The jelly-like viscous ground substance is rich in hyaluronic acid. The fibers are hardly visible and fibroblasts assume star shape, hence called stellate cells. The Wharton's jelly develops from extraembryonic mesoderm (primary mesoderm). In the adult, it is found in vitreous humor.

**MUSCULAR TISSUE**

The muscular tissue is composed of elongated muscle cells called myocytes or muscle fibers. The muscle fibers aggregate to form a muscle. The main function of the muscle is contraction to perform mechanical work like locomotion, movements of hand, facial expressions, pumping action of heart and peristaltic movement of intestines to name a few. In response to their functions, the muscle fibers are equipped in their cytoplasm with contractile proteins called actin and myosin. These proteins are filamentous in nature and hence, are called myofilaments.

**Types of Muscle Tissue**

There are three types of muscular tissue in the body:

i. Skeletal muscle
ii. Cardiac muscle
iii. Smooth muscle.

They differ in distribution, microscopic structure and function.

**Skeletal Muscle**

The skeletal muscles are so called because by and large they attach to the bones and cartilages. They are also known as striated because their cells show cross striations when examined under a light microscope. They are described as voluntary as they contract under the influence of motor neurons of somatic nervous system or in other words, they are supplied by axons of lower motor neurons like neurons of ventral horn of spinal gray matter.

**Organization of Muscle Fibers in a Skeletal Muscle**

The basic unit of a muscle is a long muscle cell called muscle fiber. Each muscle fiber is encircled by a delicate connective tissue covering called endomysium. Numerous muscle fibers aggregate and are held together by means of well-organized connective tissue to form muscle bundles or fascicles. Each bundle is covered by another connective tissue covering called perimysium. Many such bundles are held together to form a muscle (like for example deltoid muscle) by an outer common connective tissue covering called epimysium. The connective tissue provides routes for the nerves and blood vessels to reach the individual muscle fiber.

**Microscopic Structure of Muscle Fiber**

The muscle fiber is an elongated multinucleate syncytium. Its cytoplasm is called sarcoplasm and plasma membrane is called sarcolemma. The flattened nuclei
are placed at the periphery subjacent to and in a row parallel to the sarcolema. The sarcoplasm is filled with structural and functional subunits of muscle fibers called myofibrils, which are composed of bundles of thin actin and thick myosin filaments (the contractile proteins). The myofibrils are surrounded by special type of smooth endoplasmic reticulum (called sarcoplasmic reticulum), mitochondria, glycogen and myoglobin (a red colored oxygen binding protein).

Cross Striations

The characteristic cross striations of muscle fibers are due to the presence of alternating light and dark bands (composed of above mentioned contractile proteins) arranged in regular pattern on the myofilaments. The dark bands are A (anisotropic) bands and the light bands are I (isotropic) bands. A bands show light area in the middle called H band, which is bisected by a transverse dark line called M line. I band is bisected by a thin dark line called Z line. A sarcomere is the segment of a myofibril between adjacent Z lines. It is the basic contractile unit of the striated muscle.

Muscle Triad

The EM appearance of muscle fiber reveals that at A-I junctions of each myofibril there is a triad consisting of invaginated sarcolemma (T tubule) flanked on upper and lower sides by terminal cisternae of sarcoplasmic reticulum.

Functions of Muscle Triad

i. The T tubules carry the signals of depolarization from the surface sarcolemma into the deeper part of muscle fibers, so that deeper and superficial myofibrils contract synchronously.

ii. The T tubules transmit the wave of depolarization to membranes of terminal cisternae at triads. This triggers the release of calcium ions from the sarcoplasmic reticulum into the sarcoplasm. The calcium ions act on actin and myosin filaments causing contraction of muscle. When the contraction ceases, the released calcium is taken back inside the sarcoplasmic reticulum.

Nerve Supply of Skeletal Muscle and Motor Unit

The nerve and the accompanying blood vessels supplying the skeletal muscle enter the muscle at a specific point called neurovascular hilum, e.g. thoracodorsal nerve (a branch of posterior cord of brachial plexus) and thoracodorsal artery (continuation of subscapular artery) enter the neurovascular hilum on the latissimus dorsi muscle. The thoracodorsal nerve contains axons of anterior horn cells of C6, C7 and C8 segments of spinal cord, which supply the muscle fibers of latissimus dorsi via their numerous branches that pass through epimysium, perimysium and endomysium to reach the respective muscle fibers. From this we understand that one axon of anterior horn neuron supplies several muscle fibers. One motor neuron and the muscle fibers supplied by it constitute one motor unit. The number of muscle fibers is smaller in motor units of muscles which are involved in fine and precise movements (for example in extraocular muscles, the ratio of motor neuron to muscle fiber is 1: 4 to10). Conversely, the number of muscle fibers is very large in motor units of muscles like latissimus dorsi or gastrocnemius, where force of contraction rather than precision is necessary.

Cardiac Muscle

The cardiac muscle is present in the heart, where it is called myocardium. It resembles skeletal muscle structurally in having cross striations. It resembles smooth muscle functionally in being involuntary. The contraction (beating of the heart) is initiated inherently by the pacemaker located in sinuatrial node. Thus, it is clear that contraction of cardiac muscle is not totally dependent on nerve supply although the strength and rate of contraction are influenced by both sympathetic and parasympathetic nerves of autonomic nervous system.

Microscopic Structure of Cardiac Muscle

Cardiac myocytes (muscle cells) are short uninucleated cells. The nucleus is centrally placed. The muscle cells are joined end-to-end at junctional specializations called intercalated discs, which are visible under light microscope as transverse dark lines arranged like steps in a staircase. Thus, it should be appreciated that in cardiac muscle, a muscle fiber is made up of a chain of myocytes (unlike in the skeletal muscle, where muscle fiber is a single cell). The muscle fibers are disposed parallel to each other. They branch and anastomose with myocytes of adjacent fibers. The branches are compactly arranged and have the same parallel orientation like the parent fiber. The cross striations of cardiac muscle are not as prominent as found in skeletal muscle. This may be due to less number of myofibrils and more amount of cytoplasm with abundant mitochondria in cardiac myocytes.

Electron Microscopy of Intercalated Disc

The intercalated discs are located between the ends of two contiguous myocytes. They have a transverse part (corresponding to the step of staircase) and a longitudinal part (corresponding to the connection between the two steps). At this site, the plasma membranes of the two cells are joined by three distinct types of cell-to-cell junctions namely, macula adherens (desmosome), fascia adherens (similar to zonula adherens of epithelial cells) and
gap junctions. The fascia adherens and desmosomes are seen in the transverse part of the disc. They help to rapidly transmit force of contraction from one cell to another. The gap junctions are present in longitudinal part of the disc. They provide electrical coupling of cells, so that the cardiac muscle can function as physiological syncytium.

Smooth Muscle (Plain or visceral muscle)
The smooth muscle is non-striated and involuntary. It functions under the control of both sympathetic and parasympathetic nerves. It occurs in the wall of blood vessels, gastrointestinal tract, biliary tract, respiratory tract, urinary passages, genital ducts including uterus, muscles of eyeball, Müller’s muscle in upper eyelid, dartos muscle in scrotum and arrector pili muscles of skin.

Microscopic Structure of Smooth Muscle
The smooth muscle fibers are elongated cells with broad central part and tapering ends. The muscle fibers show remarkable variation in length depending on the site. The oval or elongated nucleus is located in the central part of the cell. The acidophilic sarcoplasm contains myofibrils, which are responsible for the longitudinal striations seen under light microscope. It also contains other cell organelles and inclusions. A network of delicate reticular fibers envelops the muscle fibers to bind the cells to each other and the gap junctions join the neighboring cells to facilitate intercellular transmission of electric impulse.

Additional Features of Skeletal Muscles
1. The arrangement of muscle fibers may be different according to the functional needs.
   
   Pennate (comb like) muscles are characterized by muscle fascicles that are disposed at an oblique angle to the line of contraction of the muscle. There are three types of pennate muscles.
   
   i. In unipennate muscle, the tendon (or bone) lies on one side and muscle fibers run obliquely from it (e.g. extensor digitorum longus, flexor pollicis longus, lateral two lumbricals and palmar interossei).
   
   ii. In bipennate muscle, the tendon (or bone) lies in the center and muscle fibers reach it from either side obliquely (e.g. rectus femoris, soleus, medial two lumbricals and dorsal interossei).
   
   iii. In multipennate muscle, there are numerous tendinous septa that receive fibers from various directions as in acromial fibers of deltoid and in subscapularis.

2. The type of muscle contraction depends on whether the joint moves or not. In isometric contraction, there is no movement of a joint but there is increase in the tone of muscle. On lifting a heavy suitcase, the flexor muscles contract without moving the elbow joint. In isotonic contraction, the same muscles shorten to hold a baby.

3. Depending on the actions of the muscles, they are divided into following types.
   
   i. **Prime mover** is the main muscle that performs a particular action, e.g. in flexed forearm the biceps brachii is the main supinator and in extended forearm the supinator muscle is the main supinator.
   
   ii. **Fixator** is the muscle that contracts isometrically to stabilize the prime mover. The examples of fixator muscles are quadratus lumborum (which fixes the 12th rib during inspiration facilitating contraction of diaphragm) and rhomboid muscles fixing the scapula during overhead abduction of arm.
   
   iii. **Antagonist** is the term used for a muscle that opposes the action of a prime mover as exemplified by contraction of triceps brachii (the extensor of elbow) during flexion movement of that joint.
   
   iv. **Synergist** is the term used for a muscle, which helps another muscle (prime mover) in performing its stimulated action. The flexors and extensors of carpus (flexor carpi radialis and extensor carpi radialis) and extensor carpi radialis longus and brevis and extensor carpi ulnaris) contract simultaneously to stabilize the wrist joint when long flexor or extensor muscles of the digits contract.

**NEURAL TISSUE**
The neural or nervous tissue is specialized to receive information from external and internal environment because of its inherent property of irritability and conductivity. The sensory fibers of the peripheral nerves carry the external and internal sensations to the neurons or nerve cells of CNS. The information is received, processed and integrated in the motor neurons of CNS. The response or the command of the CNS is taken to the effector organs (muscle, glands, viscera, etc.) by motor fibers of the peripheral nerves. In this way, the nervous tissue governs and co-ordinates the functions of all other tissues and organs of the body.

**Subdivisions of Nervous System**
The nervous system is subdivided into central nervous system (CNS), which includes brain and spinal cord and peripheral nervous system (PNS), which includes peripheral nerves, sensory ganglia, autonomic ganglia and autonomic nerves. The autonomic ganglia and nerves belong to sympathetic and parasympathetic divisions of autonomic nervous system. The basic components of the nervous tissue are the neurons, neuronal processes, neuroglia, Schwann cells and synapses. The neurons are the
structural and functional units of nervous system. They are specialized for reception of stimuli, their integration and interpretation and lastly their transmission to other cells. Neurons give off radiating processes from their cell bodies. These processes are of two types, dendrites and axons. The synapse is a site of close contact between two neurons for easy transmission of information from neuron-to-neuron. The neuroglia cells serve to support the neurons and their processes in CNS while Schwann cells and satellite cells serve similar function in PNS.

**Classification of Neurons**

**According to the Number of Processes**

**Unipolar Neuron**
A neuron with a single process is called unipolar neuron. It is found only in the early stages of embryonic development.

**Pseudounipolar Neurons (Fig. 2.2)**
These neurons possess one very short process, which soon divides into a peripherally directed long process and a centrally directed short process. These neurons are found in sensory ganglia of dorsal roots of spinal nerves and cranial nerves (also called dorsal root ganglia). The neurons of the mesencephalic nucleus of trigeminal nerve belong to this category.

**Bipolar Neurons (Fig. 2.2)**
These neurons have one dendrite and one axon. They are found in retina, olfactory epithelium and sensory ganglia of vestibular and cochlear nerves.

**Multipolar Neurons (Fig. 2.2)**
These neurons have one long axon and multiple short dendrites. They are found in gray matter of central nervous system (spinal cord, cerebral and cerebellar cortex, intracerebral and intracerebellar nuclei in addition to cranial nerve nuclei in brainstem).

**According to the Function of Neurons**

i. Motor neurons conduct impulses to skeletal muscles (neurons of ventral horn of spinal cord).

ii. Sensory neurons receive stimuli from external and internal environment.

**According to the Location of Neuronal Cell Body**

i. Upper motor neurons (UMN) belong to CNS as their cell bodies are located in the motor area of cerebral cortex and their long axons become the corticospinal fibers. These fibers terminate on anterior horn cells of spinal cord at varying levels. The giant pyramidal cell of Betz is an example of UMN.

ii. Lower motor neurons (LMN) belong to both CNS and PNS. Their cell bodies are located in ventral horn of spinal cord and in cranial nerve nuclei in brainstem. Their axons leave the CNS to supply the skeletal muscles via peripheral nerve.

**Microscopic Structure of Multipolar Neuron**
The body of neuron is called perikaryon. It contains a euchromatic (in which chromatin is uncoiled and active) and vesicular nucleus with prominent nucleolus. The area of cell body that gives origin to axon is called axon hillock.

i. The cytoplasm shows characteristic Nissl bodies (rough endoplasmic reticulum studded with ribosomes). The Nissl bodies are basophilic and are dispersed throughout the cytoplasm and in the dendrites but absent in axon hillock and axon. They are involved in protein synthesis. The absence of centriole is responsible for inability of the neurons to divide. The neurons are arrested in Go phase of cell cycle.

**Fig. 2.2: Types of neurons depending on the number of cell processes (Note multipolar neuron with one axon but large number of dendrites, bipolar neuron with one axon and one dendrite and pseudounipolar neuron with one very short process bifurcating into a long process directed towards the receptor and a short process directed towards CNS)**
II. Lysosomes are prominent feature of the cytoplasm. They contain hydrolytic enzymes necessary for phagocytosis. Aging neurons show cell inclusions, which are golden brown lipofuscin pigment (known as wear and tear pigment) derived from lysosomes.

III. The cell bodies also contain microtubules and microfilaments (for internal support), neurofilaments consisting of spiral proteins, plenty of mitochondria and large Golgi complex.

IV. Dendrites are the cell processes that are close to cell body. All cytoplasmic contents of the cell body (except the Golgi complex) are present. They tend to branch and are capable of forming a dendritic tree for networking with processes of other neurons.

V. Axons arise from cell bodies at axon hillock and lack Nissl bodies. There is only one axon per cell and usually it is long. The axons transmit action potential. Axons terminate by forming synapses with other neurons, muscle fibers and secretory units of exocrine glands. They form the motor fibers of peripheral nerves. The cytoplasm of axon is called axoplasm and its plasma membrane is called axolemma. Axons are either myelinated or nonmyelinated.

VI. Synapse is the specialised site of interneuronal contact for cell-to-cell transmission of nerve impulse. The synapse consists of three parts, the terminal bouton or presynaptic membrane of presynaptic neuron, synaptic cleft and postsynaptic membrane of postsynaptic neuron. The terminal bouton contains vesicles filled with neurotransmitter. The synaptic cleft is a narrow extracellular space between the two neurons. The synaptic vesicles release the neurotransmitter into synaptic cleft. As soon as the neurotransmitter comes in contact with plasma membrane of postsynaptic neuron, action potential is generated by depolarization.

**Neuroglia**

The neuroglia cells are commonly called glia (glia means glue) cells. They are non-neuronal cells in CNS, where they outnumber the neuronal population. The glia cells are capable of mitotic cell division throughout life. The glia cells play a role equivalent to connective tissue in other organ systems of the body.

**Neuroglia cells in CNS**

1. **Oligodendrocytes** (with few processes) are derived from neural tube. They myelinate nerve fibers in CNS.
2. **Astrocytes** (fibrous and protoplasmic types) are derived from neural tube. They regulate ionic milieu in CNS.
3. **Microglia** are derived from mesenchymal cells.
4. **Ependymal cells** produce CSF in ventricles of brain.

**Neuroglia Cells in PNS**

1. Schwann cells (lemnocytes or peripheral glia) are derived from neural crest. They myelinate nerve fibers in PNS.
2. Satellite cells (capsular gliocytes) are present in ganglia.

**Myelination in CNS and PNS**

1. Lipid rich plasma membranes of oligodendrocytes in CNS (for example in optic nerve) and Schwann cells in PNS (for example in sciatic nerve) tightly wrap around the axon several times with the help of mesaxon (by which the axon is suspended from the plasma membrane surrounding it).
2. Several concentric layers of plasma membrane and its lipid around the axon give the axon an appearance of a Swiss roll. This forms the myelin sheath. Oligodendrocytes or Schwann cells line up in rows along the length of the axon outside the myelin sheath. Myelin sheath is interrupted at regular intervals at nodes of Ranvier in the peripheral nerve. The node of Ranvier or nodal gap denotes the limit of adjacent Schwann cells. The myelin sheath is necessary for insulation of nerve fiber so that nerve impulse can jump from node-to-node for speed of transmission (saltatory conduction). The myelinated fibers impart white color to the white matter in CNS.

**Faulty Myelination**

1. Multiple sclerosis (MS) is disorder of brain and spinal cord in which the oligodendrocytes undergo degeneration leading to demyelination of nerve fibers (which form white matter). The symptoms include muscle weakness, loss of balance and in-coordination of movements. Cognitive symptoms include weak memory and low problem solving capacity.
2. Guillain Barre syndrome (GBS) is disorder in which the peripheral nerves lose their myelin sheath. This results in slow transmission of nerve impulses causing muscle weakness and abnormal sensations starting in the legs and spreading towards arms and upper body.

**Tumors of Neuroglia**

1. Ependymoma is the tumor arising from ependymal cells.
2. Astrocytoma is a tumor arising from astrocytes.
3. Oligodendroglioma arises from oligodendrocytes.
4. Schwannoma is the growth of Schwann cells encircling peripheral nerves. Schwannoma of acoustic nerve is an intracranial tumor seen at cerebellopontine angle.

**Clinical insight ...**
The cartilage and the bone are the special type or sclerous type of connective tissue.

**CARTILAGE**

The cartilage is composed of intercellular matrix (ground substance and fibers) and cartilage cells. The cartilage consists of chondroblasts and chondrocytes. The ground substance consists of sulfated glycosaminoglycans and proteoglycans with a large proportion of hyaluronic acid.

**General Features**

i. The outer covering of the cartilage is known as perichondrium. However, the articular cartilages covering the articular ends of bones are devoid of perichondrium.

ii. The perichondrium is composed of two layers called inner cellular and outer fibrous. The inner cellular layer contains a row of undifferentiated perichondrial cells that have a potential to turn into chondroblasts if occasion demands. The outer fibrous layer contains dense irregular connective tissue and plenty of blood vessels and sensory nerves.

iii. The cartilage is avascular. The nourishment is provided by perichondrial blood vessels by a process of diffusion through ground substance.

iv. The cartilage grows by interstitial and appositional processes. By appositional process new cartilage is added to the surface of old cartilage by the cells of perichondrium. By interstitial process new cartilage is added internally to the old cartilage by chondrocytes, which are inside the lacunae and which have retained their abilities to synthesize matrix and divide. Thus, appositional growth is called surface growth and interstitial growth is called internal growth.

**Histological Types of Cartilage**

i. Hyaline cartilage

ii. Elastic cartilage

iii. Fibrocartilage

**Hyaline Cartilage**

It is the most commonly occurring cartilage in the body. It is found in the adults in nose, larynx (thyroid, cricoid and part of arytenoid cartilages), trachea, extrapulmonary bronchi, intrapulmonary bronchi, articular cartilages and costal cartilages. The hyaline cartilage has a tendency to calcify and ossify as age advances.

The hyaline cartilage appears transparent like a glass. It is covered with perichondrium. It contains homogeneous matrix, invisible collagen fibers and chondrocytes (inside lacunae).

i. Just close to the perichondrium there is a layer of chondroblasts that secrete the ground substance. Once the chondroblasts are surrounded by matrix they become mature chondrocytes. The unique feature of chondrocytes is that they retain capacity to divide and continue to secrete the matrix. When chondrocytes divide, they form a group of two or four chondrocytes inside the same lacuna.

ii. The matrix of hyaline cartilage contains type II collagen fibers, which are masked by the ground substance. It is basophilic and exhibits metachromasia. The matrix is
Cartilage, Bones and Joints

Chapter

divisible into territorial and interterritorial according to the location and intensity of staining. The territorial matrix is more basophilic and it surrounds the lacunae like a capsule. The interterritorial matrix is less basophilic and is found at some distance away from the lacunae.

Elastic Cartilage

This cartilage occurs in the pinna of the ear, larynx (epiglottis, tips of arytenoids cartilages, corniculate and cuneiform cartilages), nasal cartilages and cartilaginous part of Eustachian tube. The elastic cartilage looks yellow in color in fresh state due to presence of abundant yellow elastic fibers in its matrix. The elastic fibers branch and anastomose to form a meshwork inside the matrix. It also contains a few type II collagen fibers. The ground substance is basophilic and the chondrocytes are housed in lacunae either singly or in groups of two. The cells appear closely placed as intercellular ground substance is lesser than in hyaline cartilage. Unlike the hyaline cartilage, elastic cartilage retains its histologic characters throughout life.

Fibrocartilage

This cartilage is found in secondary cartilaginous joints like symphysis pubis and manubriosternal joint as intra-articular plate of fibrocartilage joining the articulating bones. The intervertebral discs are composed of ring shaped annulus fibrosus (which is a fibrocartilage) surrounding the inner nucleus pulposus (which is a gelatinous hygroscopic jelly). The fibrocartilages are also found inside the knee joint as menisci and as articular discs in temporomandibular and inferior radioulnar joints. The fibrocartilage consists of minimum ground substance, very few chondrocytes but abundant collagen fibers. The type I collagen fibers are arranged in large interlacing bundles. The chondrocytes are present as single row between the collagen bundles. The fibrocartilage lacks perichondrium.

Bone or Osseous Tissue

The bone is the hardest and very strong connective tissue in the body. Paradoxically, it is a highly vascular and dynamic tissue in the body. Contrary to our usual thinking, the bone tissue shows a continuous turn over through out life.

Components of Osseous Tissue

Like any other connective tissue, the bone consists of cells, matrix and fibers. The only difference is that the matrix of bone is mineralized. That is why the bone is a storehouse of calcium and phosphorous.

Bone Cells

i. The osteoprogenitor cells are the least differentiated bone forming cells. They are present in the cellular layers of periosteum and endosteum. They are the stem cells of the bone, since they turn into osteoblasts.

ii. The osteoblasts are the bone forming cells. During bone development, they are seen on growing surfaces of newly formed bony plates and around interosseous blood vessels. Osteoblasts are round cells with single nucleus and highly basophilic cytoplasm. They are characterized by a well-developed rough endoplasmic reticulum, Golgi complex and mitochondria as they secrete type I collagen fibers and ground substance of bone matrix (osteoid). They are rich in alkaline phosphatase, which they release in blood circulation during ossification. The alkaline phosphatase is necessary during mineralization of the osteoid.

iii. The osteocytes are mature form of osteoblasts. The cell bodies of these cells are trapped inside the lacunae within a bone and their protoplasmic processes extend into small canaliculi, which radiate from the lacunae. The processes of adjacent osteocytes meet each other inside canaliculi at gap junctions, which provide pathway for transport of nutrients. It must be understood that there are no blood vessels inside the lacunae and canaliculi. The osteocytes are metabolically active, since they play a role in minimal secretion of bone matrix required for maintenance.

iv. The osteoclasts are the macrophages of bone tissue (blood monocytes being their precursors). They are largest in size among bone cells. They are multinucleated cells having lysosomes containing acid phosphatase. They are intensely eosinophilic due to plenty of lysosomes. A zone of peripheral cytoplasm and plasma membrane adjacent to osseous surface is referred to as ruffled border. Multiple cytoplasmic processes and lysosomes are found along this border. This way they bring about destruction and resorption of hard

Clinical Insight ...

Osteoarthritis

The basic pathology is degeneration of articular cartilages. The articular cartilage is hyaline cartilage (without perichondrium) that lines the articulating ends of bones. The degeneration of articular cartilages causes difficulty in walking if joints of lower limb like hip and knee are affected. Incapacitation of joints of hand leads to painful day to day activities performed by hands. Usually in severe cases of osteoarthritis of knee or hip joint, prosthetic replacement of the joint is undertaken.
bone and create a depression in the bone, which is known as lacuna of Howship or resorption bay. The activity of osteoclasts is controlled by calcitonin (thyroid hormone) and parathormone (parathyroid hormone).

**Bone Matrix**

Bone matrix approximately consists of 15 to 20 percent water, 30 to 40 percent collagen, minimum proteoglycans and 50 to 60% inorganic mineral salts (mainly the crystals of hydroxyapatite \( \text{Ca}_{10}(\text{PO}_4)_6\text{OH}_2 \)). It is the calcium in the bone that makes it opaque in radiographs. The above proportions clearly indicate that bone is the largest store of body calcium.

**Microscopic Structure of Bone**

There are two types of bony tissue, spongy and compact depending on the bony architecture.

**Structure of Spongy Bone**

The bony lamellae are arranged as interconnecting rods and plates (bony trabeculae). There are spaces between the interconnecting bony tissues. These spaces are called marrow cavities as they are filled with red marrow. The bony lamellae contain collagen fibers. The osteocytes reside between lamellae in specialized lacunae. The processes of osteocytes pass through minute channels called canaliculi, which originate from the lacunae and travel through the lamellae to connect neighboring lacunae to each other. Spongy bone tissue is present in epiphyses of long bones, e.g. in humerus it is present in head, greater and lesser tubercles at upper end and in epicondyles, capitulum and trochlea at the lower end. Similarly spongy bone occurs in head, greater and lesser trochanters in upper end of femur and in the lower end of femur. All short, irregular (vertebrae), flat bones (sternum, scapulae) and skull bones contain spongy bone tissue.

**Structure of Compact Bone**

The compact bone is found in the diaphysis of long bones. Though the compact bone also has lamellar structure like the spongy bone, the pattern of lamellae is quite unique. There are three different types, Haversian system, interstitial lamellae and circumferential lamellae.

**Lamellae of Haversian System**

This pattern of lamellae is known as osteon. Each osteon consists of a centrally located Haversian canal around which lamellae are laid down in concentric rings. The central canal contains capillaries, nerve fibers and areolar tissue. The lamellae show lacunae, from which radiate minute canals called canaliculi. The bodies of the osteocytes are lodged in lacunae and their processes occupy the canaliculi. The canaliculi connect the Haversian canal to all the lacunae in that osteon thereby bringing the nourishment from the canal to all osteocytes via canaliculal network. In the long bone, there are many osteons of this pattern. They are all longitudinally oriented. An additional source of blood supply and nerve supply to the compact bone comes from Volkmann’s canals. These canals carry blood vessels from perioisteal and endosteal surfaces to the osteons. The Volkmann’s canals are horizontally disposed and are not surrounded by concentric rings of lamellae.

**Circumferential Lamellae**

The outer circumferential lamellae are arranged in parallel bundles deep to the periosteum, encircling the entire bone. The inner circumferential lamellae are likewise seen deep to endosteum surrounding the marrow cavity.

**Interstitial Lamellae**

These lamellae are seen in between the regular osteons as irregular areas of lamellae.

**Periosteum**

It is the outer covering of a bone. It is composed of two layers, outer fibrous and inner cellular. The fibrous layer is composed of dense irregular type of connective tissue. The cellular layer consists of osteoprogenitor cells. The periosteum has rich blood supply. A few of periosteal blood vessels enter the bone via Volkmann’s canals. The periosteum is very sensitive to various stimuli. Its outer layer is richly innervated by somatic sensory nerves. The periosteum gives attachments to tendons and ligaments. The collagen fibers of the tendon occasionally enter the outer part of compact bone, where they are embedded in the matrix. Such extensions of collagen fibers from the tendons are called Sharpey’s fibers.

The periosteum performs several functions like nutrition and protection to the bony tissue. In the developing bone in both intramembranous and endochondral ossification, the osteoprogenitor cells in the cellular layer of peristeum lay down subperiosteal bone. In well-developed bone too, these cells grow into osteoblasts (when bone is injured) to help in bone repair. Following example best illustrates the ability of the periosteum to regenerate the bone. During surgical removal of cervical rib, if the surgeon performs subperiosteal resection, the cervical rib will regenerate from the cellular layer of periosteum that is left behind. The patient will once again suffer from symptoms of cervical rib.

**Development and Ossification of Bone**

Embryologically, the bones are mesodermal derivatives. Hence, they develop from undifferentiated mesenchymal tissue. These mesenchymal cells change into osteogenic
cells either directly or first they convert into cartilage cells and then form the bone. Accordingly, if a bone forms directly from osteogenic cells of mesenchyme, the process of ossification is called intramembranous. If a bone forms indirectly from osteogenic cells derived from the cartilage cells of the cartilage model of bone, the process of ossification is called endochondral or intracartilaginous (for details of steps in ossification refer to histology texts). Bones developed by intramembranous ossification (membrane bones) are spongy bones, the examples being, bones of face including mandible, bones of vault of skull and clavicle. The bones developed by endochondral ossification are called cartilage bones, e.g. ear ossicles, hyoid bone, long bones of limbs and bones of cranial base.

**Growth in Diameter of a Bone**

The bone grows in thickness by subperiosteal deposition of bone tissue by osteoblasts from cellular layer of periosteum. This is known as appositional growth. In a long bone, this is corresponding resorption of bone from endosteal side by the osteoclasts. The net result of these two diametrically opposite processes is increase in diameter without increase in width of compact bone. In this way, bone can grow in thickness even after the growth in length stops (refer epiphyseal plate below).

<table>
<thead>
<tr>
<th>Clinical insight...</th>
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<tbody>
<tr>
<td><strong>Bone Diseases due to Nutritional Deficiency</strong></td>
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<tr>
<td>i. <strong>Scurvy</strong> (vitamin C deficiency) affects the synthesis of collagen in the bone as vitamin C is essential in this process. The osteoid is scanty and hence the bone tissue is thin.</td>
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<tr>
<td>ii. <strong>Rickets</strong> (vitamin D deficiency in children) affects the mineralization of osteoid. Vitamin D deficiency leads to poor absorption of calcium and in turn poor mineralization. There are widespread effects of poor mineralization on the skeleton.</td>
</tr>
<tr>
<td>iii. <strong>Osteomalacia</strong> is found in adults, who suffer from inadequate intake of vitamin D or of calcium.</td>
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<tr>
<td>iv. <strong>Osteoporosis</strong> is found in old age. Women are more prone to osteoporosis compared to men. When resorption of bone is more than formation of bone, the bone density is reduced and hence they become fragile and prone to fracture due to slightest trauma.</td>
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**Types of Bones**

i. **Long bones** are found in limbs. Their parts are similar to earlier mentioned parts of a developing long bone, except that they lack growth plate. They are composed of compact bone, are cartilage bones and contain medullary or marrow cavity. The only exception to this is the clavicle, which is the only long bone without marrow cavity, is a membrane bone and ossifies from two primary centers. The yellow marrow fills medullary cavity and red marrow fills the epiphyses in adults. The hemopoiesis (production of erythrocytes, platelets, monocytes and granulocytes) takes place in red marrow. So, hemopoiesis takes place only in the ends of long bones in adults. There is one subtype of long bones called short long bones like metacarpals, metatarsals and phalanges. These bones have epiphyses at one end only unlike the long bones, which have epiphyses at both ends.

ii. **Short bones** are seen in hands and feet. The examples in the hand are the carpals (scaphoid, lunate, triquetral, pisiform in proximal row and trapezium, trapezoid, capitate and hamate in distal row). The examples in foot are the tarsals (talus, calcaneus, cuboid, navicular and three cuneiform bones). They are composed of spongy bone, so hemopoiesis occurs throughout life in them. They are covered with periosteum like the long bones and their articular surfaces are covered with articular hyaline cartilages.

iii. **Flat bones** are seen in bones of the vault of skull, namely frontal bone, parietal bones and occipital bone. Scapula, sternum and ribs are the other examples. The peculiarity of flat bones of skull is that they show sandwich like arrangement of structure. There are two thin plates or tables of compact bone enclosing a space called diploë, which contains red hemopoetic marrow and diploic veins in spongy bone. The diploic veins open into adjacent dural venous sinuses.

iv. **Irregular bones** are the ones that have complex and atypical shapes. The examples are hip bones, vertebrae, temporal bone, sphenoid, ethmoid, maxilla, etc. The vertebrae and the hip bones are sites of hemopoiesis.

v. **Sesamoid bones** are like sesame seeds and develop in the tendons of some muscles. The largest sesamoid bone is the patella, which develops in tendon of quadriceps femoris muscle. Smaller sesamoid bone found in lateral head of gastrocnemius is called fabella. There are few more sites where these bones develop. They are devoid of medullary cavity and periosteum.

vi. **Pneumatic bones** are flat or irregular bones containing a large cavity filled with atmospheric air. The bones containing paranasal air sinuses inside them are maxilla, ethmoid, frontal and sphenoid. The temporal bone houses air containing cavities like middle ear, mastoid antrum and mastoid air cells.
**Parts of Developing Long Bone**

The long bone consists of four parts namely diaphysis, metaphysis, epiphyseal plate or growth cartilage and epiphysis. It is covered by periosteum. A tubular cavity called marrow cavity passes through the diaphysis. It contains red marrow in the developing bone. The marrow cavity is lined by cellular layer, which is called endosteum.

i. The diaphysis is the shaft of a long bone. It is the first part to ossify. The primary center of ossification appears before birth in the cartilage model of the bone in the center of diaphysis (between 6th to 8th weeks of intrauterine life). The shaft of the bone is composed of compact bone.

ii. The metaphysis is the funnel-shaped region at either end of the diaphysis. It intervenes between the growth cartilage and the diaphysis. It is the most vascular part of developing bone as newly formed spongy bone from ossification zone of growth cartilage is laid down here. There is an anastomotic arterial ring surrounding the metaphysis. Because of its high vascularity and stasis of blood here metaphysis is a site of osteomyelitis in growing children.

iii. Epiphyseal plate or growth cartilage is a thin plate of cartilage located between the metaphysis and epiphysis at either end. This is a region of great activity as it is responsible for linear growth in bone. It consists of five zones, namely zone of resting cartilage closest to epiphysis, zone of proliferation, zone of hypertrophy, zone of calcification and zone of ossification. When full height is achieved, the cartilaginous epiphyseal plate turns into bone. The time of closure of the epiphysis varies for different bones and for the two ends of the same bone. After closure the peripheral margin of the epiphyseal plate is indicated by epiphyseal line of the bone.

iv. Epiphysis is the upper and lower end of a long bone. However, in case of short long bones (metacarpals, metatarsals, phalanges and ribs) there is epiphysis at one end only. The epiphyses are cartilaginous until secondary centers of ossification appear in them after birth (lower end of femur is the only exception where secondary center appears just before birth or at term). Thus, epiphysis is defined as part of bone that develops from secondary center of ossification. It contains spongy bone and red marrow throughout life. The articular surface of the epiphysis is covered with articular cartilage (which is hyaline type but without perichondrium). The growing end of the long bone is dependent on the time of closure of its epiphyses. The epiphysis where the center of ossification appears first but unites with the shaft last is the growing end. This is also known as rule of ossification. In upper limb the upper end of humerus and lower ends of radius and ulna are the growing ends. In lower limb, the lower end of femur and upper ends of tibia and fibula are the growing ends. The fibula breaks the rule of ossification as ossification center that appears first in its lower fuses first. By and large, the epiphyses of limb bones fuse by the age of 18 to 20 years in male and two years earlier in females.

**Types of Epiphyses**

i. **Pressure epiphysis** develops at the articulating ends of long bones. The examples are head of femur, head of humerus and capitulum and trochlea at lower end of humerus.

ii. **Traction epiphysis** develops at the line of muscular pull. The examples are greater and lesser trochanters in femur, greater and lesser tubercles in humerus, medial and lateral epicondyles of humerus, etc.

iii. **Atavistic epiphysis** is present as a separate bone in lower animals but in human skeleton it fuses with other bone. The example in human is coracoid process of scapula and posterior tubercle of talus (called os trigonum).

### Disorders of Epiphyseal Plate

Since epiphyseal plates are present until the growth in length of long bones stops its disorders can occur only in pediatric age group and teenagers. Traumatic injury to epiphyseal plate can lead to shortening of the limb. There can be excessive length of the limb if the vascularity of the plate is increased due to inflammation.

**Blood Supply of Long Bone**

The long bone is richly supplied with blood from four sources. These arteries anastomose with each other at the metaphysis. Hence, metaphysis is the most vascular part of a long bone.

i. **Nutrient artery** (Fig. 3.1) is the primary source. It enters the shaft via a nutrient foramen. Inside the bone, it travels in nutrient canal and enters the medullary cavity. It terminates in the same cavity in ascending and descending branches, which remain in contact with the endosteum. They supply medullary branches inwards and cortical branches outwards to the inner two-third of the shaft. In intramedullary nailing-of long bones, these arteries are vulnerable to injury. The ascending and descending branches run to the level of metaphysis, where they anastomose with epiphyseal and metaphyseal
arteries. The nutrient foramen is located on the surface of the bone. Its direction indicates the direction of course of nutrient artery inside the nutrient canal. The artery runs opposite to that of the growing end of the bone. It is described by following dictum in the case of limbs - ‘Towards the elbow I run and away from the knee I flee’. The direction of nutrient foramen helps in identifying the growing end of a long bone.

ii. Numerous periosteal arteries arise from the muscular arteries of the attached muscles. Therefore, bones like tibia and femur, which give attachments to large number of muscles, receive rich supply from periosteal arteries. The periosteal arteries supply approximately the outer-third of the bone.

iii. Metaphyseal arteries (juxta-epiphyseal arteries) arise from arterial anastomosis around the adjacent joint and enter through numerous vascular foramina located in this region.

iv. Epiphyseal arteries are the branches of arterial anastomosis around the adjacent joint.

Types of Synarthroses
i. Fibrous joints in which the connecting bond is connective tissue.
ii. Cartilaginous joints in which the connecting bond is a plate of cartilage.

Subtypes of Fibrous Joints
There are three types of fibrous joints, suture, syndesmosis and gomphosis.

i. The suture is the most common type. The flat cranial bones unite by sutural ligaments. The types of sutures are, serrate, denticulate, plane, squamous and schindylesis (or wedge and groove). The only example of schindylesis is the joint between vomer and rostrum of sphenoid.

ii. Syndesmosis is the fibrous joint in which the articulating bones are united by interosseous membrane or ligament, for example, inferior tibiofibular joint, middle radioulnar joint and middle tibiofibular joint.

iii. Gomphosis is a peg and socket type of fibrous joint seen between the teeth and alveolar sockets.

Subtypes of Cartilaginous Joints
i. In synchondroses or primary cartilaginous joints, the articulating bones are joined by hyaline cartilage. The primary function of these joints is growth. Once the growth is achieved, the synchondroses turns into synostoses (ossified). Hence, synchondroses are temporary joints. The best examples of this variety are, joint between diaphysis and epiphysis of long bones and the joint between basisphenoid and basiocciput at the base of the skull. The first costosternal or chondrosternal joint is also included in this category.

ii. In symphyses or secondary cartilaginous joints, the articulating bones are united by fibrocartilaginous plate. These joints are midline in location in the body and are permanent. The examples are, joints between vertebral bodies (connected by intervertebral discs, symphysis pubis (joint between two pubic parts of hip bones by fibrocartilage), manubriosternal joint, lumbosacral joint and sacrococcygeal joint.

Types of Synovial Joints
i. Plane joints are between the flat surfaces of articulating bones (e.g. intercarpal joints, intertarsal joints, facet joints of vertebrae and sacroiliac joints).

ii. Hinge joint allows movements around transverse axis (e.g. elbow joint, ankle joint and interphalangeal joints).
iii. **Pivot joint** allows rotation movements along a vertical axis. (e.g. superior radioulnar joint and median atlantoaxial joint).

iv. **Bicondylar or condylar joints** allow conjunct and adjunct rotations (e.g. temporomandibular joint and knee joint).

v. **Ellipsoidal joints** are biaxial joints (e.g. wrist joint and the metacarpophalangeal joints).

vi. **Saddle or sellar joint** is biaxial. Its articulating surfaces are reciprocally concavo-convex. The first carpometacarpal joint (trapeziometacarpal joint) of thumb belongs to this type.

vii. **Ball and socket** type of joints are freely mobile as they are multiaxial (e.g. hip joint, shoulder joint, talocalcaneonavicular joint and incudostapedial joint inside middle ear).

**Basic Structure of Synovial Joint**

i. The articulating ends of the bones taking part in the synovial joints are enclosed in a fibrous capsule.

ii. The articular surfaces of the bones are lined by articular cartilage. Histologically, the articular cartilage is a thin layer of hyaline cartilage covering the epiphysis where bone takes part in a joint. The articular cartilage is devoid of perichondrium (because of which it lacks nerve supply and capacity to regenerate). Its only nutritional source is synovial fluid. Degeneration of the articular cartilage as age advances is the root cause of osteoarthritis.

iii. The internal surface of the fibrous capsule and the non-articular parts of articulating bones inside the joint cavity are lined by synovial membrane.

iv. The joint cavity is filled with synovial fluid, which is secreted by synovial membrane. The synovial fluid is of the consistency of egg white. It is a lubricant and provides nutrition to articular cartilages.

v. In some joints, fibrocartilaginous articular discs may be present. The fibrous capsule is strengthened by ligaments.

vi. The synovial joints allow free movements.

**Movements of Synovial Joints (Fig.3.2)**
The following movements take place in the various synovial joints of the body.

**Flexion and Extension**
The flexion indicates bending or decreasing the angle between the two articulating bones of the joints. In flexion of elbow joint, ventral surfaces of arm and forearm approximate. On the contrary in case of knee joint, the dorsal surfaces of leg and thigh approximate during flexion.

The extension indicates straightening or increasing the angle between two articulating bones. In elbow extension forearm and arm align in straight line. Similarly, in knee extension the lower limb becomes a straight pillar.

**Abduction and Adduction**
The abduction means moving away from the median plane in a coronal plane. For example, moving upper limb away from the side of the body is abduction at shoulder joint.

The adduction means moving towards the median plane in a coronal plane, e.g. moving the upper limb towards the side of the body is adduction at shoulder joint.

**Lateral and Medial Rotation**
In rotation movement, the bone moves around itself along its longitudinal axis.

The medial rotation or internal rotation turns the anterior surface of the bone towards median plane.

The lateral rotation or external rotation turns the anterior surface of the bone away from median plane.
Supination and Pronation

Th supination is the movement of forearm by rotating the radius along a longitudinal axis so that the hand faces anteriorly.

The pronation is the movement of forearm by rotating the radius along a longitudinal axis, so that the dorsum of hand faces anteriorly.

Opposition and Reposition

In opposition, the tip of thumb is brought in contact with the tip or base of the other finger.

In reposition, the opposed thumb is brought back to resting position.

Dorsiflexion and Plantarflexion

In dorsiflexion, the ankle joint turns the dorsum upwards so that it faces the anterior surface of leg. In this movement one can walk on ones heel.

In plantarflexion, the ankle joint turns the dorsum of foot inferiorly so that the sole faces posteriorly. In this movement one can walk on ones toes.

Inversion and Eversion

In inversion the lateral margin of the foot is raised so that the sole faces medially. A fully inverted foot is automatically plantarflexed.

In eversion, the medial margin of foot is raised so that the sole faces laterally. A fully everted foot is automatically dorsiflexed.

Protraction and Retraction

In protraction, the bone moves anteriorly (as forward movement of mandible or scapula).

In retraction, the bone moves posteriorly (as backward movement of mandible or of scapula).

Elevation and Depression

In elevation the part moves upwards as in elevating the scapula in shrugging of shoulders.

In depression the part moves downwards as in depressing the scapula while standing at ease.
The vascular tissue is part of the cardiovascular system. The heart is a muscular pump composed of cardiac muscle. It is lined by endocardium and covered by epicardium (visceral pericardium). It pumps arterial blood into the arteries for perfusion of tissues and receives impure blood via the veins. The heart sends impure blood to lungs via pulmonary arteries and receives purified blood by pulmonary veins. Thus, it is evident that heart is the central pump for both systemic and pulmonary circulations. At the tissue level, there is anastomosis between arterioles and venules (capillary bed). It is easy to appreciate that blood vessels are larger nearer the heart and gradually become smaller and smaller closer to the tissues.

All the blood vessels irrespective of sizes are lined internally by single layer of squamous cells called endothelium. At the point of emergence or entry into the cardiac chambers, endothelium of the blood vessels is continuous with the endocardium of the heart. Structurally, the wall of the blood vessel is made of three tunics or layers (tunica adventitia, tunica media and tunica intima). The tunica intima consists of endothelium, sub-endothelial tissue and internal elastic lamina.

**General Layout of Arteries**

The arteries include large-sized arteries (conducting arteries or elastic arteries), medium-sized arteries (distributing arteries or muscular arteries), arterioles and capillaries. The arteries carry blood away from heart under high pressure. Usually, the smaller branches of different arteries join each other at arterial anastomosis. However, there are a few locations in body where the arterial branches do not take part in anastomosis. Such arteries are called anatomical end arteries (example central artery of retina). There are physiological end arteries in the body. These arteries take part in anastomosis with other arteries but the anastomoses are not of sufficient size to carry blood from one artery to the other. The coronary arteries are the best example of this type. The blood vessels supplying a larger blood vessel are called vasa vasorum. All arteries (with few exceptions) are supplied by postganglionic sympathetic fibers, which bring about vasoconstriction.

**Brief Review of Histology of Arteries and Veins**

i. The histology of large artery (for example aorta) differs from that of medium-sized artery (for example axillary and brachial arteries) basically in the composition of tunica media. In large-sized arteries, the media contains predominantly elastic fibers. In medium-sized arteries, the media contains circularly arranged smooth muscle fibers. The internal elastic lamina is prominent in medium-sized arteries but not so in large arteries, where it cannot be differentiated from similar layers of tunica media.

ii. The arterioles are less than 0.1 mm in diameter. Structurally, they are similar to arteries from which they originate except for the absence of internal elastic lamina. Nearer to their termination, they contain thin layer of intima surrounded by few smooth muscle cells. The arterioles offer resistance to blood flow by changing their diameter (hence the name resistance
vessels). Thus, constriction of arterioles raises blood pressure and relaxation decreases the blood pressure.

iii. The capillaries are thin-walled and endothelium-lined microscopic vessels connecting arterioles and veins. Microcirculation means flow of blood from arterioles to venules via capillaries. The endothelial cells are elongated and very thin. The capillaries form a network (capillary bed) at cellular level of tissues. The capillaries are the primary exchange sites of nutrients, oxygen and metabolic byproducts between blood and cells. There are three types of capillaries, continuous, fenestrated and sinusoids. The continuous capillaries have continuous basement membrane. The fenestrated capillaries have numerous fenestrations (openings or holes) in their basement membranes. These capillaries are necessary in renal glomeruli, some endocrine glands and choroid plexuses of ventricles in brain. The sinusoids are wider and irregular in shape compared to capillaries. They are seen in liver, spleen, red bone marrow and some endocrine glands.

iv. Venules are formed by union of several capillaries. They are smaller in diameter than the capillaries but their walls are fenestrated like the capillaries. They deliver the blood to medium-sized veins.

v. The medium-sized and large-sized veins have valves in their lumen. The veins have same three tunics in their walls as the arteries except that all the tunics are thinner and lack the elastic lamina typical of arteries. The large-sized veins typically show well-developed tunica adventitia containing longitudinally disposed smooth muscle bundles. The medium-sized veins contain all three layers without specific characteristics. They are thin-walled with wider lumen, which appears collapsed in a microscopic section.

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**Clinical insight ...**

**Atherosclerosis**

It is a degenerative disease of tissues in the wall of arteries. The basic pathology is damage to the endothelial cells (due to hypertension, smoking, diabetes, etc). This leads to increased permeability, accumulation of lipoproteins and death of endothelial cells in patches. The subendothelial layer is exposed in areas of patches. There is migration of smooth muscle cells of tunica media into subendothelial layer. These cells and macrophages imbibe lipoproteins. These changes finally lead to formation of atherosclerotic plaque. This is how arteries are narrowed leading to ischemia of tissues.

**Aneurysm**

Dilatation of artery is called aneurysm. When the arterial wall is inherently weak or is subjected to high pressure it gives way by dilating. Aneurysm of aorta is a common clinical condition.

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**LYMPHATIC TISSUE**

The lymphatic tissue is functionally a part of the immune system of the body. The lymphatic tissue is distributed in the body as aggregations of lymphocytes in specific lymphatic organs (such as lymph nodes, spleen, tonsils and thymus) and as diffuse lymphoid tissue in MALT (Mucosa Associated Lymphatic Tissue), GALT (Gut Associated Lymphatic Tissue), BALT (Bronchus Associated Lymphatic Tissue) and SALT (Skin Associated Lymphatic Tissue). Basically, the lymphatic tissue is composed of lymphocytes (B lymphocytes, T lymphocytes, NK cells (Natural Killer cells), plasma cells and macrophages supported by reticular fibers of connective tissue. The lymphatic tissue of the numerous lymph nodes found in the body filters the lymph, which is the tissue fluid or transudate of blood, containing particulate matter like cell debris, microbes and plasma proteins taken up by the lymphatic vessels and carried to regional lymph nodes. The filtered lymph from all regions of the body (except the right half of thorax, right upper limb and right half of head and neck) is collected in a big lymphatic duct called thoracic duct, to be poured into the blood circulation at the junction of left internal...
jugular and left subclavian veins (Fig. 4.1). The lymph from the areas mentioned in the bracket is collected by right lymphatic duct, to be poured into the corresponding venous junction on the right side.

**Functions of Lymphatic Tissue**

i. Production of cells like lymphocytes and plasma cells which have the ability to recognize and neutralize antigens (microbes, tumor cells and toxins).

ii. Phagocytosis of foreign cells such as microbes and cancer cells by macrophages.

**Types of Lymphocytes**

There are three types of lymphocytes namely, T lymphocytes, B lymphocytes and NK (Natural Killer) lymphocytes.

i. *T lymphocytes* originate in bone marrow but mature in thymus, from where they migrate to other lymphoid organs via blood circulation. Amongst the three types of lymphocytes, maximum population of T lymphocytes is present in blood circulation. T lymphocytes are responsible for cell-mediated immunity in which the microbes are killed by release of lymphokines which attach the T lymphocytes to the surface of the microbes. The example of cell-mediated immunity is polio immunization.

ii. *B lymphocytes* originate in bone marrow but undergo maturation in either the bone marrow or in GALT. The plasma cells are modified B lymphocytes. They produce antibodies (immunoglobulin) to destroy the microbes and toxins. This type of immunity is called humoral immunity. Example of humoral immunity is tetanus toxoid. There are five types of immunoglobulins in the body (IgG that crosses placental barrier, IgA, IgM, IgE in allergic reactions and IgD).

iii. *NK cells* originate in bone marrow. They are called natural killer cells because they attack virus infested cells and cancer cells without stimulation. They do not have any surface receptors.

**Primary Lymphoid Organs**

The thymus and bone marrow are the primary lymphoid organs in human being. The thymus consists of 100 percent T lymphocytes.

**Secondary Lymphoid Organs**

The lymph nodes and spleen belong to this category. They approximately consist of 60 percent T lymphocytes and 40 percent B lymphocytes.

**Lymphatic Tissue within Other Organs**

GALT (Gut Associated Lymphatic Tissue), which includes Waldreyer’s ring (a ring of lymphatic tissue composed of palatine tonsils, tubal tonsils, nasopharyngeal tonsil and lingual tonsils), Peyer’s patches in ileum, aggregations in vermiform appendix (called abdominal tonsil), BALT and SALT fall under this category.

**Thymus**

The thymus is composed of T lymphocyte population. It is unique in having a stroma of reticuloendothelial cells (referred to as epitheliocytes) inside its numerous lobules. Each thymic lobule consists of peripheral cortex of densely packed lymphocytes and central medulla of loosely packed lymphocytes. The epitheliocytes developmentally belong to endoderm of third pharyngeal pouches (same source as the thymus). These cells form an internal lining for the capsule and the septa of thymus. They also cover the surfaces of blood vessels inside the thymus. This arrangement indicates the role of epitheliocytes in forming a blood-thymus barrier, which prevents the contact between the lymphocytes of thymus and the antigens in the blood. The stem cells of bone marrow reach the cortex of each lobule via blood circulation and begin mitotic divisions to form T lymphocytes. There are no lymphatic follicles in thymus and hence no germinal centers. The T lymphocytes enter the medulla to leave the thymus via venules or efferent lymph vessels. The characteristic Hassall’s corpuscles of thymus are composed of degenerating epitheliocytes forming a homogeneous eosinophilic mass encircled by concentrically arranged epitheliocytes.

**Lymph Node**

The lymph nodes are small encapsulated structures seen along the path of lymphatic vessels that bring lymph to them for filtration. In keeping with this function, the lymph nodes have both afferent and efferent lymph vessels. The afferent vessels pierce the capsule to pour lymph into the subcapsular sinus. The interior of lymph node is divided into outer cortex and inner medulla. The stroma consists of trabeculae and reticular connective tissue. The cortex is characterized by presence of well-defined lymphatic nodules, which may show germinal centers. The cortex has densely packed lymphocytes while medulla shows cord like arrangement of lymphocytes. The inner part of cortex is called paracortex, which shows diffusely arranged T lymphocytes. The lymph from subcapsular sinus percolates along cortical sinuses into the medullary sinuses, from where it leaves by efferent lymphatic vessels at the hilum of lymph nodes.

**Spleen**

The spleen is the largest lymphoid organ in the body. It performs immunological functions, takes part in destruction of damaged and aged erythrocytes, filters
blood, produces B and T lymphocytes and acts as reservoir of blood. A dense connective tissue capsule extends into the substance of spleen as characteristic trabeculae, which carry blood vessels. The splenic parenchyma is supported by delicate reticular fibers and cells. Being a highly vascular organ, the spleen has plenty of venous sinusoids. Its parenchyma consists of white pulp and red pulp. The white pulp is composed of lymphatic follicles with germinal centers, scattered all over the interior. Each follicle surrounding an arteriole is referred to as Periarterial Lymphatic Sheath (PALS). The efferent lymph vessels from spleen leave via the hilum to join regional lymph nodes. The red pulp is composed of splenic cords (cords of Billroth) separated by venous sinusoids (mentioned above). The splenic cords are composed of lymphocytes, macrophages, granulocytes, plasma cells, erythrocytes and reticular cells plus reticular fibers. The red pulp appears red because of presence of innumerable venous sinusoids filled with blood.

**Palatine Tonsil**

The palatine tonsils are the collections of lymphatic tissue subjacent to the stratified squamous non-keratinized epithelium of oropharynx. The epithelium dips into the substance of tonsils as 15 to 20 tonsillar crypts. The crypts branch once inside the tonsil. In this way, the lymphatic follicles with germinal centers are brought in intimate contact with epithelium (at the so called lymphoepithelial symbiosis). This facilitates direct contact between the antigen (microbes ingested through oral cavity) and the lymphocytes inside the tonsils. Thus, the tonsil offers first line of defense to the body against antigens (bacteria, viruses etc) as soon as they are swallowed in food or drink.
SKIN

The skin covers the external surface of the body. The skin is considered the widest organ of human body as it performs a variety of functions.

**Functions of Skin**

i. The keratin of skin serves as an effective barrier against invasion by micro-organisms and against chemicals, heat and abrasions. It prevents excessive evaporation of water from skin surface, thus guarding against dehydration.

ii. Body temperature is regulated by dilatation (cooling) and constriction (warming) of blood vessels in the dermis. Moreover, heat induces sweat glands to secrete more, thereby cooling the body.

iii. The skin serves as a sensory organ because it perceives external sensations via sensory receptors located in it. The touch sensations are carried by Meissner’s corpuscles located in dermal papillae close to dermoeipidermal junction and Merkel’s discs associated with cells in epidermis, Krause’s end bulbs and by Ruffini endings in the dermis. The pain and temperature sensations are carried by free nerve endings. The pressure and vibration is subserved by lamellated Pacinian corpuscles (located deep in the dermis).

iv. Synthesis of vitamin D in keratinocytes of epidermis with the help of ultraviolet rays in sunlight is a major metabolic activity of the skin.

v. The cutaneous blood vessels store around 5% of the body’s blood volume. The skin therefore is a blood reservoir.

vi. The skin acts like an excretory organ by eliminating limited amounts of nitrogenous wastes from the body in sweat.

vii. Intradermal injections are given in the dermis. The best example is intradermal injection of tuberculin (Mantoux test) in the skin of ventral surface of forearm for diagnosis of tuberculosis. Other common example of intradermal injection is testing for penicillin sensitivity before giving intramuscular penicillin injection to avoid anaphylactic reaction.

**Layers of Skin**

i. Epidermis (derived from ectoderm)

ii. Dermis (derived from mesoderm)

**Layers of the Epidermis in Thick Skin (From Deep to Superficial)**

i. The *stratum basale* is the deepest layer consisting of a single row of low columnar keratinocytes resting on a well-defined basement membrane. These cells are attached to the basement membrane by hemidesmosomes. They undergo rapid and repeated mitotic divisions. Hence, this layer is also known as stratum germinativum. As the new cells are formed they move towards stratum spinosum. The basal layer also contains Merkel cells (with their associated tactile discs or Merkel discs), Langerhan’s cells and melanocytes.

ii. The *stratum spinosum* or prickly layer is composed of several layers of keratinocytes. These polygonal cells are attached to one another by desmosomes. On staining with H and E, the desmosomes appear as
small spines or thorns on the cells (hence the name stratum spinosum for this layer and the name prickle cells for keratinocytes). The cytoplasm of these cells contains keratin filaments. This layer also shows Langerhan’s cells and melanocytes. The Langerhan’s cells originate from stem cells in bone marrow and migrate into the skin for phagocytic functions. They play an important role in providing immunity to skin from viral infections. The melanocytes are derived from neural crest and they protect the stratum germinativum cells from ultraviolet rays of sunlight.

iii. The stratum granulosum consists of rows of flattened and degenerating keratinocytes. The presence of darkly staining keratohyalin granules is the distinctive feature of these cells.

iv. The stratum lucidum appears as a clear transparent band. It consists of a few rows of flat, dead keratinocytes containing eliedin and is present only in thick skin of sole and palm.

v. The stratum corneum is the outermost layer of dead keratinized cells devoid of nuclei and cell organelles. These are the oldest cells in the epidermis and are gradually sloughed off by a process called desquamation.

**Surface Epidermal Ridges**

The following sites in the body (palm, sole, finger-pads and toe-pads) present surface elevations due to epidermal thickenings (somewhat similar to epidermal ridges projecting in dermis). These epidermal irregularities are variously described as papillary ridges or friction ridges or surface ectodermal ridges. They form intricate patterns, which are unique for every individual. This is the basis of personal identification from finger prints. The study of these patterns is known as dermatoglyphics.

**Dermal-Epidermal Junction**

The basement membrane of epidermis is the demarcation line between epidermis and dermis. The anchoring fibers between the two layers are composed of both collagen and elastic fibers. This junction is wavy as it is characterized by dermal papillae and epidermal ridges (peg like extensions of epidermis into dermis), which increase the area of adhesion between the two layers. It is this junctional tissue that is defective in a disease called Epidermolysis Bullosa (EB). This is an inherited disorder characterized by recurrent blister formation on skin in response to trivial trauma like rubbing or pressure.

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**Fig. 5.1:** Organization of the skin into epidermis and dermis
(Note that the various sensory receptors in the dermis and the pilosebaceous units in dermis)
Dermis

It is the second major skin region containing strong, flexible connective tissue. It is composed of two layers, papillary and reticular.

Papillary Layer

This layer is characterized by areolar connective tissue with collagen and elastic fibers along with fibroblasts. The upward projections on dermis indenting the basement membrane of epidermis are called dermal papillae. The papillae contain capillary loops, Meissner’s corpuscles and free nerve endings.

Reticular Layer

This layer is composed of dense irregular connective tissue along with blood vessels and Pacinian corpuscles for vibration and pressure sense. The collagen fibers add to its strength and resiliency. The elastic fibers provide stretch-recoil properties. These fibers tend to atrophy as age advances resulting in wrinkling of skin. The bundles of collagen fibers are arranged parallel to one another. They are oriented along the long axis of limbs but along the perpendicular axis in the trunk. The cleavage lines of Langer (tension lines) along the long axis of limbs but along the perpendicular axis result in wrinkling of skin. The bundles of collagen fibers add to its strength and resiliency. The elastic fibers provide stretch-recoil properties. These fibers tend to atrophy as age advances resulting in wrinkling of skin. The bundles of collagen fibers are arranged parallel to one another. They are oriented along the long axis of limbs but along the perpendicular axis in the trunk. The cleavage lines of Langer (tension lines) on the skin are produced along the direction of the collagen bundles. The lines of cleavage have surgical importance since skin incisions placed along these lines heal with a fine scar compared to a surgical incision placed across the cleavage lines, which heals with a thick irregular scar.

Glands of Skin

i. The sweat glands are coiled tubular glands which are located deep in the reticular layer of dermis. Their long ducts pass through the dermis and then the epidermis to open at skin pores. The part of ducts in dermis is lined by stratified cuboidal epithelium while the part in the epidermis is lined by stratified squamous epithelium. The main function of sweat glands is to prevent overheating of the body. There are two types of sweat glands in the body. The eccrine sweat glands are the most common and are widely distributed in the body. They are supplied by cholinergic sympathetic nerve fibers. The apocrine sweat glands are localized to the skin of axilla, anogenital region and areola. They are supplied by adrenergic sympathetic nerve fibers. (Note: There is difference in the innervation of eccrine and apocrine sweat glands)

ii. The sebaceous glands are part of a complex called pilosebaceous unit, which consists of sebaceous gland, arrector pilorum muscle, hair shaft and hair-follicle. The gland is located in the triangle formed by epidermis, slanting side of hair shaft and arrector pilorum muscle. It opens by a short duct into the shaft of adjacent hair follicle. The glands secrete an oily secretion called sebum (lipid and cell debris), which softens the skin and the hair. Their mode of secretion is holocrine (associated with death of secreting cell also known as programmed death or apoptosis). The sebaceous glands are under the control of sex hormones. The arrector pilorum muscle is a smooth muscle that connects the undersurface of the hair follicle to dermal papilla. It is supplied by postganglionic sympathetic fibers. Contraction of these muscles compresses the secretory units of the glands, thereby helping in expelling the secretion out into the ducts and into the hair shaft. The contraction of muscles straightens the shafts of the hair follicles and exerts a pull on the skin surface causing dimpling known as ‘gooseflesh’. The arrector pili muscles develop from mesenchyme.

Clinical Conditions of Skin

i. The three major types of skin cancer are basal cell carcinoma, squamous cell carcinoma and melanoma. The basal cell carcinoma is the most common skin cancer. The cells of stratum basale proliferate and invade the dermis and hypodermis. The squamous cell carcinoma begins in keratinocytes of stratum spinosum. The common sites of occurrence are scalp, ears, and lower lip. The cancer grows rapidly and metastasizes if not removed. The melanoma is the cancer of melanocytes. It is the most dangerous type of skin cancer because it is highly metastatic.

ii. Albinism is an autosomal recessive disorder in which an individual lacks the ability to synthesize melanin. The melanin pigment is absent in hair, iris and skin.

iii. Skin burns are the common cause of loss of fluids from the body. Severe burns are fatal.

iv. The skin grafting is used when a large area of skin is damaged due to disease or severe burns. In split thickness graft, epidermis with tips of dermal papillae is grafted in the recipient. The donor’s skin regenerates on the body. Severe burns are fatal.

v. Acne or pimples are small elevations on facial skin due to swelling of sebaceous glands. This usually occurs in young adolescents. Under the influence of sex hormone the sebaceous glands secrete more sebum and if the ducts are blocked sebum accumulates. The swollen gland may be infected. Another condition affecting sebaceous glands is sebaceous cyst, which needs surgical removal. The scalp is the most favorite site for sebaceous cysts.

Contd...
HYPODERMIS OR SUPERFICIAL FASCIA

This layer lies subjacent to the dermis and is composed of variable amount of subcutaneous adipose tissue (panniculus adiposus), areolar connective tissue, cutaneous vessels, cutaneous lymphatics and sensory nerves. It is visible after placing an incision in the skin with a surgical knife and reflecting skin flaps in living as well as in dead. The panniculus carnosus is the subcutaneous muscle in quadrupeds. It is inserted into the skin. This muscle is represented in human beings by palmaris brevis, muscles of facial expression, platysma, dartos, subcutaneous part of sphincter ani externus and corrugator cutis ani. Of the above muscles dartos and corrugator cutis ani are smooth muscles.

Modifications of Deep Fascia

i. The retinacula around wrist and ankle are the thickened bands of deep fascia. They serve the purpose of strapping down the tendons of long flexor and extensor muscles.

ii. The palmar and plantar aponeurosis are the thickened and flattened parts of deep fascia in palm and sole respectively. Their function is to protect the underlying nerves and vessels.

iii. The fascial sheaths around neurovascular bundles are seen in neck as carotid sheath and as axillary sheath, which is extension of prevertebral fascia of neck surrounding the axillary vessels.

iv. The interosseous membranes of forearm and leg are modified deep fascia.

v. The fibrous sheaths are found around flexor tendons of fingers.

vi. The fascial sheaths are formed around muscles in certain locations. The psoas major muscle on posterior abdominal wall is covered with psoas sheath.

DEEP FASCIA

This is a tough fibrous membrane deep to the superficial fascia. In the limbs and neck, its arrangement is such that there are fascial compartments enclosing some structures. The purpose of such compartmentalization is to prevent spread of infection from one to the other. In the limbs, it forms partitions (intermuscular septa) which separate the compartments comprising muscles, nerves and vessels. In the leg, the tightly enclosed fascial compartments assume functional significance in facilitating venous return against gravity. In palm, it forms fascial spaces of surgical importance. The deep fascia does not have uniform appearance. So, depending on functional requirements its appearance and terminology change. There are a few sites in the body devoid of deep fascia like face, scalp and anterior abdominal wall.

Clinical insight ...

Subcutaneous Injections

Some drugs are administered in subcutaneous tissue, especially where slow absorption is desirable. The most common example is subcutaneous injection of insulin. The local anesthetics are injected subcutaneously. Similarly, low-molecular-weight heparin is given by this route (usually in anterior abdominal wall) in post-angioplasty patients and after coronary bypass surgeries.
ANATOMICAL POSITION (FIG. 6.1)

Definition
The position of a person standing erect, looking directly forwards, with arms resting by the side of the body, feet together and palms facing forwards is described as anatomical position. The relationship of anatomical structures to each other are described with the assumption that person is in anatomical position. To illustrate this concept let us take a simple example of direction of forearm in supine position of body and anatomical position of body. The forearm faces upwards in former and towards front in the latter position. Therefore, to have uniformity in describing anatomical interrelations anatomical position of the body is the gold standard.

VARIOUS ANATOMICAL TERMS
The different anatomical terms are enlisted in Table 6.1

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior/cranial</td>
<td>Towards head</td>
<td>Nose is superior to mouth</td>
</tr>
<tr>
<td>Inferior/caudal</td>
<td>Towards feet</td>
<td>Knee joint is inferior to hip join</td>
</tr>
<tr>
<td>Anterior/ventral</td>
<td>Towards the front</td>
<td>The toes are anterior to heel</td>
</tr>
<tr>
<td>Posterior/dorsal</td>
<td>Towards the back</td>
<td>The heel is posterior to the toes</td>
</tr>
<tr>
<td>Medial</td>
<td>Towards the midline of body</td>
<td>The eye is medial to ear of same side</td>
</tr>
<tr>
<td>Lateral</td>
<td>Away from the midline of body</td>
<td>The ear is lateral to the eye of same side</td>
</tr>
<tr>
<td>Proximal</td>
<td>Nearer the attachment of limb to the trunk</td>
<td>Shoulder is proximal to elbow</td>
</tr>
<tr>
<td>Distal</td>
<td>Away from the attachment of limb to the trunk</td>
<td>The palm is distal to forearm</td>
</tr>
<tr>
<td>Superficial</td>
<td>Near the surface of body</td>
<td>The skin is superficial to muscles and bones</td>
</tr>
<tr>
<td>Deep</td>
<td>Away from the surface of body in inward direction</td>
<td>The lungs are deeper to rib cage</td>
</tr>
<tr>
<td>Superolateral</td>
<td>Nearer the head but away from median plane</td>
<td>The ears are superolateral to chin</td>
</tr>
<tr>
<td>Superomedial</td>
<td>Nearer the head and median plane</td>
<td>The nose is inferomedial to eyes</td>
</tr>
<tr>
<td>Inferolateral</td>
<td>Nearer the feet but away from median plane</td>
<td>The shoulder is inferolateral to the point of chin</td>
</tr>
<tr>
<td>Inferomedial</td>
<td>Nearer the feet and median plane</td>
<td>The anterior ends of floating ribs run inferomedially</td>
</tr>
<tr>
<td>Ipsilateral</td>
<td>Occurring on the same side of body</td>
<td>Right upper limb is ipsilateral to right lower limb</td>
</tr>
<tr>
<td>Contralateral</td>
<td>Occurring on opposite sides of body</td>
<td>Right upper limb is contralateral to left lower limb</td>
</tr>
</tbody>
</table>
### Additional Descriptive Terms for Position of Body

i. **Supine position** is the one in which subject is lying on the back with face looking upwards.

ii. **Prone position** is the one in which subject is lying on the belly with face looking downwards.

iii. **Lateral position** is either right lateral or left lateral in which subject lies on one side of the body.

iv. **Lithotomy position** is the one in which subject lies in supine position with hip joints in flexed and abducted positions and knee joints in partially flexed positions. This position is adopted for performing cadaveric or surgical dissection of perineum and also during per vaginum (PV) examinations, vaginal deliveries and procedures like D (dilatation) and C (curettage) in gynecological practice.

### DIRECTIONAL PLANES OF HUMAN BODY (FIG. 6.1)

In order to understand relations of internal structures (organs inside the body) the body is conventionally cut in the following planes. Individual organs can also be studied by using similar planes of sectioning.

i. The **midsagittal plane** or median plane is a vertical plane that divides the body lengthwise into two equal halves. It is called midsagittal because it passes along the length of sagittal suture of the skull.

ii. The **sagittal plane** is any plane passing parallel to the median plane for dividing the body into unequal longitudinal halves.

iii. The **coronal or frontal plane** divides the body into anterior and posterior halves. It is so called because it passes through or is parallel to the coronal suture of the skull. The coronal plane is at right angles to the midsagittal plane.

iv. The **transverse or horizontal plane** divides the body or organs into superior and inferior sections. It is at right angles to both midsagittal and coronal planes.

The aforementioned anatomical terms are universally used by clinicians all over the world. In fact these terms are the integral part of the international vocabulary of health care professionals.
The new life begins as a zygote, which is a unicellular organism. A new human being is created by the complex processes of multiplication and differentiation of the cells derived from this single cell. The zygote is formed by the union of sperm (a male gamete) and a secondary oocyte (a female gamete). The gametes are haploid cells (23 chromosomes) unlike the somatic cells of the body, which are diploid (46 chromosomes). The gametes are formed in gonads (oocytes in ovaries and sperms in testes).

## GAMETOGENESIS

The formation of gametes by conversion of primordial germ cells into gametes is known as gametogenesis.

i. The oogenesis is the process of formation of oocyte from oogonium inside the ovaries.

ii. The spermatogenesis is the process of formation of sperm from spermatogonium inside the testes.

### GAMETOGENESIS

- Oogenesis
- Spermatogenesis

### FERTILIZATION

- Cleavage of Zygote and Formation of Morula
- Blastocyst Formation
- Decidua
- Normal Site of Implantation
- Formation of Bilaminar Embryonic Disc
- Amniotic Cavity
- Primary and Secondary Yolk Sac
- Chorion
- Prochordal Plate
- Primitive Streak and

### GENETIC FACTORS AND CONGENITAL ANOMALIES

- Genetic Diseases due to Gene Mutation
- Modes of Inheritance of Monogenic Diseases
- Polygenic Diseases
- Mitochondrial Inheritance

### CHROMOSOMES

- Parts of a Chromosome
- Morphological Types of Chromosomes
- Karyotyping using Giemsa Banding
- Denver Classification of Chromosomes
- Sex Chromosomes
- Role of Y chromosome in Sex Differentiation
- Structural Anomalies of Chromosomes
- Philadelphia Chromosome (Ph' chromosome)
- Numerical Anomalies of Chromosomes
- Cell Cycle, Mitosis and Meiosis

The new life begins as a zygote, which is a unicellular organism. A new human being is created by the complex processes of multiplication and differentiation of the cells derived from this single cell. The zygote is formed by the union of sperm (a male gamete) and a secondary oocyte (a female gamete). The gametes are haploid cells (23 chromosomes) unlike the somatic cells of the body, which are diploid (46 chromosomes). The gametes are formed in gonads (oocytes in ovaries and sperms in testes).

During gametogenesis, the germ cell undergoes meiotic division or reduction division. During prophase of meiosis-I homologous chromosomes exchange genetic material (ensuring genetic variation in new cells) and then move from each other during anaphase to go separate new cells (ensuring the haploid status of new cells). During meiosis II, there is no replication of DNA in the haploid cells but there is splitting of chromosomes during anaphase like in mitosis so that each new cell (gamete) formed retains the haploid status with half the amount of DNA.

### Oogenesis (Fig. 7.1)

The oogenesis begins in the ovaries of the female fetus (before birth). The oogonia are the primordial germ cells in the female. They divide by mitosis. Their number is highest during the fourth-to-fifth month of intrauterine
fetus. All primary oocytes remain arrested in this stage until the onset of puberty. From the age of puberty onwards, during each ovarian cycle one primary oocyte completes the first meiotic division just before ovulation. The first meiotic division is unequal as the larger cell is called secondary oocyte and the much smaller cell is called the first polar body. The secondary oocyte immediately enters the second meiotic division but this division is completed only if it is fertilized (or penetrated by sperm). The products of second meiotic division are unequal. The larger cell is called ovum and the smaller cell is the second polar body. If not fertilized, the secondary oocyte does not complete the meiosis and is thrown out with the next menstrual flow. The polar bodies are absorbed in the body. During ovulation, the secondary oocyte is released from the ovary by rupture of Graafian follicle (Fig. 7.2). Immediately after ovulation the secondary oocyte is surrounded by loosened cells of cumulus oophorus. These cells are arranged radially (hence the name corona radiata). The secondary oocyte encircled by corona radiata is picked up by fimbriated end of fallopian tube.

**Spermatogenesis (Fig. 7.3)**

The process of formation of sperms begins by the age of puberty in the seminiferous tubules in the male. The spermatogonia begin to divide mitotically. Some spermatogonia enlarge into primary spermatocytes, which undergo first meiotic division to give rise to two equal haploid cells known as secondary spermatocytes.
Following the second meiotic divisions of the secondary spermatocytes, four spermatids are formed.

**Spermiogenesis**
The rounded spermatids change into motile elongated sperms by a process called spermiogenesis. The nucleus of spermatid becomes the head of sperm. The acrosomic granules in Golgi body become the acrosomal cap. One centriole occupies the neck and the middle piece contains axial filament that is surrounded by mitochondrial sheath. The caudal end of middle piece is limited by ring-like second centriole. The principal piece consists of axial filament surrounded by fibrous sheath. The last segment is the long tail piece consisting of axial filament. The entire sperm (Fig. 7.4) thus formed is covered by plasma membrane.

### FERTILIZATION

The union of secondary oocyte and sperm takes place normally in the ampulla of the uterine tube. The following events occur prepatory to the fertilization.

i. The secondary oocyte (in metaphase of first meiotic division) is surrounded by a glycoprotein layer called zona pellucida, which is covered by the cells of corona radiata.

ii. The perivitelline space is located between the zona and the vitelline membrane (plasma membrane of secondary oocyte).

iii. After entering the female genital tract, the sperms undergo capacitation (functional changes) and acrosomal reaction in the uterine tube.

iv. The removal of glycoproteins, cholesterol and seminal proteins from plasma membrane around the acrosomal cap is called capacitation. Only the capacitated sperms are able to penetrate the corona radiata.

v. The head of the sperm binds with the zona pellucida. This triggers the acrosomal reaction and release of acrosomal enzymes creating a path for the sperms in the zona pellucida.

vi. Once the sperm reaches the perivitelline space, zona reaction is induced by secondary oocyte to prevent the entry of other sperms.

vii. The secondary oocyte completes its second meiotic division as soon as the head of the sperm enters its cytoplasm.

viii. The nucleus in the head of sperm develops into male pronucleus and nucleus of fertilized ovum develops into female pronucleus.

ix. The pronuclei fuse and chromosomes intermingle to form a new diploid cell called zygote.

In summary, the fertilization restores the chromosome number of the species, determines the chromosomal sex of the zygote (if a Y bearing sperm fertilizes the ovum, it results in male zygote and if X bearing sperm fertilizes the ovum, it results in female zygote) and initiates the cleavage process (rapid mitotic divisions) of zygote.

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**Clinical insight ...**

**Prevention of Fertilization by Contraceptive Methods**

i. The use of mechanical barriers like male condom or diaphragm in vagina and cervical cap in female during sexual intercourse prevents meeting of the male and female gametes.

ii. The oral contraceptive pills prevent formation of gametes in female. Thus, menstrual cycles are artificially made anovulatory.

iii. Vasectomy in male and tubectomy in female are the surgical methods to prevent fertilization.

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**Cleavage of Zygote and Formation of Morula (Fig. 7.5)**

The process in which there are rapid repeated mitotic divisions of zygote immediately after fertilization is called cleavage. The smaller and smaller cells thus formed are called blastomeres. The morula (resembling mulberry) is formed at 16-cell stage. It is covered by zona pellucida. Gradually, the morula adds to its cell population as it travels from uterine tube to uterine cavity.
Chapter III

The inner cell mass is attached to trophoblast at the embryonic pole of the blastocyst.

iv. The zona pellucida disappears by fifth day after fertilization.

v. The blastocyst begins implantation in the endometrium by sixth or seventh day after fertilization.

vi. The inner cell mass develops into the embryo and the trophoblast develops into chorion, which later takes part in the formation of placenta (the nutritive organ). The trophoblast subdivides into inner cytotrophoblast and outer syncytiotrophoblast. The latter secretes Human Chorionic Gonadotrophic (hCG) hormone.

Implantation of Blastocyst

It is a process by which blastocyst is embedded into the secretory endometrium of uterus. The syncytiotrophoblast erodes the endometrial tissue creating a passage for blastocyst to enter and embed inside the endometrium. This is the characteristic interstitial implantation in human being.

Decidua

After implantation, the endometrium is called decidua as it shows decidual reaction due to action of hCG hormone. The decidual reaction is marked by accumulation of glycogen and lipids in stromal cells plus fluid accumulation in intercellular spaces in the decidua.

**Blastocyst Formation**

Inside the uterine cavity, the morula changes into blastocyst (Fig. 7.6).

i. There is accumulation of fluid in the morula followed by segregation of cells of morula into inner cell mass and outer cell mass enclosing a cavity.

ii. Soon the cavity of blastocyst enlarges and the flattened cells of outer cell mass forming its periphery are called the trophoblast.

iii. The inner cell mass is attached to trophoblast at the embryonic pole of the blastocyst.

iv. The zona pellucida disappears by fifth day after fertilization.

v. The blastocyst begins implantation in the endometrium by sixth or seventh day after fertilization.

vi. The inner cell mass develops into the embryo and the trophoblast develops into chorion, which later takes part in the formation of placenta (the nutritive organ). The trophoblast subdivides into inner cytotrophoblast and outer syncytiotrophoblast. The latter secretes Human Chorionic Gonadotrophic (hCG) hormone.
Subdivisions of Decidua

After complete implantation of the blastocyst, the decidua is divisible into three parts.

i. Decidua basalis, which covers the blastocyst on the side that faces the uterine wall.
ii. Decidua capsularis, which covers the blastocyst on the side that faces the uterine cavity.
iii. Decidua parietalis is the extensive part of decidua, which is not related to blastocyst, but lines the rest of uterine cavity.

Normal Site of Implantation (Fig. 7.7)

The implantation of blastocyst takes place on the posterior wall of the body of uterus near to the fundus (upper part of uterus above the level of openings of uterine tubes).

Abnormal Sites of Implantation (Fig. 7.7)

i. The blastocyst may be implanted nearer the cervix of uterus. This results in formation of placenta which may cover the internal os (upper opening of cervical canal). This condition is called placenta previa.
ii. Implantation in uterine tube is called tubal pregnancy (Fig. 7.8). When the products of conceptus grow inside the tube it produces symptoms like pain in lower abdomen. The natural fate of tubal pregnancy is rupture of the tube leading to severe haemorrhage in the peritoneal cavity. It is a surgical emergency.
iii. The rare sites of implantation are ovarian surface, peritoneum, surface of intestine and rectouterine pouch.

Contraceptive Device to Prevent Implantation

IUCD (intrauterine contraceptive device) like copper-T is inserted into the uterus to prevent implantation.

Formation of Bilaminar Embryonic Disc (Figs 7.9A and B)

At the beginning of second week the cells of inner cell mass differentiate into two layers.

Endoderm

The endoderm is formed by a single layer of cells closer to the cavity of blastocyst.

Ectoderm

The ectoderm is formed from the single layer of the rest of cells of inner cell mass (above the endodermal layer).

Amniotic Cavity

The amniotic cavity appears between ectoderm and adjacent trophoblast. Its roof is formed by amniogenic cells, which are delaminated from the trophoblast. These cells produce amniotic fluid.

Primary and Secondary Yolk Sac

Soon the endodermal cells begin to line the cavity of the blastocyst, which is now called primary yolk sac. Concurrently, the cells of yolk sac proliferate to form the extraembryonic mesoderm between the trophoblast externally and the amniotic and yolk sac cavities internally. The extraembryonic mesoderm splits to form extraembryonic
coelom except adjacent to the roof of amniotic cavity. Here the mesoderm forms connecting stalk (the forerunner of umbilical cord). The extraembryonic coelom compresses the primary yolk sac reducing its size. The reduced primary yolk sac is called the secondary yolk sac.

**Chorion**

The formation of extraembryonic coelom subdivides the extraembryonic mesoderm into outer somatopleuric layer and inner splanchnopleuric layer. The somatopleuric layer of extraembryonic mesoderm lies subjacent to the trophoblast. The combination of the aforesaid two layers is called chorion. This fetal membrane is very essential for contributing towards fetal part of placenta, which is a life sustaining organ of fetus. By eighth day after fertilization syncytiotrophoblast starts secreting human chorionic gonadotrophic (hCG) hormone, which is detectable in the urine of pregnant woman.

**Prochordal Plate**

i. The prochordal plate is a rounded and thickened area at the cranial end of the embryonic disc, where the ectoderm and endoderm are in close contact. It is located cranial to the notochord.

ii. The craniocaudal axis of the disc is established by the appearance of prochordal plate.

iii. The intraembryonic mesoderm does not invaginate into the prochordal plate.

iv. After folding of embryonic disc the region of prochordal plate forms the buccopharyngeal membrane. This membrane is placed between the foregut and the stomodeum.

v. After the rupture of this membrane at the end of fourth week, the foregut communicates with buccal cavity.

**Primitive Streak and Gastrulation (Fig. 7.10)**

The third week after fertilization is characterized by gastrulation, which is crucial in converting the bilaminar embryonic disc into trilaminar embryonic disc (gastrula consists of three germ layers, endoderm, mesoderm and ectoderm).

i. The primitive streak (the primary organizer) is formed in the midline at the caudal end of the disc by proliferation of the ectodermal cells. It elongates on cranial direction and ends in a rounded area called primitive node or primitive knot or Hensen’s node. The ectodermal cells begin to proliferate and migrate towards the groove in the primitive streak to invaginate between the ectoderm and endoderm. These invaginated cells form the intraembryonic mesoderm (secondary mesoderm). After this, the embryo appears as the pear-shaped trilaminar disc.

ii. The mesoderm fails to invaginate into the prochordal plate at the cranial end and the cloacal membrane the at caudal end. These two bigeminal sites are destined to break down in due course of development.

**Fate of Primitive Streak**

Normally by fourth week of embryonic life the primitive streak regresses and disappears.
formation of notochord. The cells of primitive node di-
vide and invaginate the primitive pit (also called blast-
topore) to move in cranial direction in the midline un-
til they reach the prochordal plate. This cellular plate 
extending from primitive node to prochordal plate is 
called the notochordal process.

ii. The notochordal process elongates in caudal direction 
as a result of gradual regression of primitive streak and 
primitive node.

iii. The canalization of notochordal process results in for 
mation of notochordal canal, which opens into amni-
otic cavity by blastopore.

iv. The cells in the floor of the notochordal canal are in 
tercalated (merged) with underlying endodermal 
cells. Soon after this, the process of breaking down of 
notochordal and endodermal cells of the floor begins 
at the caudal end. This creates a temporary curved 
passage called neurenteric canal, which communi-
cates the yolk sac cavity with the amniotic cavity via 
blastopore.

v. As the process of break down of the floor is complet-
ed, the notochordal canal is converted into the no-
tochordal plate, which lies between endoderm and ectoderm.

vi. The notochordal plate changes into definitive noto-
chord (which is like a solid cellular rod) by a process 
of fusion of its margins.

Clinical insight ...

Teratogenic Effects on Primitive Streak
1. The primitive streak is highly sensitive to teratogens during 
third week.
   i. A congenital malformation called caudal dysgenesis 
or serinomelia (Fig. 7.11) occurs due to deficient 
development of caudal intraembryonic mesoderm. 
The lower limbs are fused giving the fetus a mermaid 
appearance.
   ii. High doses of alcohol intake by mother during 
gastrulation may lead to destruction of all midline 
cells in cranial region producing craniofacial 
defects like holoprosencephaly (fusion of lateral 
ventricles of brain, small cerebral hemispheres and 
hypotelorism (the eyes coming towards midline).

2. Occasionally remnants of primitive streak persist 
in sacrococcygeal region as a mass of pluripotent 
cells (stem cells). These cells proliferate and turn into 
sacroccocygeal teratomas (Fig. 54.4) in newborn. The 
teratomas are unique in that they contain undifferentiated 
tissues derived from all the three germ layers.

Formation of Notochord
i. The primitive node and primitive pit (a depression 
in the center of primitive node) play a key role in the 

Fig. 7.10A and B: Primitive streak and primitive node showing 
the process of gastrulation

Fig. 7.11: A new born showing anomaly of sirenomelia in which 
lower limbs are fused giving the appearance of mermaid
vii. The notochord provides the central axis to the embryonic disc. Its most important functional role is in inducing the overlying ectodermal cells to become neuroectodermal cells and form the neural tube (the forerunner of brain and spinal cord).

**Remnants of Notochord**

i. Nucleus pulposus of intervertebral discs
ii. Apical ligament of atlas vertebra.

**Formation of Neural Tube (Neurulation)**

i. The neuroectodermal cells of the neural tube are differentiated from the ectoderm overlying the notochord under the inductive influence of the notochord.

ii. The neuroectodermal cells gather to form a neural plate in the midline dorsally. The neural plate has broad cranial end and narrow caudal end.

iii. The neural tube develops a neural groove centrally and raised edges (neural folds) on either side.

iv. The neural tube is formed with the fusion of neural folds.

v. The fusion of neural folds begins in the cervical region and extends in cranial and caudal directions.

vi. Thus, the neural tube remains open cranially by anterior neuropore and caudally by posterior neuropore (Fig. 7.12).

vii. The time of closure of anterior neuropore is around day 25 and that of posterior neuropore is around day 27.

**Clinical insight ...**

**Neural Tube Defects (NTD)**

The failure of closure of neuropores results in Neural tube Defects (NTD).

i. Anencephaly (Fig. 7.13) results due to failure of closure of anterior neuropore.

ii. Spina bifida with exposure of neural tube results due to failure of closure of posterior neuropore. These defects can be prevented by peri-conceptional intake of folic acid by the prospective mothers.

**Neural Crest**

During the process of fusion of neural folds, a few junctional cells at the crest or summit of the neural folds separate and give rise to a cluster of cells called neural crest on either side.

**Derivatives of Neural Crest**

i. Autonomic ganglia (sympathetic and parasympathetic)

ii. Sensory or dorsal root ganglia (of spinal and cranial nerves)

iii. Medulla of adrenal gland

iv. Schwann cells

v. Melanocytes

vi. Pia-arachnoid

**Subdivisions of Intraembryonic Mesoderm (Fig. 7.14)**

From medial to lateral side the intraembryonic mesoderm is subdivided into:
Introduction

Section i. Paraxial mesoderm

ii. Intermediate mesoderm

iii. Lateral plate mesoderm.

Paraxial Mesoderm

i. The paraxial mesoderm is located dorsally on either side of midline.

ii. It is a thickened column of mesoderm, which breaks up into segments called somites. The segmentation takes place in craniocaudal order.

iii. The number of pairs of somites is about 42 to 44 (4 occipital, 8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 8 to 10 coccygeal) Soon the first occipital and 5 to 7 coccygeal somites degenerate.

iv. The somite period of embryonic life extends from day 20 to day 35.

v. Each somite is further subdivided into three components. The laterally placed dermatome forms the dermis of skin. The centrally-placed myotome forms the skeletal muscles supplied by the segmental nerve. The medially placed sclerotome forms the vertebrae and annulus fibrosus of intervertebral discs.

Intermediate Mesoderm

The intermediate mesoderm is located between the paraxial mesoderm medially and lateral plate mesoderm laterally. It develops into organs of excretion (kidney, ureter, part of urinary bladder) and organs of reproduction (gonads, genital ducts, etc).

Lateral Plate Mesoderm

i. The lateral plate mesoderm is organized into the shape of inverted U. Its right and left halves of the mesoderm are continuous cranial to prochondral plate.

ii. It splits into two layers, somatopleuric intraembryonic mesoderm and splanchnopleuric intraembryonic mesoderm.

iii. These layers enclose a cavity called intraembryonic coelom, which forms the body cavities (pericardial cavity, pleural cavities and peritoneal cavity).

iv. A small part of lateral plate mesoderm cranial to pericardial coelom fails to split. This unsplit part is known as septum transversum, which is the most cranial landmark of the trilaminar germ disc.

Folding of Embryonic Disc

i. The pear-shaped two dimensional embryonic disc is converted into a three dimensional cylindrical human like form by a process of embryonic folding.

ii. The folding in the median plane produces ventrally-directed cranial fold and a caudal fold. Folding in transverse plane produces ventrally directed lateral folds. As a result of cranial folding, the septum transversum (the most cranial landmark of trilaminar disc) is shifted caudal to pericardium, which itself is brought ventral to the foregut.

iii. The ectodermal depression called stomodeum is located between the pericardial bulge and head bulge.

iv. The buccopharyngeal membrane (derived from prochondral plate) separates the foregut and stomodeum and caudal end of hindgut is closed by cloacal membrane. The buccopharyngeal membrane breaks down at end of fourth week.

v. The cloacal membrane breaks down at seventh week.

vi. The ectoderm lines the external surface of embryo and the amniotic cavity completely surrounds the embryo. The amnioectodermal junction is shifted around the umbilicus.

vii. The yolk sac is partly taken inside the embryo to form primitive gut (foregut, midgut and hindgut).

viii. The body stalk (umbilical cord) comes to get attached to the ventral surface carrying inside it the extraembryonic mesoderm, umbilical vessels, allantois and extraembryonic part of yolk sac.

Fetal Membranes (Fig.7.15)

The fetal membranes develop to protect and nourish the embryo and fetus during intrauterine life. After birth, they are discarded. The structures that are included under fetal membranes are:

i. Yolk sac

ii. Allantois

iii. Amnion

iv. Chorion

v. Umbilical cord
Yolk Sac

i. The primary yolk sac is the first to form from the cavity of blastocyst in the second week.

ii. It is converted into secondary yolk sac after the reduction in its size with formation of extraembryonic coelom.

iii. The main functions of the yolk sac during third week are angiogenesis and formation of primordial germ cells, which migrate to the developing gonads and give rise to oogonia or spermatogonia.

iv. After the folding of the embryo, the yolk sac is incorporated into the primitive gut. However, the midgut remains in communication with the definitive yolk sac by means of a narrow tube called vitello-intestinal duct.

v. The definitive yolk sac is taken inside the umbilical cord.

vi. The vitellointestinal duct atrophies. Occasionally, it may persist in its proximal part as Meckel’s diverticulum.

Allantois

i. It is a small diverticulum from the yolk sac into the connecting stalk of the trilaminar embryonic disc. It performs the function of hemopoiesis.

ii. After the embryonic folding, the allantois appears as a diverticulum from the hindgut (as the yolk sac in the tail fold becomes the hindgut).

iii. The allantois divides the hindgut into pre-allantoic part and post-allantoic part or endodermal cloaca, which is subdivided into anterior part called urogenital sinus and posterior part called rectum.

iv. The allantois is shifted to the urogenital part of cloaca.

v. Its intraembryonic part is called urachus, which extends from the urogenital sinus to the umbilical cord.

vi. After birth, the urachus changes into median umbilical ligament extending from apex of urinary bladder to the umbilicus. It raises a peritoneal fold called median umbilical fold.

vii. If the urachus remains patent at birth, the urine leaks out at umbilicus (weeping umbilicus as shown in Fig. 79.12).

Amnion

i. The amnion is a transparent membrane that bounds the amniotic sac, which contains the amniotic fluid.

ii. The amniogenic cells are formed in the roof of amniotic cavity by delamination from the adjacent trophoblast (in the second week). They produce amniotic fluid, which fills the amniotic cavity.

iii. The amnio-ectodermal junction is evident at each side of the cavity.

iv. After embryonic folding, the fluid filled amniotic cavity surrounds the embryo and later the fetus and the bilateral amnio-ectodermal junctions come closer and fuse surrounding the umbilical opening on the ventral body wall of the embryo.

v. As the amniotic cavity expands, the surrounding extraembryonic coelom disappears and amnion comes in contact with and fuses with the trophoblast to form chorioamniotic membrane. Further expansion of amniotic cavity takes place at the expense of uterine cavity, which is obliterated by fusion of chorio-amniotic membrane with decidua parietalis.
vi. The amniotic fluid is formed by various sources like, amniogenic cells, diffusion from maternal tissues across chorioamniotic membrane, diffusion from maternal blood in intervillous space and urine secreted by fetal kidneys.

vii. The amniotic fluid is drained by diffusion across chorioamniotic membrane. In addition to this, the fetus regularly swallows the amniotic fluid. The swallowed fluid is absorbed in fetal blood at respiratory tract and gastrointestinal tract. From the fetal blood, it is drained into placenta.

viii. The amount of amniotic fluid at term is around 700 ml to 1000 ml. The fluid-filled amniotic sac provides a ‘swimming pool’ for free movements of fetus. It acts as a shock absorber during external pressure or trauma to mother’s abdomen. It helps in regulation of temperature of the fetus.

ix. Excessive amniotic fluid is called polyhydramnios or hydramnios and scanty amniotic fluid is called oligohydramnios.

x. An investigative procedure called amniocentesis is performed to withdraw amniotic fluid to find out presence of genetic diseases (like Down syndrome, neural tube defects and inborn errors of metabolism) in fetus before birth.

**Chorion**

The chorion consists of trophoblast lined internally by extraembryonic mesoderm or primary mesoderm. The chorion develops during second week after the formation of extraembryonic coelom. It surrounds the germ disc uniformly.

**Formation of Chorionic Villi**

As the syncytiotrophoblast erodes the maternal decidua, innumerable small lacunar spaces appear inside it. Simultaneously, the syncytiotrophoblast erodes the uterine blood vessels. In this way, lacunar spaces are filled with maternal blood and utero-placental circulation is established. Soon the smaller lacunar spaces fuse to enlarge and appear to be separated from each other by columns of syncytiotrophoblast. The chorionic villi (finger like extensions from the chorion) develop all around. The chorionic villi in contact with decidua basalis grow vigorously like a bush, hence this chorion is called **chorion frondosum**. The chorionic villi in contact with decidua capsularis degenerate.

**Stages in Formation of Chorionic Villi**

There are three stages in the development of chorionic villi.

1. The **primary villi** are formed when columns of syncytiotrophoblast are invaded by cytotrophoblast.
2. The **secondary villi** are formed with the invasion of underlying extra-embryonic mesoderm (primary mesoderm) into the center of primary villi.
3. The **tertiary villi** are formed when fetal capillaries develop in the mesodermal core.

**Development of Cytotrophoblastic Shell**

As the chorionic villi grows, the cells of cytotrophoblast come out of the tip of syncytiotrophoblast and spread to form a layer that forms a barrier between the syncytiotrophoblast of the villi and the decidua. This barrier is called cytotrophoblastic shell.

**Types of Chorionic Villi**

i. The anchoring or stem villi are the villi that develop first. They are like a stems of trees. They arise from the fetal side of placenta and are fixed to the cytotrophoblastic shell on the maternal side.

ii. Free villi float into the maternal blood in the intervillous space. They are the branches of stem villi.

**Intervillous Space**

The interconnecting lacunar spaces together form intervillous space, which is filled with maternal blood. The circulation of maternal blood in intervillous space is carried out by spiral arteries (which pour oxygen rich and nutrition rich blood under high pressure) and spiral veins (which take away metabolic waste back into maternal circulation). The openings of these blood vessels in the cytotrophoblastic shell are visible. The stem villi give out free villi, which project into the intervillous space. These innumerable free villi, bathed in maternal blood are the functional units of the placenta. On microscopic examination, in a cross section the villi appear as irregular shaped units of variable sizes surrounded by outer syncytiotrophoblast and inner cytotrophoblast and containing a core of extraembryonic mesoderm holding fetal capillaries. The extraembryonic mesoderm shows characteristic Hofbauer cells.

**Developmental Sources of Placenta**

The placenta develops from two sources.

i. The fetal component of placenta develops from chorion frondosum.

ii. The maternal component develops from decidua basalis.

**Placental Barrier**

i. The mesodermal core of chorionic villi contains fetal capillaries containing fetal blood with nucleated
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erythrocytes. The intervillous space contains maternal blood with anucleated erythrocytes. The tissue barrier between fetal and maternal blood is called placental barrier.

ii. Starting from intervillous space, it consists of following layers, syncytiotrophoblast, cytotrophoblast, extraembryonic mesoderm and endothelium of fetal capillaries.

iii. Towards the end of pregnancy (towards term) the placental barrier thins out to such an extent that it consists of syncytiotrophoblast and endothelium of fetal capillaries.

The human placenta is described as hemochorial as the maternal blood comes in direct contact with fetal chorionic villi.

Functions of Placenta

i. Exchange of blood gases

ii. Passage of nutrients and antibodies of IgG category from maternal to fetal side

iii. Passage of waste products from fetal to maternal side.

iv. Production of hormones like human chorionic gonadotropin, human placental lactogen, estrogen, progesterone and relaxin

Gross Appearance of Placenta

On gross examination, a normal full-term placenta appears disc shaped. It weighs around 500 to 600 gm with a diameter of 15 to 20 cms. The placenta shows two surfaces, maternal and fetal.

Maternal Surface (Fig. 88.32)
The rough, cobblestone appearance of the maternal surface is due to presence of cotyledons (which are aggregations of chorionic villi) separated by grooves occupied by incomplete placental septa (which are the extensions of decidua basalis inside the intervillous space and hence do not come off with placenta). About 15 to 20 cotyledons are seen on the maternal surface. Each cotyledon is composed of about 3 to 4 bushy anchoring villi.

Fetal Surface (Fig. 88.32)
The fetal surface of placenta is smooth and transparent as it is covered with amnion. The umbilical cord is normally attached to the center of this surface. At the site of attachment the amnion covering the fetal surface is continuous with the amnion covering the umbilical cord. The ramifications of chorionic vessels (which are the branches of umbilical vessels after reaching the fetal surface) are distinctly visible through the amnion.

Clinical insight ...

Placental Pathology

i. The vesicular mole is the condition in which chorionic villi degenerate producing grape like cystic swellings.

ii. The gestational carcinoma or choriocarcinoma is a highly malignant condition of chorionic villi.

Umbilical Cord

i. The umbilical cord attaches the fetal surface of placenta to the umbilicus of the fetus. At full-term its average length is 50 to 55 cms. A very long umbilical cord tends to prolapse into vagina causing hindrance during childbirth. Occasionally, the cord encircles the neck of fetus in utero causing fetal distress.

ii. The umbilical cord is surrounded by amnion. It contains jelly like myxomatous connective tissue called Wharton’s jelly, which supports the umbilical blood vessels (two umbilical arteries and one umbilical vein). The umbilical vein carries oxygenated blood from the placenta to the fetus. The paired umbilical arteries bring deoxygenated blood from the fetus to the placenta for purification.

iii. The umbilical cord develops from the connecting stalk of the embryo. Its contents vary depending on the developmental stage of the embryo/fetus.

Clinical insight ...

Teratogenesis

The organogenetic period (4th to 8th weeks) is regarded as the critical period of human development as during this period there is optimal cell division and cell differentiation and hence highest susceptibility to teratogenic agents (viruses, drugs, chemicals, ionizing radiation, etc). Congenital anomalies (birth defects) in various organs are the feared complication, if pregnant mother is exposed to teratogens during organogenetic period, e.g. the developing limbs are most susceptible to tranquilizers like thalidomide during 24 to 36 days after fertilization (critical period of developing limbs). Such exposure leads to anomalies like amelia (absence of limbs) and phocomelia (absence of arm and forearm resulting in seal limbs (Fig 7.16). A pregnant mother suffering from German measles due to exposure to rubella virus during critical period of development of eyes, heart and ears (4 to 5 weeks after fertilization) is in danger of having a baby born with congenital cataract, cardiac defects and deafness (rubella syndrome).

GENETIC FACTORS AND CONGENITAL ANOMALIES

The magnitude of the problem of congenital anomalies due to genetic causes can be appreciated taking a look at
the prevalence of genetic diseases in the developing countries (1 out of 50 newborns with major congenital anomaly like anencephaly), 1 out of 100 newborns with monogenic disease (e.g. hemophilia) and 1 out of 200 newborns with major chromosomal anomaly (like Down syndrome). It is estimated that 50 percent of mental retardation is due to genetic causes of which 30 percent is due to Down syndrome.

Genetic Diseases due to Gene Mutation

Monogenic diseases occur due to mutation of DNA sequence of a single gene. The genes are the specific units of the chromosomal DNA. The normal function of the gene is to produce the proteins, which carry out most of life functions. When the gene is altered or mutated, its protein product can no longer carry out its normal functions and the consequence of this is a genetic disease.

Modes of Inheritance of Monogenic Diseases

i. **Autosomal dominant inheritance** is characterized by a dominant gene that expresses in a single dose (heterozygous state). The examples of the diseases transmitted by this mode are achondroplasia (circus dwarf), Huntington’s chorea, Marfan’s syndrome, osteogenesis imperfecta, neurofibromatosis and familial hypercholesterolemia. The dominant trait and the disease appear in every generation. If one parent is affected, half the children are affected. The normal children do not transmit the trait. If both parents are affected all children are affected.

ii. **Autosomal recessive inheritance** is characterized by a recessive gene that expresses as disease only in double dose (homozygous state). This means both the parents must carry this gene to pass on to the offspring to express as disease. Therefore, these diseases are more common in consanguineous marriages (cousin marriages or maternal uncle—niece marriages). The examples of the diseases transmitted by this mode are, albinism, cystic fibrosis, hemoglobinopathies, inborn errors of metabolism including phenyl ketonuria and homocystinuria. If both the parents carry the trait, there is chance of 25% children being affected. If one parent carries the trait there is probability of 50% children to be normal and 50% carrier (carrier means having the trait but phenotypically normal).

iii. **X-linked recessive inheritance** is characterized by presence of a mutant gene on X chromosome. Here a point to be emphasized is that male receives maternal X-chromosome which means whether the gene on it is recessive or dominant it will always be expressed. The examples of this mode of inheritance are red green color blindness, hemophilia or bleeder’s disease, glucose 6 Phosphatase Dehydrogenase Deficiency (G6PD deficiency) and Duchenne Muscular Dystrophy (DMD). There is no male-to-male transmission yet males are affected more. Affected father and carrier mother will produce 25% affected sons, 25% carrier daughters and 50% normal children. If both parents are affected all children will be affected. A marriage between affected man and normal woman will produce normal sons and carrier daughters. In such situations, parents request to know the sex of the unborn. If female (in order to prevent the propagation of the gene) there is provision to abort the embryo.

iv. **X-linked dominant inheritance** is rare. One example of this mode of inheritance is vitamin D resistant rickets. This trait manifests in heterozygous state. The genetic risk is as follows. If one parent is affected (heterozygous affected) and the other is unaffected 50% children will be normal and 50% will be affected.

v. **Holandric or Y-linked inheritance** is from father to son. There are very few genes on Y chromosome, hence, only one example of this inheritance is hairy pinna.

Polygenic Diseases

Polygenic or multifactorial diseases are caused by a combination of environmental factors and mutation of multiple
genes. The examples of multifactorial diseases are atherosclerosis, high blood pressure, Alzheimer’s disease, schizophrenia, epilepsy, diabetes, cancer and obesity.

**Mitochondrial Inheritance**

The nonchromosomal DNA is located in the mitochondria (mtDNA). The mitochondria are inherited only from the mother (as the sperm does not contribute cell organelles to the zygote). Through mitochondrial inheritance, the mutated genes are transmitted by mother’s mitochondria to all her children (irrespective of sex). The affected sons do not transmit the mutant gene but affected daughters do. Leber’s Hereditary Optic Neuropathy (LHON), Leigh’s syndrome and Kearns Sayre syndrome are the examples of this inheritance.

### Chromosomes

The chromosomes are located inside the nucleus. They are the vehicles of genes (which contain DNA-protein packages on specific positions called gene loci) from one generation to the next. The DNA is the blueprint of the individuality of the individual. The number of chromosomes is species specific (in human it is 46 in somatic cells). In somatic cells, 46 chromosomes are arranged in 23 pairs of homologous chromosomes (one member of the pair derived from father and another from mother). The somatic cells are known as diploid (2n) cells and gametes containing 23 chromosomes are known haploid (n) cells. There are 44 autosomes and 2 sex chromosomes (XY in normal male and XX in normal female). The chromosomes are best seen during cell division (mitosis and meiosis) under a microscope.

#### Parts of a Chromosome (Fig. 7.17)

Each chromosome presents two chromatids held together by a primary constriction called centromere. On one side of the centromere is situated the long arm (q) and on the other side is the short arm (p). The free ends of chromatids are called telomeres.

#### Morphological Types of Chromosomes

Depending upon the placement of centromere, the chromosomes are classified into 4 types.

i. **Metacentric chromosome** presents the centromere near its central point so that p arm equals to q arm.

ii. **Sub metacentric chromosome** presents the centromere near the central point so that q arm is longer than p arm.

iii. **Acrocentric chromosome** presents the centromere near the end of the chromatid so that chromatids have long arms only. They present secondary constriction on short arm. The part distal to the secondary constriction is called satellite (which contains small chromatin masses). Such chromosomes are known as SAT-chromosomes.

iv. **Telocentric chromosomes** present centromere at one end of chromosome.

#### Karyotyping

The karyotyping is a method of chromosome preparation and staining used for cytogenetic mapping and identification of individual chromosome under the microscope in the metaphase of cell division. The enlarged photomicrograph of the stained metaphase spread is taken. Then individual chromosomes are cut out and arranged in homologous pairs in descending order of height. This photographic representation of the entire chromosome complement is called karyotype. The karyotyping is indicated to detect chromosomal anomalies (both structural and numerical).
Common Techniques for Studying Chromosomes

i. Karyotyping using Giemsa banding.
ii. FISH (Fluroscent in situ Hybridization) is a rapid method as no culture is necessary.

Karyotyping using Giemsa Banding

i. Five milliliter venous blood is collected in heparinized syringe and red cells are separated off by centrifugation.
ii. The white cell suspension is transferred to culture vials containing culture medium, fetal calf serum, phytohemagglutinin (mitogenic agent extracted from French beans) and antibiotics.
iii. Culture vials are kept in incubator at 37° centigrade (body temperature) for 3 days.
iv. Around 70 hrs, colchicine is added to the culture to arrest the mitoses at metaphase by preventing spindle formation.
v. After centrifugation for 5 minutes, supernatant is discarded and cell pellet at the bottom of the test tube is treated with hypotonic solution.
vi. The cells swell on treatment with hypotonic solution thereby separating the chromosomes from each other.
vii. The cells are fixed in a solution of acetic acid and methanol in the ratio of 1:3.
viii. The cells are dropped on a chilled slide from a height to release the chromosomes out of the cells. The chromosomes are stained with Giemsa.
ix. The photographic representation of stained chromosomes in descending order of height is called karyotype (Fig. 7.18)

Denver Classification of Chromosomes

After identifying the chromosomes from their banding patterns, it is possible to arrange them in seven groups according to their morphological features.

i. Group A consists of pairs of following chromosome numbers 1, 2 and 3 (total chromosome number being 6). They are the longest and metacentric.
ii. Group B consists of pairs of chromosome numbers 5 and 6 (total chromosome number being 4). They are long and submetacentric.
iii. Group C consists of pairs of chromosome numbers from 6 to 12 and X. They are of medium size and submetacentric. The total number in this group varies with sex. In female, the total number of chromosomes in C-group is 16 while in male it is 15.
iv. Group D consists of pairs of chromosome number 13, 14 and 15. They are medium-sized acrocentric chromosomes. They are SAT- chromosomes. Their total number is 6.
v. Group E consists of pairs of chromosome number 16, 17 and 18. They are shorter than the previous group and submetacentric.
vi. Group F consists of pairs of chromosome number 19 and 20. They are short metacentric.
vii. Group G consists of pairs of chromosomes 21 and 22 in addition to Y chromosome (total number being 5). They are shortest and acrocentric SAT- chromosomes.

(Note: A short-cut method to identify sex from a metaphase spread is to count shortest acrocentric chromosomes. If the total count is 5, it is the spread of male and if the count is 4, it indicates female)

Sex Chromosomes (Fig. 7.19)

X and Y chromosomes are called sex chromosomes because they play crucial role in determination of sex of zygote at the time of fertilization and sexual differentiation in indifferent genital organs (Table 7.1). If a Y-bearing sperm fertilizes the secondary oocyte, the resultant zygote develops into male. If the X-bearing sperm fertilizes the secondary oocyte the resultant zygote develops into female.

Role of Y chromosome in Sex Differentiation

i. Until six weeks of development, the genital organs are undifferentiated. Hence, it is known as indifferent stage (neither male nor female). The reproductive organs consist of gonads and genital ducts (both Wolffian and Müllerian).
ii. In the presence of SRY (Sex Determining Region on Y) gene (that produces testis determining factor) the indifferent gonad develops into testis.
iii. The Sertoli cells in fetal testis secrete Müllerian inhibiting Factor (MIF), which suppresses the Müllerian ducts and stimulates the growth of Wolffian ducts (epididymis, vas deferens, seminal vesicles and ejaculatory ducts).

iv. The Leydig cells of fetal testis secrete testosterone to stimulate the development of indifferent external genitalia on male line.

v. In the female, due to absence of SRY gene, the indifferent gonad becomes ovary. In the absence of MIF, the Müllerian ducts differentiate into female genital ducts (fallopian tubes, uterus and vagina) and the indifferent external genitalia develop on female line. The Wolffian ducts regress.

**Sex Chromatin or Barr Body (Fig. 7.20)**

It is the heterochromatic and inactive X chromosome found inside the nuclei of somatic cells of female in the interphase of cell cycle. It is usually found in cells of buccal mucosa (adjacent to nuclear membrane), neurons (attached to nucleolus) and neutrophils (drum-stick from nucleus). This condensed clump of chromatin is intensely basophilic. It is named Barr body after its discoverer Murray L Barr who along with Bertram discovered it in neurons of female cats in the year 1949. It is in the year 1962 that Mary Lyon explained the reason and time of X-inactivation. According to Lyon hypothesis, the inactivation of one sex chromosome (either Xm or Xp) takes place from around 16th week of embryonic life. The condensed X chromosome lags in replication of DNA (it is out of sync with the rest of chromosomes). There is X inactivation gene on the long arm of X chromosome.

**Significance of Barr Bodies**

The number of Barr bodies is one less than the number of X chromosomes. Therefore, by counting the number of Barr bodies or body (by simple test of buccal smear) one can understand the numerical anomalies of sex chromosomes (Table 7.2).

**Structural Anomalies of Chromosomes**

These include change in the structure of chromosome by breakage of chromosome and subsequent reunion of broken piece. This may result in abnormal genotype and

### Table 7.1: Comparative features of X and Y chromosomes

<table>
<thead>
<tr>
<th>Feature</th>
<th>X Chromosome</th>
<th>Y Chromosome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Long</td>
<td>Very short</td>
</tr>
<tr>
<td>Group</td>
<td>C- medium-sized, medium</td>
<td>G- short acrocentric</td>
</tr>
<tr>
<td></td>
<td>submetacentric</td>
<td>with satellite</td>
</tr>
<tr>
<td>Staining with quinacrine dye</td>
<td>---------------------------</td>
<td>Vivid fluorescence in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>interphase and metaphase</td>
</tr>
<tr>
<td>Pseudoautosomal region</td>
<td>Xpter (at terminal part of p arm)</td>
<td>Ypter (at terminal part of p arm)</td>
</tr>
<tr>
<td>Number of genes</td>
<td>Several X-linked genes on both arms (around 400)</td>
<td>SRY (sex determining region on Y) gene on p-arm</td>
</tr>
<tr>
<td>X-inactivation for maintaining gene balance in two sexes</td>
<td>Inactivation center on band Xg13 on either paternal or maternal X chromosome</td>
<td>No X inactivation</td>
</tr>
</tbody>
</table>

### Table 7.2: Number of Barr bodies in normal and abnormal individuals

<table>
<thead>
<tr>
<th>Normal/Female</th>
<th>XX</th>
<th>1 Barr Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal male</td>
<td>XY</td>
<td>Very short</td>
</tr>
<tr>
<td>Turner syndrome- female</td>
<td>45X</td>
<td>0 Barr body</td>
</tr>
<tr>
<td>Isochromosome- X in Turner syndrome- female</td>
<td>46X i(Xq)</td>
<td>1 Barr body</td>
</tr>
<tr>
<td>Klinefelter syndrome- male</td>
<td>47 XXX</td>
<td>1 Barr body</td>
</tr>
<tr>
<td>Superfemale</td>
<td>47XXX</td>
<td>2 Barr bodies</td>
</tr>
<tr>
<td>Down syndrome-female</td>
<td>47XX +21</td>
<td>1 Barr body</td>
</tr>
<tr>
<td>Down syndrome-male</td>
<td>47XY +21</td>
<td>0 Barr body</td>
</tr>
</tbody>
</table>
consequently the altered phenotype (genetic disease). There are different types of structural anomalies.

**Deletion**

In deletion, there is loss of a piece of one arm or both arms of a chromosome.

i. Cri du chat (or cat’s cry) syndrome is due to deletion of short arm of chromosome 5 (designated by the symbol 5p-).

ii. A ring chromosome is formed if there is deletion at both ends and the broken arms reunite to form a ring.

**Translocation**

In this structural defect, there is break in two different chromosomes and later exchange of broken parts. So the genetic material is transferred from one chromosome to another.

**Reciprocal Translocation (Fig. 7.21)**

This involves breakage of two nonhomologous chromosomes with exchange of fragments. There is no loss of genetic material and no change in chromosome number. Yet it may be problematic during segregation in meiosis and may lead to early abortion.

**Robertsonian Translocation (Fig. 7.22)**

This translocation (e.g. D/G translocation) results when two acrocentric chromosomes (belonging to groups D and G) break at their centromeres and there is subsequent fusion of their long arms (short arms of the chromosomes are lost). Thus, the total chromosomal number is reduced by one (45 chromosomes).

The chromosome formula of a male with Robertsonian translocation is 45, XY, t (14q, 21q). This individual is carrier of translocation. The carrier is a normal person. However, at the time of meiotic segregation a few gametes with translocated chromosome (14/21) and normal chromosome number 21 may be formed. Union of such a sperm and a normal ovum results in translocation Down syndrome and its chromosome formula will be 46 XX or XY, t (14q, 21q).
Isochromosome

The isochromosome is produced due to transverse division at the centromere. There is separation of short and long arms. Thus, the isochromosome is composed of two long arms only. This anomaly is common in X chromosome and is the cause of Turner’s syndrome in some patients. The isochromosome is as good as nonfunctional. Hence, this type of Turner syndrome patient has 46 chromosomes and is Barr body positive.

Philadelphia Chromosome (Ph\(^1\) chromosome)

This is an acquired abnormality of chromosomes in white blood cells in peripheral blood and bone marrow of patients with Chronic Myeloid Leukemia (CML). Philadelphia chromosome is a shortened chromosome 22 due to replacement of a segment of its long arm by a fragment of long arm of chromosome 9. This anomaly is designated symbolically as t (22q, 9q).

Numerical Anomalies of Chromosomes

i. The basic cause of numerical anomalies of chromosomes (autosomal and sex chromosomal) is the nonjunction of chromosome pairs during the reductive division of gametogenesis. The gametes formed in this way are numerically abnormal. Therefore, if a gamete with abnormal number of chromosomes unites with normal gamete at fertilization, the zygote has either more chromosomes than the normal number or lesser chromosomes than the normal number. 

ii. In some cases, after union of both normal gametes and formation of normal zygote, there is nondisjunction in one cell line during rapid mitotic divisions (cleavage) in inner cell mass of embryo. This is the basis of mosaicism (having two cell lines in body tissues with differing numbers of chromosomes). Therefore, it is essential at this stage to revise the steps in cell cycle, mitosis and meiosis.

Cell Cycle in Somatic Cells (Fig.7.23)

The interphase of cell cycle is between two mitotic divisions. It is divisible into G\(_1\) (gap 1), S (synthesis) and G\(_2\) (gap 2) phases. A cell that does not divide exits the cell cycle to go into G\(_0\) phase.

During G\(_1\) phase there is duplication of cell organelles. During S phase, there is replication of DNA. During G\(_2\) phase, the enzymes and other proteins are formed.

The stages in mitosis are depicted in figure 7.24 and stages in meiosis are depicted in figure 7.25.

Nondisjunction during Gametogenesis (Fig. 7.26)

Nondisjunction means failure of separation of one member of the homologous chromosome pair during anaphase of oogenesis or spermatogenesis. The non-disjunction occurs more commonly during reduction division during oogenesis because the primary oocyte remains arrested in metaphase for protracted period (from before birth until the time of ovulation). The homologous chromosomes fail to separate and both copies of the same chromosome move into one cell and while the other cell receives no copy. This explains why there is increase in the incidence of numerical chromosomal anomalies (like Down syndrome) with advanced maternal age.

Types of Numerical Anomalies

There are two broad categories as follows:

i. Aneuploidy

ii. Polyploidy.

Aneuploidy

This is a numerical anomaly in which the chromosome number is not an exact multiple of haploid number (23 = n). The gamete may show one chromosome less (22 = n-1) or one chromosome more (24 = n+1). After fertilization with normal gamete, the zygote will have monosomy (22+23 = 45 chromosomes i.e. 2n-1) or trisomy (24 + 23 = 47 chromosomes, i.e. 2n+1).

i. **Monosomy** is characterized by a single copy of a chromosome. Monosomy of X chromosome (45X) is compatible with life but monosomy of autosomes is not
compatible with life. Such embryos are aborted very early.

ii. *Trisomy* is characterized by three copies of a chromosome. Trisomy of chromosome 21 resulting in Down syndrome is very common.

**Polyploidy**

This is a numerical anomaly in which the chromosome number is an exact multiple of haploid number but more than diploid (69, 92, etc).

i. In triploidy, the chromosome number is 69. This occurs during second meiotic division when chromosome number is doubled but cell division fails to take place. In this way one gamete will have 46 chromosomes and if this gamete is fertilized by normal gamete the result will be (46+23 = 69 chromosomes) triploidy.

ii. In tetraploidy, there are 92 chromosomes. This anomaly is produced due to failure of separation of cells during first mitotic division of the zygote.

**Clinical insight ...**

**Down Syndrome (Trisomy 21)**

Down syndrome is an autosomal numerical anomaly in which there are three copies of chromosome 21 instead of normal two copies. It is the most important single cause of mental retardation in children. There is a strong association between advancing maternal age and Down syndrome.

**Cytogenetic types of Down Syndrome**

i. Free trisomy with three copies of chromosome 21 (47, XX or XY+21) is most common (95%). The cause of the free trisomy 21 is non disjunction during oogenesis.

ii. Translocation Down syndrome is seen in 4%. Its cytogenetic formula is 46, XX or XY, t(14q, 21q). One of the parents presents a D/G translocation which is transmitted during gametogenesis to the offspring.

iii. Mosaic Down syndrome is seen in 1%. It is due to nondis junction during cleavage (rapid mitotic divisions of zygote) in one cell line in the embryo. This results in some cells with 46 chromosomes and some cells with
47 chromosomes. The cytogenetic formula of a boy with mosaic Down syndrome is 46, XY/47, XY+21.

**Clinical Features (Fig. 7.27)**
Phenotype of Down syndrome is typical. The short-statured patient has Mongoloid facies, low bridge of nose, upward and laterally slanting eyes, low set ears and protruding furrowed tongue. The palms show characteristic Simian crease (single palmar crease) and clinodactyly (incurving 5th digit). In the feet, there is wide gap between first and second digits.

For prenatal diagnosis of Down syndrome refer to page number 56.

**Klinefelter’s Syndrome**
This is the trisomy caused by nondisjunction of a pair of X chromosomes during oogenesis. When a gamete with two X chromosomes is fertilized by a Y-bearing sperm, the result is a zygote with three sex chromosomes. This results in Klinefelter’s syndrome with 47, XXY karyotype. This patient is phenotypically male but he is Barr body positive.

**Clinical Features (Fig. 7.28)**
The grown-up patients have thin and tall stature with poorly-developed male secondary sexual characters. There is hypogonadism, azoospermia (low sperm count) and gynecomastia.

**Turner’s Syndrome**
This is a monosomy of X chromosome (45,X). There are three ways by which Turner’s syndrome results.

i. As a result of nondisjunction of a pair of X chromosomes during oogenesis, if the gamete without X chromosome is fertilized by a normal X bearing sperm the result will be monosomy of X (45, X female who is Barr body negative).

ii. Presence of isochromosome X in one of the gametes produces isochromosome X Turner’s syndrome. The chromosome formula of this type of Turner’s syndrome is 46X, i(Xq). This is an example of Barr body positive Turner’s syndrome.

iii. The mosaic Turner syndrome (46, XX/45X) is produced if there is non-disjunction in X chromosome pair during mitosis in one cell line in the zygote.

Contd...
Nondisjunction during gametogenesis producing a gamete with 22 chromosomes or a gamete with 24 chromosomes (Note that nondisjunction during mitosis at cleavage stage can lead to mosaicism)

Clinical Features (Fig. 7.29)
The affected female has short stature, low hair line, webbed neck, decreased carrying angles and lymphedema over feet. They have poorly developed secondary sexual characters with streak gonads. Often patients come to doctors with the complaint of amenorrhea.

Prenatal Diagnosis of Genetic Disorders
Prenatal Diagnosis (PND) is an important part of clinical genetics. The primary purpose of PND is to detect all types of abnormalities of embryo or fetus like NTD, syndromes associated with chromosomal anomalies, cleft lip, cleft palate, cystic fibrosis, thalassemia, sickle cell anemia and
hemophilia, etc. before birth. This makes the parents aware about the impending traumatic event in their life and gives them a chance to be prepared psychologically, socially and financially to accept a disabled baby. It can also give parents time to think about another option called MTP (Medical Termination of Pregnancy) if a serious abnormality is detected very early in embryonic period. So, the foremost concern under the delicate situation is to advise the parents to seek genetic counseling from experts in the field.

Methods of Prenatal Diagnosis
The methods are described under two headings.

Noninvasive Methods

i. Fetal visualization by ultrasound scan to determine fetal age in cases where date of conception is not clear and to evaluate progress in fetal growth. It is used specifically for detecting thickness of nuchal translucency at 11 to 13 weeks in pregnancies at risk for Down syndrome.

ii. Screening test in mother for NTD in fetus is done to find out level of maternal serum alpha fetoprotein. The alpha fetoprotein is produced in embryo by yolk sac and later in fetus by liver. It enters the amniotic fluid and into the maternal blood. MS AFP level reflects the AFP level in fetus. Rise in MS AFP after 16 week indicates possibility of NTD such as spina bifida or anencephaly.

iii. Screening (triple test) for Down syndrome is done by measuring three parameters in maternal serum (beta HCG, uE3 or unconjugated estriol and MS AFP). Increase in hCG, decrease in alpha fetoprotein and decrease in estriol indicate probability of Down.

Contd...
If inhibin-A is measured along with above three parameters it is called quadruple test (quad test for Down screening).

**Invasive Methods**

i. Amniocentesis (Fig. 7.30) is done during 16 to 20 weeks of gestation. The amniotic fluid sample is drawn by passing a needle through mother’s abdomen into the amniotic cavity under the guidance of ultrasound. The amniotic fluid can be used for biochemical analysis and the fetal cells (amniocytes shed by fetal skin) can be cultured for chromosome analysis. Rise in alpha fetoproteins is indicative of neural tube defects.

ii. Chorionic villus sampling (Fig. 7.31) is done during 9 to 12 weeks of gestation. A catheter is passed either through vagina or through abdomen under ultrasound guidance to suction out a small amount of tissue from chorionic villi. The cells of chorion are dividing hence, the results of chromosome analysis are available much quicker than amniocentesis.

**Figs 7.30A and B:** Amniocentesis, biochemical examination of amniotic fluid and culture of fetal cells for karyotyping

**Fig. 7.31:** Chorionic Villus Sampling (CVS) for prenatal diagnosis of genetic diseases
CASE 1

A 25-year-old woman was rushed to the hospital in the midnight because she had intense lower abdominal pain. She gave history of two missed periods. Vaginal examination revealed early pregnancy and ultrasound of pelvic cavity showed empty uterus and fluid in pouch of Douglas. This is a case of ectopic pregnancy.

Questions and Solutions

1. Name the common site of ectopic pregnancy.
   Uterine tube

2. Which embryological event normally takes place at this site?
   Fertilization

3. Which embryological event takes place at this site to cause ectopic pregnancy?
   Implantation of blastocyst

4. What is the natural fate of pregnancy at this site?
   Rupture of the uterine tube with bleeding in peritoneal cavity with accumulation of blood in pouch of Douglas.

5. Describe the embryological stages in transformation of zygote into blastocyst.

   The zygote undergoes a series of rapid mitotic divisions called cleavage, as a result of which there is increase in the number of cells and gradual decrease in the size of cells (now called blastomeres). Around third day after fertilization, the 16 cell stage is reached. This stage of the embryo is called morula (mulberry like). The blastomeres of morula are held together tightly inside the zona pellucida. When the morula reaches the uterine cavity, it changes into blastocyst as follows. It begins to absorb fluid through zona pellucida. The fluid enters the intercellular spaces, which coalesce to form a cavity called blastocele. The blastomeres segregate to form embryoblast and trophoblast. The embryo-blast consists of clump of cells called inner cell mass at the embryonic pole. The trophoblast consists of flattened cells forming the outer limit of blastocele. The trophoblast divides into outer syncytiotrophoblast and inner cytotrophoblast. The syncytiotrophoblast secretes human chorionic gonadotrophic (hCG) hormone. When on day five the blastocyst loses zona pellucida, it is ready for implantation in the endometrium of uterus.

6. What is the normal site of implantation?
   The site of implantation is the body of uterus near fundus (usually on the posterior wall).

7. Which is the surgical contraceptive measure in women that prevents fertilization?
   Tubectomy

8. Describe the subdivisions of decidua.

   After implantation of blastocyst inside the endometrium, the endometrium is called decidua. The decidua is histologically recognized by decidual reaction, which shows characteristic changes in the stromal cells and the stroma of endometrium under the influence of hCG hormone. The stromal cells enlarge by accumulating glycogen and lipids. The stroma becomes edematous by accumulation of fluid. The decidua is divisible into three parts, decidua basalis, decidua capsularis and decidua parietalis. At the site of implantation, the decidua is divided into decidua basalis and decidua capsularis. The decidua basalis is the one that comes in contact with the embryonic pole of the blastocyst and the decidua capsularis covers the abembryonic pole. The decidua parietalis is the most extensive, as it lines the rest of the uterine cavity.
CASE 2
A congenitally malformed baby shows fusion of lower limbs, vertebral anomalies, imperforate anus, renal agenesis and genital anomalies. This is known as caudal dysgenesis or sirenomelia. This anomaly results from teratogenic effects during third week of embryogenesis.

Questions and Solutions
1. Describe the major event during third week of prenatal development.
   Gastrulation is the process that establishes all three germ layers (ectoderm, mesoderm and endoderm) and changes the bilaminar embryonic disc into trilaminar embryonic disc during third week by formation of intraembryonic mesoderm.
   The primitive streak (which develops as midline linear thickening of ectoderm) is essential for the process of gastrulation. It is made up of pluripotent cells. Its cranial end is called primitive node. The cells originating from the node insinuate cranially in the midline and form notochord. From the rest of the primitive streak there is continuous migration of cells in all directions between the ectoderm and endoderm giving rise to intraembryonic mesoderm. During 4th week, the primitive streak rapidly shrinks in size and disappears.

2. What is the unique feature of primary organizer?
   The primitive streak is the primary organizer. It is composed of pluripotent cells and hence highly susceptible to teratogenic effects.

3. Give the subdivisions of intraembryonic mesoderm.
   The subdivisions of the intraembryonic mesoderm on each side from medial to lateral are paraxial mesoderm, intermediate mesoderm and lateral plate mesoderm. The paraxial mesoderm undergoes segmentation into somites (about 42 to 44 pairs). Each somite divides into sclerotome, myotome and dermatome. The intermediate mesoderm develops into urinary and genital organs. The lateral plate mesoderm splits into somatopleuric and splanchnopleuric layers enclosing a cavity called intraembryonic coelom (forerunner of body cavities or serous cavities, which are pleural, pericardial and peritoneal).

4. What is the basic defect in caudal dysgenesis or sirenomelia?
   There is insufficient formation of intraembryonic mesoderm in caudal region of embryo. This is responsible for fusion of lower limbs and genitourinary and vertebral anomalies.

CASE 3
A 44-year-old woman consults her obstetrician when she misses two periods. The obstetrician confirms the pregnancy and advises her to undergo triple test.

Questions and Solutions
1. Considering the age of the mother, which chromosomal anomaly (in the unborn) is suspected by the obstetrician?
   Down syndrome or trisomy 21 is the most common chromosomal anomaly found in elderly (above 35 years) mothers.

2. Describe the clinical features of this condition.
   Down syndrome babies present typical phenotype. The short-statured children have Mongoloid facies, low bridge of nose, upward and laterally slanting palpebral fissures (Mongoloid eyes), low set ears and protruding furrowed tongue. The palms show characteristic Simian crease (single palmar crease) and clinodactyly (incurving 5th digit). In the feet, there is wide gap between first and second digits. Down syndrome babies are born with mental retardation (this is the most agonizing aspect to the parents).

3. What is triple test?
   It is a noninvasive screening test for prenatal diagnosis of Down syndrome in which three biochemical parameters are tested in maternal serum- hCG, AFP and unconjugated estriol (uE3). There is increase in hCG and decrease in level of other two parameters in this syndrome.

4. How is amniocentesis performed?
   Amniocentesis is an invasive procedure by which a sample of amniotic fluid is withdrawn from the amniotic cavity surrounding the fetus at the age of 16 weeks. This procedure is done under ultrasound guidance so that location of placenta is avoided while inserting a needle in the amniotic cavity. The amniotic fluid contains fetal cells that are shed from the skin. These cells are cultured to obtain a karyotype of fetus to confirm prenatal diagnosis of trisomy 21.

5. What is chorionic villus sampling?
   Chorionic villus sampling is done during 9 to 12 weeks of gestation. A catheter is passed either through vagina
or through abdomen under ultrasound guidance to suction out a small amount of tissue from the chorionic villi (chorionic villi belong to fetal component of placenta). At this stage the cells of cytotrophoblast are mitotically active, hence the cell culture is not needed and results of chromosome analysis are available much quicker as compared to amniocentesis.

6. **Give reason for high risk above mentioned chromosomal anomaly in babies born to mothers over 40 years.**

There is extra copy of chromosome 21 in free trisomy 21 (47, XY or XX, +21). This is a numerical chromosome anomaly. Therefore, the basic cause is nondisjunction of chromosome pair 21 during gametogenesis. Nondisjunction means failure of separation of one member of the homologous chromosome pair during anaphase of meiosis. The non-disjunction occurs more commonly during oogenesis because the primary oocyte remains arrested in metaphase for protracted period (from before birth until the time of ovulation). This implies that with increase in the maternal age there is proportionate increase in the duration of arrested metaphase of primary oocyte. This may be in one of the factors responsible for the failure of homologous chromosomes 21 to separate with the result that two copies of chromosome 21 move into secondary oocyte while the first polar body receives no copy. If the secondary oocyte bearing 2 copies of chromosome 21 is fertilized by normal sperm bearing one copy of chromosome 21 the net result is a zygote with 3 copies of chromosome 21 (trisomy 21).

7. **What is D/G translocation? Explain its significance.**

The translocation is the structural anomaly of chromosomes in which there is break in two different chromosomes and later fusion of the broken segments. So, the genetic material is transferred from one chromosome to another. The Robertsonian translocation (D/G translocation) results when two acrocentric chromosomes (belonging to groups D and G) break at their centromeres and subsequently there is fusion of their long arms (the short arms of the chromosomes are lost). Thus, the total chromosomal number is reduced by one.

The chromosome formula of a male with Robertsonian translocation is 45, XY, t (14q, 21q) and of female is 45,XX, t (14q,21q). An individual with D/G translocation is called carrier. The carrier is a normal person. However, at the time of meiotic segregation (gametogenesis) a few gametes may receive a combination of translocated chromosome (14/21) and a normal 21 chromosome. At the time of fertilization, when there is union of a gamete carrying two copies of 21 (one free copy and another as part of translocated chromosome) with a normal gamete, the result is translocation Down syndrome (chromosome formula is 46, XX or XY, t (14q, 21q)).

### CASE 4

A six feet tall 14-year-old high school student (an aspirant for school basketball team) undergoes physical fitness examination. It is noted that the student has very long limbs, the tips of his fingers reach just below his knees, sternum is incurving (pes cavus) and his joints are very loose and flexible. It was decided to send him for cardiac and ophthalmic check up, since the findings of physical examination were suggestive of Marfan’s syndrome.

### Questions and Solutions

1. **Enumerate the four basic tissues of the body.**

Epithelium, connective tissue, muscular tissue and neural tissue.

2. **Which basic tissue is affected in Marfan’s syndrome?**

Connective tissue.

3. **Name the three histological components of the affected basic tissue.**

Connective tissue cells, connective tissue fibers and matrix (ground substance).

4. **Enumerate the cells of the affected tissue.**

A variety of cells performing different functions are present in the connective tissue. The resident cells in the connective tissue are fibroblasts, adipocytes, macrophages, mast cells and plasma cells. The non-resident or wandering cells (which enter the connective tissue for specific functions from other sites) are lymphocytes and leukocytes.

5. **Name the three types of fibers in this basic tissue.**

Collagen, reticular and elastic.

6. **Synthesis of which fibers is affected in Marfan’s syndrome?**

The synthesis of elastic fibers is affected in Marfan’s syndrome.
7. Describe the physical and chemical properties of the above fibers and enumerate their locations in the body.

The elastic fibers impart elasticity to the tissues. They are composed of a protein called elastin. They run singly and individual fibers branch and anastomose. They are highly refractile. They stain poorly with ordinary hematoxylin and eosin stains. Special stains like orcein, resorcin-fuchsin and Verhoeff’s are used to visualize them. The elastic fibers are produced by fibroblasts and smooth muscle cells.

They are widely distributed in the body. They occur in loose areolar tissue, ligaments of joints, dermis of skin, lung, large arteries (tunica media of aorta is mainly composed of elastic fibers), ligamentum nuchae, ligamentum flava (connecting the laminae of adjacent vertebrae), suspensory ligament of lens, elastic cartilage, etc.

8. Why is the student referred to cardiologist and ophthalmologist?

The cardiac check up in a suspected case of Marfan’s syndrome is necessary to find out the presence of aneurysm of thoracic aorta (dilatation of aortic wall due to defective elastic fibers in its wall). The ophthalmic check-up is to rule out visual problems due to dislocation of lens (lens is held in position by suspensory ligament, which is composed of elastic fibers).
1. The luminal cells belonging to the following type of epithelium are provided with extra reserve of plasma membrane in the form of membrane bound vesicles in apical cytoplasm.
   a. Stratified squamous
   b. Transitional
   c. Stratified cuboidal
   d. Stratified columnar

2. The secondary center of ossification appears in following part of the bone
   a. Diaphysis
   b. Metaphysis
   c. Epiphysial plate
   d. Epiphysis

3. Which of the following connective tissue cells is active in tissue healing?
   a. Plasma cell
   b. Myofibroblast
   c. Mast cell
   d. Leukocyte

4. The prickles that characterize the keratinocytes in stratum spinosum represent
   a. Ribosomes
   b. Tight junctions
   c. Desmosomes
   d. Hemidesmosomes

5. A cell that migrates into epidermis during embryonic life and may turn into skin cancer is
   a. Keratinocyte
   b. Langerhan’s
   c. Fibroblast
   d. Melanocyte

6. The reticular layer of dermis consists of following type of connective tissue
   a. Loose areolar
   b. Dense irregular
   c. Dense regular
   d. Adipose tissue

7. Which of the following are pressure receptors in skin?
   a. Merkel’s discs
   b. Meissner’s corpuscles
   c. Pacinian corpuscles
   d. Ruffini’s endings

8. Which of the following is the frontal plane?
   a. Sagittal
   b. Midsagittal
   c. Coronal
   d. Horizontal

9. Which of the following is found inside Volkmann’s canal?
   a. Blood vessel
   b. Process of osteocytes
   c. Sharpey’s fiber
   d. Lymphatic vessel

10. The linear growth of a long bone is disrupted by a fracture passing through
    a. Diaphysis
    b. Epiphysis
    c. Epiphysial plate
    d. Metaphysis

11. Laminin is a structural protein mainly found in
    a. Plasma membrane
    b. Nuclear membrane
    c. Basal lamina of basement membrane
    d. Reticular lamina of basement membrane

12. What is the surface modification seen in epithelial cells of epididymis?
    a. Microvilli
    b. Ruffles
    c. Stereocilia
    d. Cilia

13. Which of the following is not a fibrous joint?
    a. Schindylesis
    b. Symphysis
    c. Gomphosis
    d. Syndesmosis

14. Which of the following is a pressure epiphysis?
    a. Os trigonum
    b. Radial tuberosity
    c. Head of radius
    d. Fabella
15. Which of the following cell is a histiocyte?
   a. Plasma cell
   b. Fibroblast
   c. Macrophage
   d. Monocyte

16. Metachromasia is characteristic of following cell
   a. Plasma cell
   b. Melanocyte
   c. Macrophage
   d. Mast cell

17. T tubule in a skeletal muscle is part of
   a. Smooth endoplasmic reticulum
   b. Rough endoplasmic reticulum
   c. Myofilaments
   d. Sarcolemma

18. Myelination of axons of optic nerve and of sciatic nerve is the function of which of the following pair (cells are arranged in the order of the nerves)
   a. Satellite cells and oligodendroglia
   b. Protoplasmic astrocytes & Schwann cells
   c. Fibrous astrocytes & ependymal cells
   d. Oligodendroglia & Schwann cells

19. In Guillain Barre syndrome following cells are affected
   a. Anterior horn cells
   b. Schwann cells
   c. Ependymal cells
   d. Dorsal root ganglion cells

20. Which of the following is a resistance vessel?
   a. Medium-sized artery
   b. Medium-sized vein
   c. Arteriole
   d. Venule

21. All the following regions drain into thoracic duct except
   a. Left lower limb
   b. Abdomen
   c. Right half of head and neck
   d. Right lower limb

22. The neurons of following site are example of upper motor neuron
   a. Motor cortex of cerebrum
   b. Cerebellar cortex
   c. Ventral horn of spinal cord
   d. Motor nuclei of cranial nerves

23. Structural component of bone responsible for tensile strength is
   a. Calcium
   b. Phosphorus
   c. Collagen
   d. Hydroxyapatite

24. Where does conversion of procollagen to tropocollagen occur?
   a. Rough endoplasmic reticulum
   b. Smooth endoplasmic reticulum
   c. Extracellular compartment
   d. Golgi complex

25. The osteoclast is formed by undergoing the following processes
   a. Apoptosis
   b. Cytokinesis and karyokinesis
   c. Cytokinesis but no karyokinesis
   d. Karyokinesis but no cytokinesis

26. What is the epithelium lining the mesothelium?
   a. Simple cuboidal
   b. Simple columnar
   c. Stratified columnar
   d. Simple squamous

27. Which of the following is the outer covering of the peripheral nerve?
   a. Perineurium
   b. Neurilemma
   c. Epineurium
   d. Endoneurium

28. Which of the following is the content of canaliculi in an osteon?
   a. Lymph
   b. Blood capillaries
   c. Processes of osteocytes
   d. Nerve fibers

29. What is not true about articular cartilage?
   a. Avascular
   b. No capacity of regeneration
   c. Rich nerve supply
   d. Devoid of perichondrium
30. Lipofuscin pigment in aging neurons is derived from which of the following?

a. Nissl granules
b. Neurofibrils
c. Golgi bodies
d. Lysosomes

Key to general anatomy MCQs

1-b, 2-d, 3-b, 4-c, 5-d, 6-b, 7-c, 8-c, 9-a, 10-c, 11-c, 12-c, 13-b, 14-c, 15-c, 16-d, 17-d, 18-d, 19-b, 20-c, 21-c, 22-a, 23-c, 24-c, 25-d, 26-d, 27-c, 28-c, 29-c, 30-d.
1. A couple with a history of first born with mental retardation came for genetic counseling. The karyotype of the couple revealed Robertsonian translocation in father. Which of the following configurations correctly indicates the above translocation?
   a. A/C
   b. D/G
   c. C/F
   d. A/E

2. Which of the following is the feature of Y chromosome?
   a. Telocentric
   b. Metacentric
   c. Acrocentric
   d. Submetacentric

3. Which is the critical period of organogenesis in an embryo?
   a. 1 to 3 weeks
   b. 2 to 3 months
   c. 4 to 8 weeks
   d. 12th week

4. Which of the following in an embryo represents oral cavity?
   a. Stomodeum
   b. Prochordal plate
   c. Primitive knot
   d. Primitive pit

5. A cell that does not divide is arrested in following phase
   a. Metaphase
   b. G₁
   c. G₂
   d. G₀

6. Which of the following is not X-linked recessive disorder?
   a. Color blindness
   b. Hemophilia
   c. DMD
   d. Marfan syndrome

7. All the following cells contain 23 chromosomes except
   a. First polar body
   b. Second polar body
   c. Primary oocyte
   d. Secondary oocyte

8. The failure of closure of anterior neuropore results in
   a. Holoprosencephaly
   b. Sacrococcygeal teratoma
   c. Anencephaly
   d. Serinomelia

9. Which of the following is the usual cause of aneuploidy?
   a. Disjunction at meiosis
   b. Mosaicism
   c. Nondisjunction during meiosis
   d. Translocation

10. Chorion consists of following layers
    a. Ectoderm and endoderm
    b. Amnion and extraembryonic mesoderm
    c. Syncytiotrophoblast and cytotrophoblast
    d. Trophoblast and extraembryonic mesoderm

11. Which of the following cells undergoes meiosis?
    a. Primordial germ cell
    b. Primary spermatocyte
    c. Secondary spermatocyte
    d. Spermatid

12. At which time in the life of a female, the germ cells are highest in the ovaries?
    a. Birth
    b. Menarche
    c. 5 months of intrauterine life
    d. 25 years

13. The time of completion of first division of meiosis by primary oocyte is
    a. After fertilization
    b. Just after ovulation
    c. Just before ovulation
    d. At ovulation

14. Müllerian inhibiting factor is produced by
    a. Cytotrophoblast
    b. Syncytiotrophoblast
    c. Leydig cells of fetal testis
    d. Sertoli cells of fetal testis
15. Sex determining region is located on the following chromosome
   a. Short arm of Y
   b. Short arm of X
   c. Long arm of Y
   d. Long arm of X

16. Which of the following possibilities is true if a woman carrying an autosomal recessive trait is married to a normal man?
   a. All children affected
   b. 25% children carrier
   c. All children carrier
   d. 50% normal and 50% carrier

17. On staining with quinacrine, the cells of buccal mucosa show two fluorescent spots. This is indicative of which of the following?
   a. 2 Y chromosomes
   b. 2 Barr bodies
   c. 2 nuclei
   d. 2 foreign bodies

18. A man affected with X-linked recessive disorder marries a normal woman. What is the probability of having normal sons?
   a. 25%
   b. 50%
   c. 0%
   d. 100%

19. The following trait expresses only in homozygous state
   a. Sex linked recessive
   b. Sex linked dominant
   c. Autosomal recessive
   d. Autosomal dominant

20. Which of the following is the final fate of prochordal plate?
   a. Nucleus pulposus
   b. Atlas
   c. Buccopharyngeal membrane
   d. Degeneration

21. Ideal time for performing chorionic villus sampling is
   a. 20 weeks
   b. 5-6 weeks
   c. 10-12 weeks
   d. 16 weeks

22. The dermis of the skin develops from following embryonic source
   a. Ectoderm
   b. Intermediate mesoderm
   c. Septum transversum
   d. Somites

23. The corona radiata is formed from following source
   a. Theca interna cells
   b. Cumulus oophorus
   c. Follicular cells
   d. Ovarian stroma

24. Amniotic cavity obliterates the uterine cavity by fusion of chorioamniotic membrane with
   a. Decidua basalis
   b. Decidua capsularis
   c. Decidua parietalis
   d. Chorion levae

25. What is not true about human placenta?
   a. Placental barrier is formed by endothelium of fetal and maternal capillaries
   b. Full-term normal placenta weighs around 500-600 gms
   c. Chorionic vessels are seen through amnion on fetal surface of placenta
   d. Maternal part develops from decidua basalis

26. The human placenta belongs to the following type
   a. Hemoendothelial
   b. Endotheliochorial
   c. Epitheliochorial
   d. Hemochorial

27. High level of alpha fetoprotein in maternal serum after 16 weeks is indicative of which of the following conditions in the fetus?
   a. Trisomy 21
   b. Marfan’s syndrome
   c. Anencephaly
   d. Monosomy X

28. The neural tube develops under the inductive effect of
   a. Primitive streak
   b. Primitive node
   c. Notochord
   d. Prochordal plate
29. Thalidomide baby is characterized by
   a. Agenesis of all limb
   b. Phocomelia
   c. Sirenomelia
   d. Syndactyly

30. The extraembryonic mesoderm develops from
   a. Amnion
   b. Trophoblast

**KEY TO EMBRYOLOGY AND GENETICS MCQs**
1-b, 2-c, 3-c, 4-a, 5-d, 6-d, 7-c, 8-c, 9-c, 10-d, 11-b, 12-c, 13-c, 14-d, 15-a, 16-d, 17-a, 18-d, 19-c, 20-c, 21-c, 22-d, 23-b, 24-c, 25-a, 26-d, 27-a, 28-c, 29-b, 30-b.
UPPER EXTREMITY
The clavicle or collar bone is the long bone that is placed horizontally at the junction of the pectoral region and posterior triangle of the neck. It is a subcutaneous bone, hence palpable in its entire extent.

**Parts**

The clavicle presents a shaft and two ends, sternal (or medial) and acromial (or lateral). The sternal end is larger in size.

**Shaft**

i. The lateral one-third is flat. It presents superior and inferior surfaces. Its inferior surface bears a conoid tubercle and a trapezoid line. It has concave anterior margin and convex posterior margin.

ii. The medial two-third is rounded. Its anterior surface is convex and posterior surface is concave. Its inferior surface bears a groove for the subclavius muscle. The nutrient foramen is present in this groove.

**Junctional Point of Shaft**

The junction of medial two-third and lateral one-third is the weakest point of clavicle since it is located at the differently shaped and differently curved parts of the bone. Therefore, this area is most vulnerable to fracture in all age groups.

**Articulations**

The sternal end articulates with the manubrium sterni at the sternoclavicular joint and the lateral end articulates with acromion of scapula at the acromioclavicular joint. (Note: These two joints are called girdle joints, where movements of scapula take place).

**Unique Features of Clavicle**

i. It is S-shaped long bone.

ii. It is the only subcutaneous long bone that is placed horizontally in the body

iii. It is the only long bone without medullary cavity.

iv. It is the first long bone to ossify.
v. There are two primary centers, which appear during fifth to sixth weeks of intrauterine life.
vi. It is the only long bone to ossify in membrane.
vii. The supraclavicular nerves (cutaneous branches of cervical plexus) cross in front of the clavicle. Sometimes they pierce the clavicle.

**Posterior Relations of Medial Two-third**

i. At the medial end, there are three veins (internal jugular vein, subclavian vein and the beginning of brachioccephalic vein by the union of previous two veins).
ii. The anterior and posterior divisions of the trunks of the brachial plexus and the subclavian vessels enter the cervicoaxillary canal (apex of axilla) just behind this part (Fig. 11.3).
iii. The cervical pleura extends posterior to the subclavian vessels.

**Ligaments Attached to Clavicle**

i. The coracoclavicular ligament is composed of conoid and trapezoid parts. It is located below the clavicle as it extends from the coracoid process to the conoid tubercle and trapezoid line. This ligament is important in weight transmission from upper limb to axial skeleton (sternum)
ii. The costoclavicular ligament is attached to the rough impression on inferior surface of sternal end of clavicle and to the first costal cartilage and adjacent first rib.
iii. The interclavicular ligament passes between the medial ends of right and left clavicles via suprasternal space.

**Growing End**
The sternal end is the growing end. An epiphysis appears in this end at the age of 18 to 20 years and unites with the shaft at 25 years. It is the last of all the epiphyses in the body to unite with the shaft.

**Blood Supply**
The nutrient artery of the clavicle arises from clavicular branch of acromiothoracic artery.

**Special Features**
The attachments of muscles and ligaments to the clavicle are shown in Figures 9.1 and 9.2.

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**Fracture of Clavicle**
The clavicle is the most commonly fractured bone (Fig. 9.3). When the clavicle fractures medial to the attachment of the coracoclavicular ligament, its two fragments are displaced in the directions, corresponding to the muscle pull (Fig. 9.4). The medial fragment is shifted upwards due to sternomastoid whereas the lateral fragment is drawn downwards by the weight of the upper limb. The contraction of pectoralis major pulls the lateral fragment medially (by adduction of the arm). This results in over-riding of the two fragments and shortening of the clavicle. The time honored method of treating the fracture of clavicle by figure of eight sling is still in practice (Fig. 9.5).

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**SCAPULA**
The scapula is a flat triangular bone. It is located on the posterior thoracic wall. It articulates with the humerus at the shoulder joint and with the clavicle at the acromioclavicular joint. The scapula is suspended from the cranium.
Bones of Upper Extremity

Chapter

General Features

i. The scapula presents three borders namely, superior, medial (vertebral) and lateral. The superior margin is characterized by suprascapular notch near the base of coracoid process. This notch is converted into foramen by transverse scapular ligament.

ii. The scapula presents three angles, lateral (glenoid), superior and inferior. The glenoid angle bears pear-shaped glenoid cavity for articulating with head of humerus at shoulder joint.

iii. The scapula presents three processes, coracoid, acromion and spinous.

iv. The coracoid process is shaped like a bent finger. It is an example of atavistic epiphysis.

v. The tip of the acromion is the lateral most palpable bony point of the shoulder. It projects from the lateral end of the spine. Its superior surface is subcutaneous and inferior surface is related to subacromial bursa.

vi. The scapula presents two surfaces, costal surface facing anteriorly and dorsal surface facing posteriorly. The dorsal surface is characterized by a shelf like projection called spine. The free lateral border of spine bounds the spinoglenoid notch. The spine of scapula divides the dorsal surface into supraspinous and infraspinous fossae. Its posterior free margin is called the crest of the spine.

Palpable Parts

The tip of coracoid process is felt through the infraclavicular fossa. The acromion and the crest of the spine are palpable. The medial border is palpable below the spine. The inferior angle is a palpable landmark.

Vertebral Levels

i. The superior angle corresponds to second thoracic vertebral spine.

ii. The base of spine (meeting point of the crest of the spine with the medial margin of scapula) is at the level of third thoracic spine.

iii. The inferior angle corresponds to seventh thoracic vertebral spine. This is a useful landmark for counting the ribs and vertebrae.

Triangle of Auscultation

The lower part of the medial border of scapula laterally, lateral margin of trapezius medially and latissimus dorsi below, are the boundaries of this triangle.

(For muscular attachments of scapula refer to Figures 9.6 and 9.7)

Neurovascular Relations (Fig. 9.8)

i. The superior border presents suprascapular notch, which is converted into suprascapular foramen by superior transverse ligament. The suprascapular artery passes

Fig. 9.3: Radiograph showing fracture of right clavicle

Fig. 9.4: Overlap of fragments of broken clavicle due to muscle pull

Fig. 9.5: Figure of 8-bandage to immobilize the clavicle by trapezius and held close to the posterior thoracic wall by serratus anterior muscle.
Winging of Scapula

This is the deformity in which the vertebral border and inferior angle of scapula protrude posteriorly due to paralysis of serratus anterior muscle (Fig. 9.9).

clinical insight ...

Winging of Scapula

This is the deformity in which the vertebral border and inferior angle of scapula protrude posteriorly due to paralysis of serratus anterior muscle (Fig. 9.9).
HUMERUS

It is the long bone of the arm articulating with glenoid cavity of scapula at the shoulder joint and with bones of forearm, the radius and ulna at the elbow joint.

General Features
The humerus presents upper end, shaft and lower end.

Upper End
The upper end presents a head, three necks (anatomical, surgical and morphological), greater tubercle, lesser tubercle and intertubercular sulcus (bicipital sulcus).

i. The hemispherical head bears articular surface for articulating with glenoid cavity of scapula.

ii. The anatomical neck is a slight constriction surrounding the margin of the head. It gives attachment to the capsule of shoulder joint except at its inferomedial part.

iii. The surgical neck encircles the junction of upper end and shaft. It is prone to fracture in which case, the axillary nerve and posterior circumflex humeral vessels are liable to injury (as these structures are closely related to medial part of surgical neck).

iv. The morphological neck corresponds to the epiphyseal line between the upper end and the shaft. In the adult, its position is about half centimeter above the surgical neck.

v. The greater tubercle projects from anterolateral side of upper end. It shows three facets for insertion of supraspinatus, infraspinatus and teres minor (from above downwards).

vi. The lesser tubercle projects anteriorly from the upper end. It provides insertion to subscapularis muscle.

vii. The intertubercular sulcus is between the greater and lesser tubercles. It lodges the tendon of long head of biceps brachii. The pectoralis major is inserted into its lateral lip and teres major into its medial lip. The floor provides insertion to latissimus dorsi.

Shaft
The shaft of humerus is cylindrical in upper half and triangular in lower half. It presents three borders (anterior, medial and lateral) and three surfaces (anterolateral, anteromedial and posterior). The medial border begins in the medial lip of bicipital groove and runs downwards to continue as medial supracondylar ridge of distal shaft. Similarly, the lateral border begins in the lateral lip of bicipital groove and runs downwards to continue as lateral supracondylar ridge of distal shaft. The posterior surface presents a spiral groove, which houses the radial nerve and profunda brachii vessels.

In the midshaft fracture of humerus, these structures are injured. The V-shaped deltoid tuberosity on the middle of lateral border gives insertion to deltoid whereas coracobrachialis is inserted into the middle of medial border.

Lower End
The lower end presents articular and nonarticular parts.

i. The articular parts are capitulum and trochlea. The rounded capitulum articulates with disc-shaped head of radius. The pulley like trochlea (lying medial
Upper Extremity
Section

to capitulum) has longer and larger medial flange. It articulates with trochlear notch of upper end of ulna. Together these articulations form elbow joint.

ii. There are three fat filled depressions at the lower end of the shaft. The olecranon fossa is present on posterior aspect and it receives olecranon process of ulna in extended elbow. There are two fossae on the anterior aspect. The radial fossa lodges head of radius and coronoid fossa lodges coronoid process of ulna in flexed elbow.

iii. The nonarticular parts are the medial and lateral epicondyles.

iv. The posterior surface of medial epicondyle is closely related to ulnar nerve, which can be palpated against it. The medial epicondyle is called funny bone because a hit on the epicondyle by a hard object evokes painful and tingling sensations along the medial side of forearm and hand. The anterior aspect of medial epicondyle presents area for common flexor origin for five muscles (pronator teres, flexor carpi radialis, palmaris longus, flexor carpi ulnaris and humeral head of flexor digitorum superficialis).

v. The anterior surface of lateral epicondyle presents area for common extensor origin for four muscles (extensor digitorum, extensor carpi radialis brevis, extensor carpi ulnaris and extensor digiti minimi) below which it gives origin to supinator. The posterior surface of lateral epicondyle gives origin to anconeus.

(Note: For muscular attachments of humerus refer to Figures 9.10 and 9.11)

Growing End

The upper end of humerus is its growing end (the nutrient foramen is directed towards the elbow). The nutrient artery takes origin from profunda brachii artery.

Clinical insight ...

Supracondylar Fracture of Humerus

The fracture of distal end of humerus just above the epicondyles is called supracondylar fracture (Figs 9.12A and B). It occurs most often in children as a result of a fall on the outstretched hand. The distal fragment of humerus moves backwards and upwards. The proximal fragment moves forwards causing compression of the brachial artery and the median nerve.

Nerves Related to Humerus

i. The axillary nerve is related to surgical neck, hence is injured in fracture of surgical neck and in anterior dislocation of humeral head.

ii. The radial nerve is related to posterior aspect of shaft at spiral groove, hence is injured in fractures of mid-shaft and due to careless injection into triceps muscle.

iii. The ulnar nerve is related to posterior aspect of medial epicondyle, where it can be palpated when thickened (as in leprosy) and is injured in fracture of medial epicondyle.

Know More ...
**RADIUS**

The radius is the lateral bone of the forearm. It is the weight bearing bone, hence more prone to fractures compared to ulna.

**Articulations of Radius**

i. Elbow joint
ii. Proximal (superior) radioulnar joint
iii. Middle radioulnar joint
iv. Inferior radioulnar joint
v. Wrist joint

**General Features**

The parts of the radius are upper end, shaft and lower end.

**Upper End**

This consists of disc-shaped head, neck and radial or bicipital tuberosity.

i. A shallow depression on the upper surface of the head of radius articulates with capitulum of humerus. The head moves inside the annular ligament during pronation and supination of forearm. These movements of radial head can be felt in a depression just below the lateral epicondyle of humerus. The medial side of the circumference of head bears the ulnar notch for articulation with radial notch of ulna to form superior radioulnar joint.

ii. The neck of radius is a slight constriction below the head.

iii. The radial tuberosity lies below the anteromedial part of the neck. Its posterior part is rough as it gives insertion to biceps brachii muscle. Its anterior surface is smooth as a synovial bursa lies between it and the biceps tendon.

**Shaft of Radius**

The shaft presents three borders (anterior, posterior and interosseous) and three surfaces (anterior, posterior and lateral). The upper oblique part of anterior border is referred to as anterior oblique line. The interosseous borders of radius and ulna are connected by the interosseous membrane, through which weight is transmitted from the radius to ulna.

It is noteworthy that the muscles of pronation (pronator teres and pronator quadratus) and of supination (biceps brachii and supinator) are inserted into the radius (Fig. 19.4)

(Note: For muscular attachments of radius refer to Figures 9.13 and 9.14)

**Lower End**

The lower or distal end of radius is expanded and is characterized by five surfaces and a styloid process.
i. A prominent Lister’s tubercle or dorsal tubercle is present on the dorsal surface. The tendon of extensor pollicis longus grooves the medial aspect of the tubercle as it changes direction around it.

ii. The styloid process of radius extends from the lateral surface and is longer than ulnar styloid process. The radial styloid process lies in the floor of anatomical snuffbox.

iii. The medial surface of lower end bears ulnar notch to articulate with head of ulna to form inferior radio-ulnar joint.

iv. The lower articular surface articulates with scaphoid, lunate and triquetral bones to form wrist joint.

v. The radial artery is palpated against the anterior surface of distal end lateral to the tendon of flexor carpi radialis.

Growing End

The lower end of the radius is the growing end.

Clinical insight ...

Colles’ Fracture

This is the fracture of the lower end of radius (Fig. 9.15). It commonly occurs due to a fall on outstretched hand. The wrist and hand show a dinner fork deformity, (Fig. 9.16A) which occurs due to the displacement of the lower fragment of radius in the posterior and upward direction. As a result, the radial styloid process moves upwards so that it is at the same level or at a higher level than that of ulnar styloid process (Fig. 9.16B).

ULNA

The ulna is the medial bone of the forearm.

Articulations of Ulna

i. Elbow joint

ii. Proximal (superior) radioulnar joint

iii. Middle radioulnar joint

iv. Inferior radioulnar joint

It is to be noted that ulna is excluded from taking part in wrist joint by an articular disc.
Bones of Upper Extremity

Chapter

General Features

The ulna consists of proximal or upper end, shaft and distal or lower end.

Upper End

The upper end has two processes (olecranon and coronoid) and two notches (radial and trochlear).

i. The olecranon process is hook-shaped. Its anterior surface is articular and posterior surface is subcutaneous. The tip of olecranon process provides insertion to triceps brachii muscle. The violent contraction of this muscle may fracture the olecranon process. A subcutaneous olecranon bursa is present between the triceps tendon and capsule of elbow joint. The student’s elbow is due to inflammation of this bursa.

ii. The coronoid process projects forwards. Its upper surface is articular. Its rough anterior surface gives insertion to brachialis muscle and continues down as ulnar tuberosity. Its lateral surface bears a radial notch for articulation with head of radius. The annular ligament is attached to the anterior and posterior margins of the radial notch. A small depressed area called supinator fossa (below the radial notch) presents sharp posterior margin called supinator crest. This crest gives origin to supinator muscle.

iii. The trochlear notch is formed by articular surfaces of olecranon and coronoid processes. It articulates with trochlea of humerus.

Shaft

The shaft of ulna has three borders (anterior, posterior and interosseous) and three surfaces (anterior, medial and posterior). The posterior border is rounded and subcutaneous.

(Note: The muscular attachments of ulna are shown in Figures 9.13 and 9.14).

Lower End

The lower tapering end of ulna shows head and styloid process. The ulnar styloid process is palpable in supinated position of forearm about one centimeter proximal to the plane of radial styloid process. The groove between the head and styloid process is occupied by tendon of extensor carpi ulnaris. The head of ulna articulates with ulnar notch of the radius at inferior radioulnar joint. The articular disc of the inferior radioulnar joint is placed below the ulnar head, because of which ulna is excluded from wrist joint.
Growing End

The lower end of ulna is its growing end.

Carpal Bones

The carpal bones are arranged in two rows.

Proximal Row

The bones are (from lateral to medial) scaphoid, lunate, triquetral and pisiform.

Distal Row

The bones are (from lateral to medial) trapezium, trapezoid, capitate and hamate.

Features

i. Scaphoid is boat-shaped. Its neck or waist subdivides the scaphoid into proximal and distal segments. A tubercle projects from its lateral side. It lies in the floor of anatomical snuff-box, where it can be palpated.

ii. Lunate is shaped like lunar crescent (shape of half moon).

iii. Triquetral is pyramidal in shape.

iv. Pisiform is pea-shaped. It is a sesamoid bone in the tendon of flexor carpi ulnaris.

v. Trapezium is quadrilateral and bears a crest and groove (for lodging tendon of flexor carpi radialis). It takes part in the first carpometacarpal joint, which imparts unique mobility to human thumb.

vi. Trapezoid is irregular like a baby’s shoe.

vii. Capitate bears a big head.

viii. Hamate has a hook-shaped process.

Carpal Tunnel

The carpal tunnel is an osseofibrous tunnel formed by anterior concavity of carpus (carpal bones as one unit) and flexor retinaculum, which is attached to the four corners of the carpus as follows, on lateral side to the tubercle of scaphoid and crest of trapezium and on medial side to pisiform and hook of hamate.

Ossification

The ossification of carpus is important. It helps in determining the bone age. Each carpal bone ossifies from one primary center, which appears after birth. Capitate is the first bone to ossify and pisiform is the last to ossify.

Time of Appearance of Ossification Centers

Capitate—second month, Hamate—end of third month, Triquetral—third year, Lunate—fourth year.

Scaphoid and trapezoid—fifth year, trapezium—sixth year, pisiform—twelfth year.
Of all the carpal bones the scaphoid is the most commonly fractured. The reason for this is that the distal half of scaphoid belongs to the distal row and proximal half belongs to proximal row of carpal bones. The waist or narrow part between the two halves of the bone lies in intercarpal line, which is subjected to maximum stresses. Hence, waist is the common site of fracture. Most commonly the artery supplying the scaphoid enters through its distal half (Fig. 9.19). So, if the waist is fractured blood supply to the proximal half is endangered. Hence, proximal half undergoes avascular necrosis resulting in the nonunion of fracture. In fracture of scaphoid pain and tenderness are felt in the anatomical snuff-box.

Dislocation of Lunate
The lunate is commonly dislocated in the anterior direction, which may cause compression of the median nerve in the carpal tunnel.

**Fig. 9.18:** The skeleton of hand showing muscular attachments

**Fig. 9.19:** Fracture of scaphoid bone (Arrow)
**METACARPAL BONES**

The five metacarpal bones are numbered from lateral to medial. Each metacarpal consists of head distally, shaft and base proximally.

i. The heads of the metacarpals are prominently visible on the dorsum of hand on making a fist. They are called knuckles in common language. The heads articulate with bases of corresponding proximal phalanges to form metacarpophalangeal joints.

ii. The shafts are concave on palmar aspect.

iii. The base of each metacarpal bone articulates with carpal bone/bones of distal row. The first metacarpal articulates with trapezium, the second with trapezoid, third with capitate and fourth and fifth with hamate.

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**Unique Features of First Metacarpal**

i. It is shortest and strongest.

ii. It is the modified first phalanx of thumb.

iii. It is not in line with the other four metacarpals as it is more anteriorly placed.

iv. It gives great mobility to the thumb by its saddle type of articulation with the trapezium.

v. Its base does not articulate with adjacent metacarpal bone (to maintain its independence) unlike the other metacarpals, which articulate with each other at their bases.

vi. Its mode of ossification is like that of phalanx.

**Bennett’s Fracture**

It is the fracture of the base of first metacarpal involving the first carpometacarpal joint. This is often caused by direct blow with closed fist, as in boxing.
PECTORAL REGION

The pectoral region is the name given to the front of the chest or thorax. This region contains the breast or mammary glands, pectoral muscles, clavipectoral fascia, origin of platysma and pectoral nerves.

Surface Landmarks (Fig. 10.1)

i. The sternum (breastbone) is located in the midline. The manubrium sterni, body and xiphoid process, which are the three parts of sternum from above downward are palpable. The sternal angle is the palpable ridge indicating the manubriosternal joint. The second costal cartilage articulates with the sternum at the sternal angle. The sternal angle is an important landmark during examination of the chest of the patient as it indicates the position of second rib from which the other ribs are counted.

ii. The clavicle is palpable in the upper part of pectoral region.

iii. The coracoid process of scapula is palpable in the infraclavicular fossa.

iv. The anterior axillary fold produced by pectoralis major muscle is a visible landmark when the muscle contracts against resistance.

Superficial Fascia

i. The main feature of the superficial fascia is the presence of breasts or mammary glands.

ii. The platysma (Fig. 10.2) seen in the upper part of the pectoral region is a thin subcutaneous muscle. It takes origin from the deep fascia covering the upper part of pectoralis major and adjacent deltoid muscle. It crosses the clavicle to enter the neck and is inserted into the lower margin of the body of mandible partly and into the facial muscles around the mouth. In its course through the neck, the platysma lies in the superficial fascia of the neck. The platysma is supplied by the facial nerve (seventh cranial nerve).
The skin above the sternal angle is supplied by the medial, intermediate and lateral supraclavicular nerves (C3, C4), which arise in the neck from the cervical plexus. These nerves descend to the pectoral region by crossing in front of the clavicle or frequently by piercing it. The medial supraclavicular nerve supplies the skin overlying the manubrium. The intermediate nerve supplies the skin over the upper part of pectoralis major muscle and the lateral nerve supplies the skin over the shoulder.

The anterior cutaneous branches of the second to the sixth intercostal nerves enter the pectoral region along the lateral margin of sternum after piercing the sterno-costal head of pectoralis major and the deep fascia. These branches are accompanied by corresponding arteries (which are the branches of internal thoracic artery). The area of supply of these cutaneous nerves extends from the anterior median plane to the midclavicular line.

The lateral cutaneous branches of the intercostal nerves appear along a vertical line just behind the anterior axillary fold. They supply the skin beyond the midclavicular plane.

### Line of Discontinuous Dermatomes

Since the first intercostal nerve does not give cutaneous branches to the pectoral region, C4 and T2 dermatomes approximate each other (Fig. 10.3) at the level of sternal angle. This interruption in the sequential order of dermatomes occurs due to the fact that C5 to T1 dermatomes are carried into the upper limb bud during embryonic life.

### Deep Fascia

The deep fascia of the pectoral region is called pectoral fascia because it covers the pectoralis major muscle. It is continuous with the periosteum of the clavicle and of the sternum. It passes over the deltopectoral groove to become continuous with the fascia covering the deltoid. The upper portion of the pectoral fascia gives origin to fibers of platysma. At the lower margin of pectoralis major, the pectoral fascia and the fascia covering the latissimus dorsi are connected by the axillary fascia, which lies in the floor of the axilla. The suspensory ligament of axilla connects the axillary fascia to the clavipectoral fascia at the lower margin of pectoralis minor.
Deltopectoral Triangle (Fig. 10.1)
The boundaries of this triangle are the upper margin of pectoralis major medially, anterior margin of deltoid laterally and the clavicle superiorly. The triangle contains cephalic vein, deltoid branch of thoracoacromial artery and the deltopectoral lymph nodes. The coracoid process of scapula projects in its upper part.

Pectoralis Major (Fig. 10.3)
This is the largest muscle of the pectoral region. It forms the anterior axillary fold.

**Origin**

i. The clavicular head takes origin from the anterior surface of the medial half of the clavicle.

ii. The sternocostal head arises from the front of the manubrium, body of the sternum and from second-to-sixth costal cartilages.

iii. The aponeurotic fibers arise from the aponeurosis of the external oblique muscle of the anterior abdominal wall.

**Insertion**
The pectoralis major is inserted into the lateral lip of the intertubercular sulcus of humerus by a U-shaped bilaminar tendon (the two limbs of the U being called anterior and posterior laminae). The anterior lamina is formed by clavicular fibers. It is inserted into the lower part of the lateral lip of intertubercular sulcus. The posterior lamina is formed by aponeurotic fibers. It is inserted into the upper part of the lateral lip of intertubercular sulcus. The sternocostal fibers form the base of the U.

**Nerve Supply**
The medial pectoral (C8, T1) and lateral pectoral (C5, C6, C7) nerves supply the muscle.

**Actions**

i. The contraction of entire muscle produces medial rotation and adduction of arm as for example while putting the hand on one's hip and pushing inwards forcibly.

ii. The contraction of clavicular part alone produces flexion of arm. This part becomes prominent, when the arm is flexed against resistance, e.g. in pushing the edge of a heavy table.

iii. The contraction of sternocostal part alone produces extension of the flexed arm against resistance, e.g. while pulling a heavy table by holding on the edge of the table.

iv. In climbing on a rope or a tree, the sternocostal part of pectoralis major along with latissimus dorsi produces a very powerful movement of extension of the arm from its fully flexed position.

**Testing Function of Pectoralis Major**
The subject abducts the arms to about 60° and then flexes the elbows. Now the subject attempts to bring the arms together. The examiner watches for the prominence of the anterior axillary folds. (Another method of testing the muscle function is by asking the subject to place hands on the hips and press firmly inwards and observe for the prominence of anterior axillary folds).

**Poland Anomaly**
In congenital absence of pectoralis major muscle (Poland anomaly), the anterior axillary fold is absent.

Pectoralis Minor (Fig. 10.4)
This is a triangular muscle in the anterior wall of axilla, placed posterior to the pectoralis major. It has anterior and posterior surfaces and upper or medial and lower or lateral margins.

![Fig. 10.4: Attachments of pectoralis minor](Note its relations to axillary vein and the axillary lymph nodes)
Origin
It takes origin from the outer surfaces of third, fourth and fifth ribs near the costal cartilages.

Insertion
It is inserted into the medial border and upper surface of the coracoid process of scapula.

Relations
The pectoralis minor muscle is completely enclosed in the clavipectoral fascia.

i. Anteriorly, it is related to the interpectoral lymph nodes (Rotter’s nodes) and the pectoralis major muscle.

ii. Posteriorly, it is related to the second part of axillary artery, axillary vein and cords of brachial plexus.

iii. Its lower (lateral) margin is related to lateral thoracic vessels and anterior group of axillary lymph nodes.

Nerve Supply
The medial pectoral nerve pierces the pectoralis minor and supplies it (lateral pectoral nerve sends twigs via its communication with the medial pectoral nerve).

Actions
i. The pectoralis minor protracts the scapula along with serratus anterior muscle.

ii. It depresses the scapula along with lower fibers of trapezius.

Subclavius
This is a small muscle that takes origin by a narrow tendon from the first costochondral junction and is inserted into the subclavian groove on the lower surface of clavicle.

Nerve Supply
The muscle receives twigs from the nerve to subclavius, which is a branch of the upper trunk of brachial plexus (The nerve to subclavius contributes C5 fibers to phrenic nerve through accessory phrenic nerve)

Action
The subclavius steadies the clavicle during movements of the scapula.

Clavipectoral Fascia (Figs 10.5A and B)
The clavipectoral fascia is located in the anterior wall of axilla deep to the pectoralis major muscle.

Vertical Extent
In its vertical extent, the clavipectoral fascia splits twice to enclose two muscles (subclavius and pectoralis minor) and it forms two ligaments (costocoracoid ligament and suspensory ligament of axilla).

i. Superiorly, it splits to enclose the subclavius muscle and its two layers are attached to inferior surface of clavicle at the lips of subclavian groove.

ii. These two layers unite to form a single sheet of strong clavipectoral fascia, which bridges the gap between the subclavius muscle and the upper margin of pectoralis minor muscle.

iii. The fascia splits to enclose the pectoralis minor muscle. At the lower margin of the pectoralis minor, the two layers unite to form the suspensory ligament of axilla, which becomes continuous with the axillary fascia.

Horizontal Extent
i. Medially, the strong part of clavipectoral fascia is attached to the first rib medial to subclavius and...
blends with the fascia covering the first two intercostal spaces.

ii. Laterally, it is attached to the coracoid process of scapula and to the fascia covering the short head of biceps brachii.

**Costocoracoid Ligament**

The part of clavipectoral fascia between the first rib and the coracoid process is known as costocoracoid ligament.

**Structures Piercing Clavipectoral Fascia**

i. Lateral pectoral nerve

ii. Thoracoacromial artery

iii. Cephalic vein

iv. Lymph vessels

**Pectoral Nerves**

i. The medial pectoral nerve (C8, T1) arises from the medial cord of the brachial plexus. It lies behind the first part of axillary artery initially but soon curves forwards to give a communicating ramus to the lateral pectoral nerve in front of the axillary artery. The medial pectoral nerve supplies both pectoralis minor and major muscles.

ii. The lateral pectoral nerve (C5, C6, C7) arises from the lateral cord of the brachial plexus. It travels forwards on the lateral side of axillary artery and pierces the clavipectoral fascia and clavicular fibers of pectoralis major muscle, which it supplies.

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**BREAST OR MAMMARY GLANDS**

The breasts or mammary glands are a pair of modified sweat glands, located in the superficial fascia of the pectoral region. Each breast is composed of glandular tissue and fibro-fatty stroma. The breast is covered with the skin, areola and nipple. In male, the breasts are rudimentary. In female, after the onset of puberty the breasts grow in size.

**Embryologic insight ...**

In the seven-week embryo, ectodermal milk line appears on the ventral body wall on each side, extending from the limb bud of the upper limb to that of the lower limb. The milk lines in the pectoral region give rise to a pair of glands and the remaining milk lines disintegrate (Fig. 10.6).

**Congenital Anomalies**

i. Accessory nipples (polythelia) may be found anywhere along the milk line.

ii. A complete accessory breast (polymastia) may develop along the milk line.

iii. Amastia or amazia is bilateral agenesis of breast and athelia is absence of nipple.

iv. In Poland anomaly, there is complete or partial absence of glandular tissue but the nipple is normal. The pectoralis major muscle is partly or fully absent in this anomaly.

**Female Breast**

The breast extends vertically from the second to the sixth ribs and in the transverse plane, from the sternal margin to the mid-axillary line.

**Fig. 10.5B:** Structures piercing clavipectoral fascia

**Fig. 10.6:** Development of breast in pectoral region from the ectodermal milk line (Note that sites of accessory nipples are shown on left side)
Parts of Breast
The breast consists of a broad base in contact with the chest wall and a pointed apex, which bears the nipple. A projection of the glandular tissue from the upper and outer quadrant of the breast, into the axilla, is called axillary tail of Spence (Fig. 10.7). This deep part of the breast passes through an opening (foramen of Langer) in the axillary fascia. It is in direct contact with the anterior group of axillary lymph nodes. Due to this proximity cancer of the axillary tail may be mistaken for an enlarged anterior lymph node.

Base of Breast (Fig. 10.8)
The base of the breast is in contact with the pectoral fascia, deep to which it rests on three muscles. The pectoralis major muscle is in contact with the greater part of the base. The serratus anterior is related superolaterally and the aponeurosis of external oblique muscle of the abdomen inferiorly. These three muscles form the bed of the mammary gland. Between the base and the pectoral fascia, there is a retromammary space filled with loose connective tissue and fat. This space allows some degree of mobility to the breast. When the pus collects in this space it is called retromammary abscess.

Nipple and Areola
The nipple lies approximately in the fourth intercostal space unless the breast is pendulous. It is covered with thick hairless skin, which contains involuntary muscle and is rich in sensory receptors needed for the sucking reflex. About 15 to 20 lactiferous ducts open by 15 to 20 minute apertures at the summit of the nipple. The areola is the rounded area of pigmented skin that encircles the nipple. Permanent darkening of the areola and nipple occurs during first pregnancy. The areola contains involuntary muscles, sebaceous glands and sweat glands. The sebaceous glands enlarge during pregnancy as subcutaneous tubercles (Montgomery tubercles). The oily secretion of these glands is a protective lubricant to nipple during lactation.

Structure (Fig. 10.8)
The breast consists of parenchyma (ducts and secretory acini), connective tissue stroma, adipose tissue, blood vessels and lymphatics. The parenchyma is arranged in 15 to 20 lobes. Each lobe has one main lactiferous duct, which converges towards the nipple. The number of lactiferous ducts is equal to that of the lobes. Each lactiferous duct receives numerous smaller ducts and as it approaches the nipple, it dilates beneath the areola to form the lactiferous sinus, and then narrows again to reach its opening at the summit of the nipple. The lactiferous ducts converge towards the nipple in a radiating manner. Therefore, while draining a breast abscess a radial incision is placed to

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Fig. 10.7: Quadrants of breast and tail of Spence

Fig. 10.8: Structure of breast and muscles related to base of breast
avoid injury to these ducts. The ligaments of Cooper are the special thickened parts of stromal tissue, which serve to anchor the gland to the overlying skin at certain points. They also connect the base of the gland to the pectoral fascia, without hampering the mobility of the normal gland on the contracted pectoralis major muscle (Fig. 10.9).

**Modes of Secretion**

The breast is a compound tubuloalveolar gland. According to its modes of secretion, it is classified as both merocrine and apocrine gland. The release of protein molecules without loss of plasma membrane falls under merocrine mode whereas release of fat globules by loss of apical plasma membrane falls under apocrine mode.

**Arterial Supply**

The breast receives arteries mainly from four sources (Fig. 10.10).

i. The branches of lateral thoracic artery supply the lateral part of the gland.

ii. Twigs from the perforating cutaneous branches of internal mammary artery in the second, third and fourth intercostal spaces supply the medial part of the gland.

iii. The pectoral branches of acromiothoracic and superior thoracic arteries provide additional supply to the upper part of breast.

iv. The posterior intercostal arteries in the second, third and fourth spaces supply the breast from its base.

**Venous Drainage**

The veins radiate from the circular venous plexus subjacent to the areola. They drain into the surrounding veins namely, axillary, internal thoracic and intercostal veins. The communication of posterior intercostal veins with the internal vertebral venous plexus (via intervertebral veins) is the basis of spread of cancer to the vertebrae and skull bones (vide infra).

**Lymphatic Drainage**

The lymph vessels are grouped into the superficial and deep sets.

1. The superficial lymph vessels (Fig. 10.11A) drain the skin overlying the breast except that of nipple and areola. A few lymph vessels from the skin of the upper part of the breast directly reach the supraclavicular nodes by crossing the clavicle whereas a few terminate in the deltotrapezial nodes. The skin of the medial part drains in to the internal mammary (parasternal) nodes of the same side. A few lymphatics cross over to communicate with the lymphatics of the opposite breast. The skin of the rest of the breast drains in to the anterior group of axillary nodes.

2. The deep lymph vessels (Fig. 10.11B) drain the gland parenchyma and the skin of the nipple and areola. The lymph plexuses in the parenchyma around the lactiferous ducts and in the stroma communicate with the sub-areolar plexus of Sappey.
i. The lymph vessels from the parenchymal plexuses and the subareolar plexus mainly drain into pectoral (anterior) group of axillary nodes. A few drain into the interpectoral or Rotter’s nodes and others to the subscapular (posterior) and brachial (lateral) groups of axillary nodes. From these axillary nodes, the lymph passes to the central nodes and finally to the apical nodes. Some vessels from the peripheral part of superior quadrants pass directly into apical group.

ii. About 75 percent of lymph from the breast drains into the axillary nodes.

iii. Rest of the parenchyma drains into the internal mammary (parasternal) nodes.

iv. The lymph vessels that leave the deep surface of the breast reach the posterior intercostal nodes.

v. A few lymph vessels from the base communicate via the rectus sheath on anterior abdominal wall with the subperitoneal lymph plexuses.

**Spread or Metastasis of Breast Cancer**

The spread of cancer cells from the primary lesion in the breast is by three routes, lymphatic, local infiltration and blood borne.

(Note: All routes have anatomical basis)

**Spread to Axillary Lymph Nodes**

The axillary lymph nodes are usually involved in very early stage of cancer. Therefore, clinical examination of breast is incomplete without the palpation of axillary lymph nodes (Fig. 10.13). The biopsy of lymph nodes is taken for histopathological confirmation of the diagnosis.

**Local Spread**

i. Involvement of the ligaments of Cooper results in dimpling or puckering of skin. The fibrosed ligaments of Cooper, at the base of the breast cause fixation of the breast to the underlying pectoral fascia leading to loss of mobility of the breast.

ii. The blockage of cutaneous lymph vessels causes edema of the overlying skin. The points of openings of sweat ducts (sweat pores) do not show edema and hence remain depressed. As a result, the skin over the breast presents an appearance of an orange peel (peau d’orange appearance shown in figure 10.14).

iii. Retraction of the nipple (10.12A) may occur if the cancer cells invade the lactiferous ducts.

**Malignancy of Breast**

The breast cancer in women is a global problem. The cancer usually arises from the epithelium of the ducts. The upper outer quadrant of the breast is the most common site. The early symptom of cancer is the presence of a painless hard lump in the breast. However, the patient may seek help of the surgeon at various stages of the cancer (Fig. 10.12).
Chapter 10

Figs 10.12A to C: Different presentations of breast cancer (as indicated by arrow)

Fig. 10.13: Examination of anterior axillary lymph nodes in a patient

Fig. 10.14: Peau d’orange appearance of the skin of breast

Contd...

**Distant Spread**

i. The cancer cells spread to subdiaphragmatic and hepatic nodes via the subperitoneal lymph plexuses. A few cells may drop in the peritoneal cavity to deposit on any organ usually, the ovary. Secondary deposits through transcoelomic spread are called Krukenberg’s tumors.

ii. The cancer cells spread to vertebral column, cranial bones, ribs and femur by entering the venous...
circulation. During rise in intrathoracic pressure (in acts like coughing, straining, etc.) there is reversal of blood flow in the intervertebral veins, which facilitates the spread into the internal vertebral venous plexus and into vertebral bodies (Fig. 10.15) and cranial bones. For this reason, radiological examination of the skeleton is mandatory in cases of breast cancer.

**Fig. 10.15:** Venous route of cancer cells to spread to vertebral column

**Mastectomy (Figs 10.16A and B)**
The breast cancer is surgically treated in the majority of cases. The surgical removal of breast is called mastectomy. To perform this operation the knowledge of anatomy of the breast, pectoral region and axilla is essential. Nowadays radical mastectomy (in which the breast, pectoral muscles, clavicular fascia, deltopectoral lymph nodes and axillary fat along with all the axillary lymph nodes are removed) is rarely performed. In its place the standard modified radical mastectomy is preferred. This procedure includes simple mastectomy with removal of axillary lymph nodes (level I and II) and the preservation of pectoral muscles. While dissecting the axillary lymph nodes, the surgeon identifies the nerve to serratus anterior, nerve to latissimus dorsi and the intercostobrachial nerve in order to safeguard them. The surgeon also identifies axillary blood vessels and their major branches and tributaries.

**Early Detection of Breast Cancer**
The mammography is a soft tissue X-ray of the breast, with minimum radiation risk. It is taken by placing the breast in direct contact with ultra sensitive film and exposing it to low voltage X-rays. The presence of macrocalcification is an indication of malignancy. This method is useful in locating clinically undetected lesion, hence mammogram (Fig. 10.17) is a part of prevention or early detection of breast cancer in women.

**Figs 10.16A and B:** (A) Exposure of axilla during mastectomy; (B) Enlarged axillary lymph node (arrow) in breast cancer
The gynecomastia is the abnormal enlargement of male breast. In some individuals it may be idiopathic (without any cause). The pathological causes of gynecomastia are, liver disease, hormone secreting tumors, side effects of drugs and leprosy. Gynecomastia is one of the characteristic features in XXY sex chromosomal anomaly (Klinefelter’s syndrome).
The axilla is a roughly pyramidal space situated between the lateral surface of chest wall and the medial aspect of the upper part of the arm. The anatomy of axilla is important not only because it gives passage to the neurovascular structures of the upper limb but also because it is examined clinically for enlargement of axillary lymph nodes and dissected during mastectomy for removing lymph nodes in cancer of the breast.

Contents of Axilla (Fig. 11.1)
- Axillary artery and its six branches
- Axillary vein and its tributaries
- Axillary lymph nodes
- Adipose tissue (axillary pad of fat)
- Infraclavicular part of brachial plexus (which includes three cords and their branches), long thoracic nerve and intercostobrachial nerve
- Axillary tail of Spence

Walls of Axilla (Fig. 11.2)
When the arm is abducted, the narrow space of axilla increases in size forming a recognizable armpit bounded by anterior and posterior axillary folds. The axilla has anterior, posterior, medial and lateral walls and a base and an apex.
- The anterior wall consists of the pectoralis major and deeper to it, pectoralis minor, clavipectoral fascia and subclavius muscle in that order from below upward. The lateral thoracic vessels and anterior or pectoral group of lymph nodes are present inside this wall. The anterior axillary fold formed by lower margin of pectoralis major muscle becomes prominent, when the arm is adducted against resistance.
- The posterior wall of axilla consists of (from above downward) subscapularis, teres major and latissimus dorsi muscles. However, as the teres major and latissimus dorsi twist around each other, they come to lie in the same plane. The important relations of the posterior wall are subscapular vessels, subscapular and thoracodorsal nerves and posterior or subscapular lymph nodes. The posterior axillary fold is formed by the teres major and latissimus dorsi muscles and it becomes prominent, when the arm is adducted against resistance.
- The medial wall of axilla consists of first four ribs with intervening intercostal muscles and the upper four digitations of serratus anterior muscle. The long
Chapter 11

Axilla and Axillary Lymph Nodes

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The thoracic nerve descends on the surface of serratus anterior muscle. The intercostobrachial nerve (lateral cutaneous branch of second intercostal nerve) pierces the serratus anterior to enter the axilla. As the nerve crosses from medial to lateral side of axilla, it passes through the central group of axillary lymph nodes to join the medial cutaneous nerve of arm. Compression of intercostobrachial nerve due to enlarged central lymph nodes gives rise to pain in its area of supply (upper medial side of arm including the floor of axilla).

iv. The lateral wall of axilla is the narrowest as it is formed by the bicipital groove of the humerus with tendon of long head of biceps brachii. The conjoint tendon of coracobrachialis and short head of biceps brachii is closely related to this wall, so also the axillary vessels.

v. The base or the floor of axilla is composed of (from below upwards) the skin, superficial fascia and the dome-shaped axillary fascia. The axillary tail of Spence passes through the foramen of Langer in the medial part of axillary fascia to enter in to the axilla.

vi. The apex or cervicoaxillary canal is the communicating passage between the axilla and the posterior triangle of the neck. The boundaries of the apex (Fig. 11.3) are the middle-third of clavicle anteriorly, the superior margin of scapula posteriorly and the outer margin of the first rib medially. The structures that pass through the apex are axillary vessels, cords of brachial plexus, long thoracic nerve and the subclavian lymph trunk.

Clinical insight ...

Drainage of Axillary Abscess

The vascular relations of the walls of axilla should be borne in mind while placing an incision on the base of axilla for draining an abscess. The safe site to place the incision is midway between the anterior and posterior margins of the base closer to the medial wall.

Serratus Anterior Muscle (Fig. 11.4)

This is a broad and flat muscle of the trunk in the medial wall of the axilla.

i. The serratus anterior arises from the anterior aspect of the outer surfaces of upper eight ribs by eight fleshy digitations.

ii. It passes backwards around the chest wall for insertion into the medial border of the ventral (costal) surface of scapula. The first digitation arises from the outer border of the first rib and from the second rib. It is inserted in the superior angle of scapula. The second, third and fourth digitations arise from respective ribs and spread out to be inserted along the entire medial border. The lower four digitations arise from the respective ribs and converge for insertion in the inferior angle of scapula.

Nerve Supply

The long thoracic nerve (nerve of Bell) supplies the serratus anterior muscle. The nerve descends on the superficial surface of the muscle and gives separate twig to each digitation.

Actions

i. The serratus anterior muscle protracts the scapula with the help of pectoralis minor. Protraction is required during punching and pushing movements, hence serratus anterior is called the boxer’s muscle.
ii. The lateral rotation of scapula is brought about by the lower five digitations with the help of trapezius.

**Testing Muscle Function**

The subject is asked to place the stretched hands on the wall and push forwards (Fig. 9.9). Normally, the scapulae will remain fixed to the thoracic cage. If the medial border of scapula is raised during this act it is indicative of weakness or paralysis of serratus anterior muscle.

**Long Thoracic Nerve (Fig. 11.4)**

This is also known as the nerve of Bell. It is a branch of the root stage of the brachial plexus. It is a purely motor nerve. The long thoracic nerve begins from C5, C6 and C7 nerve roots in the neck.

**Cervical Course**

The three roots pass downwards behind the supracleavicular part of the brachial plexus. The C5 and C6 roots separately pierce the scalenus medius muscle and then unite with each other. This common trunk and the C7 root enter the axilla through its apex and unite with each other to form the long thoracic nerve.

**Axillary Course**

The long thoracic nerve is closely related to the lateral surface of serratus anterior muscle (the medial wall of the axilla). It gives separate twigs to each of the eight digitations of the muscle.

### Clinical insight ...

**Winging of Scapula (Fig. 11.5)**

The long thoracic nerve may be injured during surgical removal of axillary lymph nodes, leading to paralysis of serratus anterior muscle. Nonfunctioning of serratus anterior results in a deformity called winged scapula. In this, the medial border and inferior angle of scapula stand out from the chest wall and the patient experiences difficulty in abduction above 90 degrees.

### AXILLARY LYMPH NODES

The axillary lymph nodes are arranged into five groups. The area of their drainage includes the entire upper extremity and the thoracoabdominal walls up to the level of umbilicus on the front and up to the level of iliac crest on the back. The axillary nodes drain nearly 75 percent of the breast tissue.

i. The anterior or pectoral group of lymph nodes is located in the anterior wall of the axilla along the course of lateral thoracic vessels. These nodes receive lymph from major portion of breast tissue, anterior chest wall and anterior abdominal wall up to the level of umbilicus. Its efferent vessels mainly go to the central nodes. The axillary tail of Spence (deep part of mammary gland), lies in close contact with these nodes.

ii. The posterior or subscapular group is located in the posterior wall of axilla along the subscapular vessels. These nodes receive lymph from the posterior chest wall and posterior abdominal wall up to the level of iliac crest.

iii. The lateral or brachial group is located on the lateral wall of axilla along the axillary vein. The lymph nodes of lateral group receive lymph from the entire upper limb. A few vessels accompanying the cephalic vein drain in...
the delto-pectoral nodes and others from lateral aspect of proximal arm terminate directly in to the apical nodes. Some lymph vessels accompanying the basilic vein terminate in the epitrochlear (supratrochlear or cubital) nodes, the efferent vessels from which drain into the lateral group. Inflammatory lesion anywhere in the upper limb causes enlarged and painful lateral group of lymph nodes.

iv. The central group is composed of three or four large lymph nodes embedded in the fatty tissue along the axillary vein. These nodes receive lymph from anterior, posterior and lateral groups and drain in to the apical nodes. The intercostobrachial nerve passes through the central nodes. Therefore, the swollen central nodes may be the cause of pain along the medial side of upper part of arm and the base of axilla.

v. The apical group consists of six to eight lymph nodes lying partly in the apex of the axilla and along the axillary vein in the triangular space between the axillary vein, outer margin of first rib and the upper margin of pectoralis minor muscle. These nodes receive lymph from the central group, deltopectoral or infraclavicular nodes and interpectoral nodes. They receive a few lymphatics directly from the superior peripheral region of the breast and a few from the proximal arm. The apical lymph nodes are the terminal nodes of the upper extremity. Their efferent vessels unite to form the subclavian lymph trunk, which terminates in the jugulo-venous junction or the subclavian vein or the jugular lymph trunk or the right lymph trunk, on the right side and the thoracic duct on the left side.

Fig. 11.6: Examination of pectoral group of nodes standing in front of the patient

Fig. 11.7: Examination of subscapular group of nodes standing behind the patient

Know More ...

The surgeons include the interpectoral or Rotter’s nodes as a sixth group of axillary lymph nodes. The interpectoral nodes are situated between the pectoralis major and minor muscles, closer to the anterior wall of axilla. They receive deep lymphatics from the breast and drain directly in to the apical group or in to the central group. (For levels of axillary lymph nodes refer to lymphatic drainage of breast in chapter 10).

Clinical insight ...

Axillary Lymphadenopathy
The enlargement of lymph nodes is called lymphadenopathy. The cancer of the breast causes painless enlargement of the axillary lymph nodes. The painful enlargement is due to any infective focus in the area of drainage of the axillary lymph nodes. The nodes are also enlarged in generalized lymphadenopathy due to other causes like Hodgkin’s lymphoma, lymphatic leukemia and AIDS.

Palpation of Axillary Lymph Nodes
While palpating the axillary lymph nodes in a patient, the examiner uses his or her right hand for the left axilla and left hand for the right axilla. The examiner supports the arm of the patient in a slightly abducted position so as to relax the axillary floor and walls. Standing in front of the patient the semiflexed fingers are gently but firmly pushed into the floor of the axilla to palpate the nodes of pectoral group (Fig. 11.6), then central, apical and lateral nodes. Standing behind the patient the examiner feels the subscapular nodes (Fig.11.7).
BRACHIAL PLEXUS

The brachial plexus is a plexus of nerves, which is responsible for the nerve supply of the upper limb including a few muscles of the trunk. Through its connections with the sympathetic ganglia, the branches of the brachial plexus provide pilomotor supply (to the arrector pili muscles), sudomotor supply (to sweat glands) and vasomotor supply (to the smooth muscle of blood vessels) of the skin of the upper limb.

Location and Parts (Fig. 12.1)
The brachial plexus lies partly in the posterior triangle of the neck and partly in the axilla. So, it is divisible into the supraclavicular and infraclavicular parts. The supraclavicular part consists of roots, trunks and divisions. The infraclavicular part consists of the cords and peripheral nerves that arise from the cords. Usually, five stages (roots, trunks, divisions, cords and branches) are described in the formation of brachial plexus.

Formation (Fig. 12.2)
The ventral rami of C5, C6, C7, C8 and T1 spinal nerves take part in the formation of the brachial plexus. Usually C4 ventral ramus contributes a small twig to C5 and T2 ventral ramus to T1.

Root Stage
The roots of brachial plexus consist of C5, C6, C7, C8 and T1 ventral rami, which are located behind the scalenus medius and scalenus anterior muscles of the neck. The roots unite to form the trunks.

Branches from Root Stage
i. Dorsal scapular nerve or nerve to rhomboids (C5)
ii. Long thoracic nerve or nerve of Bell (C5, C6, C7).

Fig. 12.1: Location of supraclavicular (in posterior triangle of neck) and infraclavicular (in axilla) parts of brachial plexus
Trunk Stage

There are three trunks (upper, middle and lower) in the brachial plexus.

i. The **upper trunk** (Erb’s point) is formed by union of C5 and C6 roots at the lateral margin of the scalenus medius.

ii. The **middle trunk** is the continuation of C7 root (hence its root value is C7).

iii. The **lower trunk** is formed by the union of C8 and T1 roots behind the scalenus anterior. The trunks emerge through the interscalene space (between the scalenus anterior and scalenus medius muscles) to enter the lower part of the posterior triangle of neck (also known as subclavian triangle), where they are superficially placed. The upper and middle trunks lie above the subclavian artery and the lower trunk lies directly on the superior surface of the first rib along with the subclavian artery.

Branches of Upper Trunk

i. Suprascapular nerve (C5, C6)

ii. Nerve to subclavius (C5, C6)

Division Stage

As each trunk slants obliquely downwards towards the middle-third of the clavicle, it terminates into anterior and posterior divisions just behind the clavicle.

Cord Stage

The cords are formed at the cervicoaxillary canal which are as follows (Table 12.1):

i. The posterior cord is formed by the union of all the three posterior divisions. Its root value is C5, C6, C7, C8 and (T1). The T1 fibers are usually absent because the slender posterior division of the lower trunk carries C8 fibers only.

ii. The lateral cord is formed by the union of anterior divisions of upper and middle trunks. Its root value is C5, C6, and C7.

iii. The medial cord is the continuation of the anterior division of the lower trunk. Hence its root value is C8, T1.

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<th>Table 12.1: Branches of cords</th>
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<td>Lateral cord</td>
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Contd...
Relations of Cords to Axillary Artery

The cords are related to the first and second parts of the axillary artery.

i. Around the first part, the medial cord is in posterior position whereas the lateral and posterior cords are in lateral position.

ii. Around the second part, the cords take up the positions as indicated by their names.

iii. Around the third part, the nerves given off by the respective cords are related.

Connections with Sympathetic Chain

The ventral rami of the C5 to C8 and T1 spinal nerves receive postganglionic sympathetic fibers from the middle cervical and stellate ganglia of the sympathetic chain via the Gray Rami Communicantes (GRC). In this way, the branches of the plexus carry postganglionic sympathetic fibers to the upper limb. The ventral ramus of T1 presents additional connection to stellate ganglion via the first White Ramus Communicans (WRC) (Fig. 12.3). The preganglionic sympathetic fibers in the first WRC supply the head and face. They synapse in the superior cervical ganglion, from where the postganglionic fibers supply the dilator muscle of the pupil, smooth muscle of the upper eyelid (Müller’s muscle) and vasomotor, sudomotor and pilomotor supply to the skin of the face. The T1 ventral ramus may be avulsed in traumatic injury to the brachial plexus, which results in avulsion of preganglionic fibers for head and face. The symptoms and signs due to loss of sympathetic supply to the face and eye produce Horner’s syndrome (refer to total branchial plexus avulsion in branchial plexus injuries).

Know More ...

Prefixation of Brachial Plexus

A prefixed brachial plexus moves one segment higher than usual. In this type, the contribution from C4 is larger, that from T1 is reduced and that from T2 is absent.

Postfixation of Brachial Plexus

A post fixed brachial plexus moves one segment lower than usual (for example due to cervical rib). In this type, the contribution from T2 is larger, that from C5 is reduced and that from C4 is absent. Post fixed brachial plexus has mechanical disadvantage since the lower trunk is more angulated and hence stretched on the upper surface of the first rib. This may give rise to symptoms of compression of the lower trunk.

Connections with Sympathetic Chain

The ventral rami of the C5 to C8 and T1 spinal nerves receive postganglionic sympathetic fibers from the middle cervical and stellate ganglia of the sympathetic chain via the Gray Rami Communicantes (GRC). In this way, the branches of the plexus carry postganglionic sympathetic fibers to the upper limb. The ventral ramus of T1 presents additional connection to stellate ganglion via the first White Ramus Communicans (WRC) (Fig. 12.3). The preganglionic sympathetic fibers in the first WRC supply the head and face. They synapse in the superior cervical ganglion, from where the postganglionic fibers supply the dilator muscle of the pupil, smooth muscle of the upper eyelid (Müller’s muscle) and vasomotor, sudomotor and pilomotor supply to the skin of the face. The T1 ventral ramus may be avulsed in traumatic injury to the brachial plexus, which results in avulsion of preganglionic fibers for head and face. The symptoms and signs due to loss of sympathetic supply to the face and eye produce Horner’s syndrome (refer to total branchial plexus avulsion in branchial plexus injuries).

Clinical insight ...

Brachial Plexus Injuries

The brachial plexus may be damaged due to trauma, compression and malignancy of breast and lung. The traumatic causes of the brachial plexus injury are, forceps delivery, gunshot or stab injuries, fall from a height and automobile accidents. The plexus may be compressed due to aneurysm (dilatation) of the axillary artery.

Types of Injuries

i. Total brachial plexus paralysis is a serious injury. The roots of the plexus are avulsed so the upper limb is paralysed with total loss of sensation. The serratus anterior and rhomboid muscles are also paralyzed. The damage to T1 ventral ramus (involving preganglionic sympathetic fibers) results in Horner’s syndrome on the affected side. This syndrome consists of partial ptosis (due to paralysis of Müller’s muscle), constriction of pupil (due to paralysis of dilator pupillae), loss of sweating (due to loss of sudomotor supply) and flushing of face (due to loss of vasomotor supply).
ii. The upper trunk or Erb’s palsy in new born usually occurs during forceps delivery, during which, there may be forceful separation of neck and shoulder with resultant stretching of the upper trunk (Erb’s point). Hence it is also known as obstetrical palsy. The Erb’s point is described as the meeting point of six nerves (Fig.12.4), which include ventral rami of C5 and C6, two branches (suprascapular and nerve to subclavius) of upper trunk and two divisions of upper trunk. The upper limb is held in porter’s tip or policeman’s tip or waiter’s tip position, in which the arm is adducted and medially rotated and the forearm is extended and pronated. This characteristic position is due to paralysis of following muscles and overaction of antagonist muscles as given in Table 12.2.

iii. The lesion of lower trunk or Klumpke’s paralysis is usually produced by traction on the lower trunk exerted by a cervical rib or forcible hyperabduction in a fall from a height or malignant infiltration of the lower trunk (as in pancoast tumor of lung or carcinoma breast) or postfixed brachial plexus. This lesion results in complete claw hand (Fig. 12.5), in which there is slow progressive weakness in interossei and lumbricals of hand supplied by T1 root via branches of ulnar and median nerves. In claw hand deformity, the fingers are hyper extended at metacarpophalangeal joints and hyperflexed at interphalangeal joints. The wrist joint is hyperextended due to paralysis of flexors of wrist and overaction of extensors. There is pain and numbness along the medial side of the arm, forearm and medial one and half fingers. Horner’s syndrome may be produced due to injury to the ventral ramus of T1 spinal nerve or the first WRC.

### Brachial Plexus Block

The brachial plexus block is preferred method of anesthesia for surgery on upper limb (repair of complicated wounds of hand, fracture of forearm bones, reduction of shoulder dislocation, etc.). The brachial plexus in the subclavian triangle (lower subdivision of posterior triangle of neck) is accessible via the supraclavicular and infraclavicular (or axillary) approaches. The supraclavicular route is depicted in a patient in Figures 12.6A and B.
Figs 12.6A and B: SuprACLavicular brachial pLEXus block in a patient (the point for inserting the needle is just above the midpoint of clavicle lateral to the pulsation of subclavian artery)

AXILLARY ARTERY AND VEIN

The axillary artery is the main artery of the upper limb. It begins as a continuation of the subclavian artery at the outer border of the first rib and continues as the brachial artery at the lower border of teres major muscle. The axillary artery and the cords of brachial plexus are wrapped in a fascial sheath derived from the prevertebral fascia of the neck.

Surface Marking (Fig. 12.7)

There are two methods of marking the axillary artery on the surface of the body.

Course

As the axillary artery enters the axilla through the apex, it is in intimate relation to the medial wall of axilla, which is formed by the first two digitations of serratus anterior muscle. As it courses downwards with a lateral convexity, it comes in very intimate relation to the lateral wall of the axilla.

Parts of Axillary Artery (Fig. 12.8)

The axillary artery is subdivided into three parts by the pectoralis minor muscle, which crosses it anteriorly.

i. The first part extends from the outer margin of the first rib to the upper margin of pectoralis minor.

ii. The second part lies deep or posterior to the pectoralis minor.

iii. The third part extends from the lower margin of the pectoralis minor to the lower margin of teres major.

Variation

The axillary artery may divide into ulnar and radial arteries at the distal border of teres major. In such cases the brachial artery is absent.
Brachial Plexus and Axillary Vessels

Chapter

(Note: First and second parts of the axillary artery are related to the cords of the brachial plexus and the third part to the branches of the cords).

Relations of First Part (Fig. 12.9)

i. The anterior relations (from superficial to deep) are the skin, superficial fascia and the platysma, pectoral fascia and the clavicular head of the pectoralis major muscle. Deeper still the clavipectoral fascia and the structures that pierce it lie in front of the artery. The communication between medial and lateral pectoral nerves crosses in front of the first part.

ii. The posterior relations are the first two digitations of the serratus anterior muscle, with medial cord of brachial plexus and the long thoracic nerve.

iii. Laterally it is related to lateral and posterior cords of brachial plexus and the lateral pectoral nerve.

iv. Medially it is related to axillary vein.

Relations of Second Part

i. The anterior relations (from superficial to deep) are the skin, superficial fascia, the pectoral fascia and the clavicular head of pectoralis major. Deeper to this, the second part is crossed by the pectoralis minor muscle (covered with clavipectoral fascia).

ii. Posteriorly, the artery is related to the subscapularis muscle and the posterior cord of the brachial plexus.

iii. Lateral relations are the coracobrachialis, short head of biceps brachii and the lateral cord of brachial plexus.

iv. The medial relations are the medial cord of brachial plexus and medial pectoral nerve, beyond which lies the axillary vein.

Relations of Third Part

i. The anterior relations proximally, are the skin, superficial fascia, deep fascia and pectoralis major muscle. Distally, this part of the artery is covered with skin and fasciae only. The medial root of the median nerve crosses the third part anteriorly.

ii. The immediate posterior relations are the axillary and radial nerves. The muscles in posterior relations are the subscapularis and the tendons of teres major and latissimus dorsi.

iii. Laterally, the immediate relations are the median and the musculocutaneous nerves, beyond which lies the axillary vein.

Fig. 12.8: Extent and parts of axillary artery

Fig. 12.9: Relations of various parts of axillary artery
(LC) Lateral cord; (PC) Posterior cord; (MC) Medial cord; (MN) Median nerve; (MCN) Musculocutaneous nerve; (AN) Axillary nerve; (RN) Radial nerve; (UN) Ulnar nerve; (MCNF) Medial cutaneous nerve of forearm; (MCNA) Medial cutaneous nerve of arm
are located coracobrachialis and short head of biceps brachii.

iv. Medially, the medial cutaneous nerve of forearm and the ulnar nerve lie between the axillary artery and the axillary vein.

**Branches (Fig. 12.8)**
The first part of the axillary artery gives origin to superior thoracic artery, the second part to thoracoacromial and lateral thoracic arteries and the third part to the subscapular, anterior and posterior circumflex humeral arteries.

i. The superior thoracic artery supplies the upper two intercostal spaces anteriorly.

ii. The thoracoacromial artery pierces the clavipectoral fascia and then divides into clavicular, deltoid, pectoral and acromial branches, which diverge from each other.

iii. The lateral thoracic artery takes a larger share in the supply of lateral part of the breast and the axilla.

iv. The subscapular artery, the largest branch, courses downwards along the posterior wall of the axilla lying on subscapularis muscle. The circumflex scapular artery, a branch of the subscapular artery, passes through the triangular space at the lateral border of scapula (Fig. 9.8). The terminal part of the subscapular artery, which accompanies the thoracodorsal nerve, is called thoracodorsal artery.

v. The anterior circumflex humeral artery travels on the anterior aspect of the surgical neck of the humerus and supplies mainly the shoulder joint and deltoid muscle.

vi. The posterior circumflex humeral artery and the axillary nerve pass behind the surgical neck of humerus after passing through the quadrangular space. This artery supplies the deltoid muscle and shoulder joint.

**Scapular Anastomosis (Fig. 12.10)**
The scapular anastomosis brings in to communication the first part of subclavian artery with the third part of axillary artery. Thus it acts as a collateral channel in case the subclavian artery or axillary artery is blocked anywhere between the first part of subclavian artery and third part of axillary artery.

The following branches from the first part of subclavian artery and of the third part of axillary artery take part in the anastomosis:

i. The suprascapular artery, a branch of thyrocervical trunk of the first part of the subclavian artery supplies the costal and dorsal surfaces of scapula after it enters the supraspinous fossa.

![Fig. 12.10: Scapular anastomosis on anterior aspect of right scapula. Arrows indicate direction of blood flow in case of block in third part of axillary artery proximal to origin of its subscapular branch](image-url)
ii. Either the deep transverse cervical artery (a branch of the thyrocervical trunk of the first part of the subclavian artery) or the dorsal scapular artery (a branch of third part of subclavian artery) supplies branches to the scapula.

iii. The circumflex scapular branch of subscapular artery (from the third part of the axillary artery) reaches the dorsal surface of scapula by winding round the lateral margin of scapula. Free anastomoses between these branches ensures adequate circulation to the upper limb. In case of a block in the subclavian or axillary artery the anastomoses enlarge to a considerable extent. This may give rise to ‘pulsating scapula’.

Axillary Vein
The axillary vein extends from the lower margin of teres major to outer margin of the first rib (where it continues as the subclavian vein).

Formation
There are two ways of formation of axillary vein.

i. It is formed by the union of basilic vein and the venae comitantes accompanying the brachial artery (brachial veins) at the lower margin of teres major muscle.

ii. It is the continuation of basilic vein at the lower margin of teres major and the brachial veins open in to the axillary vein at the lower margin of the subscapularis.

Course
The axillary vein lies medial to the axillary artery throughout its course. It is related on the medial side to medial cutaneous nerve of arm and on lateral side to the medial cutaneous nerve of forearm and ulnar nerve in its initial course (Fig. 12.9)

Tributaries
i. The cephalic vein from the upper limb is its largest tributary.

Axillary Vein Thrombosis
i. Thrombosis in the terminal segment of the axillary vein at the apex of axilla may occur due to traction, as seen in people, who have to keep the arm hyperabducted for long stretches of time (for example during plastering or painting the ceiling).

ii. The apical, central and lateral groups of axillary lymph nodes are very closely related to the axillary vein (Fig.10.4). These nodes are removed during mastectomy. If the axillary vein is injured during removal of the nodes postoperative thrombosis may occur. This leads to venous stasis causing edema of the upper limb and dilatation of superficial veins of the pectoral region and upper limb.
The superficial muscles on the back of thorax are disposed in two layers. The outer layer is composed of two flat muscles—trapezius and latissimus dorsi. The inner layer consists of muscles attached to the medial border of scapula and to dorsal surface of scapula.

**Trapezius (Fig. 13.1)**

Each trapezius muscle is triangular in shape. The muscles of the two sides lie side by side in the midline along their linear attachment to the vertebral column and together form an outline of a diamond or a trapezoid. The trapezius is the only muscle that suspends the pectoral girdle from the cranium.

**Origin**

The trapezius has a wide origin from the medial-third of superior nuchal line, external occipital protuberance, ligamentum nuchae, spine of seventh cervical vertebra and the supraspinous ligaments and spines of all thoracic vertebrae.

**Insertion**

i. Upper fibers pass downwards and laterally to insert into the posterior aspect of lateral-third of clavicle.

ii. Middle fibers pass horizontally to the medial aspect of acromion and crest of the spine of scapula.

![Fig. 13.1: Two superficial muscles of back on right side, trapezius above and latissimus dorsi below enclosing triangle of auscultation (Note the muscles arising from medial margin of scapula and dorsal scapular nerve deep to trapezius on the left side)](image-url)
iii. Lower fibers pass upwards and laterally for attachment to a well-marked tubercle on the crest of spine of scapula nearer to the base of spine.

**Actions**

i. The upper fibers elevate the scapula along with levator scapulae (as in shrugging implying ‘I dont know’).
ii. The middle fibers cause retraction of scapula along with rhomboids (thus moving it towards the median plane). When a person clasps the hands behind the lower back as in ‘stand at ease position’
iii. The upper and lower fibers of trapezius in conjunction with lower five digitations of serratus anterior bring about lateral or forward rotation of scapula.
iv. The cervical fibers of trapezius of both sides act together to extend the neck.

**Nerve Supply**
The spinal part of accessory nerve gives motor supply and the C3 and C4 ventral rami are proprioceptive.

**Testing Function of Trapezius**
The subject is asked to raise shoulders towards the ears and simultaneously the examiner depresses the shoulders forcibly.

**Latissimus Dorsi (Fig. 13.1)**

This is a large and flat muscle and is the only muscle that connects the pelvic girdle and the vertebral column to the upper limb. This muscle is part of the posterior axillary fold.

**Origin**
The latissimus dorsi has a wide origin from the lower six thoracic spines and the intervening supraspinous ligaments, the spines of lumbar and sacral vertebrae (through the posterior lamina of thoracolumbar fascia) outer lip of the posterior part of iliac crest, the lower three or four ribs and by a few slips from the inferior angle of scapula.

**Insertion**
The muscle winds round the teres major muscle in the posterior wall of axilla, where it gives rise to a narrow flat tendon. The tendon of latissimus dorsi is inserted into the floor of the intertubercular sulcus of humerus.

**Nerve Supply**
It is supplied by thoracodorsal nerve, which accompanies the thoracodorsal artery (continuation of subscapular artery beyond the origin of circumflex scapular artery) to enter the latissimus dorsi at the neurovascular hilum.

**Actions**

i. The latissimus dorsi brings about adduction and medial rotation of the arm.
ii. It is responsible for extension of arm along with teres major and posterior fibers of deltoïd.
iii. It elevates the trunk as in climbing (Fig. 13.2) by extending the flexed arms to the side against resistance. This action is performed along with pectoralis major muscle.
iv. The muscle is active in coughing and sneezing, which are the expiratory processes.
  (Note: The latissimus dorsi is called ‘swimmer’s muscle’ as it is used in back stroke swimming and is active in persons who use crutches)

**Testing Function of Latissimus Dorsi**
When the subject is asked to adduct the arm abducted to 90 degree against resistance, the muscle can be felt in the posterior axillary fold. An alternative method is to ask the subject to cough and then feel the contraction of latissimus dorsi.

**Triangles Related to Latissimus Dorsi**

i. The **triangle of auscultation** is present near the inferior angle of scapula (for boundaries of the triangle refer to chapter 9). The apical segment of the lower lobe of

![Fig. 13.2: Combined action of latissimus dorsi and pectoralis major muscles in climbing on a tree](image)
the lung is auscultated here after the patient folds the arms in front of the chest and flexes the trunk in order to expand the triangle.

ii. The triangle of Petit or lumbar triangle is related to the lower part of latissimus dorsi. It is bounded by the iliac crest, the free posterior margin of external oblique muscle and anterior margin of latissimus dorsi muscle. The hernia passing through this triangle is called lumbar hernia.

Muscles Taking Origin from Medial Border of Scapula (Fig. 13.1)

i. The levator scapulae takes origin from the transverse processes of the upper four cervical vertebrae and is inserted into the medial border of scapula opposite to the supraspinous fossa.

ii. The rhomboideus minor takes origin from the lower part of ligamentum nuchae and the spines of seventh cervical and the first thoracic vertebrae. It is inserted into the medial border of scapula opposite to the root of the spine.

iii. The rhomboideus major takes origin from the spines of second to fifth thoracic vertebrae and the intervening supraspinous ligaments. It is inserted into the medial border of the scapula opposite to the infraspinous fossa.

Nerve Supply

The above three muscles receive branches from the dorsal scapular nerve (C5). Additionally, the levator scapulae receives twigs from C3 and C4 ventral rami in the posterior triangle of neck.

Actions

i. The levator scapulae and rhomboid muscles stabilize the scapula during shoulder movements and transmit the body weight to the vertebral column especially during lifting of heavy weight.

ii. The levator scapulae elevates the scapula along with upper fibers of trapezius.

iii. The rhomboid muscles along with middle fibers of trapezius retract the scapula.

iv. All the three muscles help in reverse or medial rotation of scapula.

Dorsal Scapular Nerve (Nerve to rhomboid)

This nerve takes origin from the C5 root of brachial plexus in the neck. It is a purely motor nerve. In its cervical course, the nerve passes through the scalenus media muscle and comes to lie on the anterior aspect of the levator scapulae muscle in the posterior triangle. Here the deep branch of the transverse cervical artery (or the dorsal scapular artery) joins it. The neurovascular bundle thus formed descends in the back along the anterior surface of the levator scapulae muscle and the rhomboids. It supplies levator scapulae, rhomboid major and minor muscles.

Deltoid Muscle (Fig. 13.3)

The deltoid muscle is triangular in shape. It surrounds the shoulder joint on all sides except inferomedially and is responsible for the rounded contour to the shoulder.

Origin

i. The anterior fibers take origin from the lateral-third of the anterior aspect of the clavicle

ii. The middle or acromial fibers arise from the lateral margin of the acromion. Only the acromial fibers are multipennate.

iii. The posterior fibers arise from the lower margin of the crest of scapular spine.

Insertion

The deltoid is inserted into a V-shaped deltoid tuberosity of the lateral surface of humeral shaft.

Nerve Supply

The axillary nerve supplies the deltoid muscle.
Actions
i. The anterior fibers cause flexion and medial rotation of arm.
ii. The acromial (middle) fibers cause abduction of arm from 15 to 90°.
iii. The posterior fibers cause extension and lateral rotation of arm.

Testing Function of Deltoid
The subject is asked to hold the arm abducted and hold it in abducted position against resistance. Contracted muscle can be seen and felt.

Clinical insight ...

Effect of Paralysis
There is loss of rounded contour of shoulder due to wasting of deltoid and there is loss of ability to abduct the arm beyond 15 to 20°.

Teres Minor
The teres minor is a narrow muscle that takes origin from the upper two-thirds of the dorsal surface of lateral border of scapula by two sets of fibers. The circumflex scapular artery enters the infraspinous fossa through the two sets of fibers (Fig.13.4). The teres minor is inserted into the lower facet on the greater tubercle of humerus.

Nerve Supply
The axillary nerve supplies the teres minor via a branch that has pseudoganglion on it.

Actions
The teres minor is a lateral rotator of arm.

Teres Major
The teres major muscle takes origin from the dorsal surface of lateral border of scapula below the teres minor. The fibers pass upwards and laterally onto the anterior surface of humerus for insertion into the medial lip of the intertubercular sulcus of humerus, just below the insertion of subscapularis muscle.

Nerve Supply
The lower subscapular nerve supplies teres major muscle.

Actions
The teres major brings about adduction, medial rotation and extension of the arm.

Clinical insight ...

Supraspinatus
The supraspinatus takes origin from the supraspinous fossa of scapula and is inserted into the upper facet of the greater tubercle of the humerus. It is transversely disposed from origin to insertion.

Infraspinatus
The infraspinatus takes origin from infraspinous fossa of scapula and is inserted below the supraspinatus on greater tubercle.

Actions
i. The action of supraspinatus is to initiate the abduction of the shoulder joint.
ii. The infraspinatus is the lateral rotator of arm.

Nerve Supply
Both supraspinatus and infraspinatus receive branches from suprascapular nerve.

Testing Function of Supraspinatus
The subject is asked to initiate abduction of the arm from the side against resistance.

Testing Function of Infraspinatus
The subject keeps the flexed elbow by the side of the trunk. Then the forearm is turned backwards against resistance (this is to test the lateral rotation of arm).

Features of Supraspinatus
i. It is fused with the tendons of infraspinatus, teres minor and subscapularis muscles (SITS muscles) to form rotator cuff around the shoulder joint.
ii. The supraspinatus tendon is separated from the coracoacromial arch by the subacromial bursa. At the end of abduction, the greater tuberosity of humerus and the attached supraspinatus tendon (along with subacromial bursa) slide under the acromion.

Clinical insight ...

i. The tendon of supraspinatus shows degenerative changes from the age of forty and above. Hence, rupture, inflammation and calcium deposits in the tendon are very common. Supraspinatus tendinitis (with or without subacromial bursitis), calcification and rupture are some of the causes of supraspinatus syndrome. This presents with painful arc of abduction, which is characterized by painless abduction up to 60°, painful abstraction from 60° to 120° and painless beyond this.
Subscapularis
The subscapularis (Fig. 16.3) is a bulky multipennate muscle that fills the subscapular fossa. It takes origin from the medial two-thirds of subscapular fossa (anterior or costal surface of scapula). It is inserted into the lesser tubercle of humerus by a wide tendon that lies immediately anterior to the capsule of shoulder joint. A subscapular bursa is in communication with the cavity of the shoulder joint. Since the muscle is part of the posterior wall of the axilla, its anterior surface is related to the posterior cord of brachial plexus and its branches, axillary artery and the subscapular artery.

Nerve Supply
The upper and lower subscapular nerves supply the muscle.

Actions
i. Along with supraspinatus, infraspinatus and teres minor muscles, the subscapularis forms the rotator cuff around the shoulder joint to reinforce the capsule.
ii. The subscapularis is a medial rotator of the humerus when the arm is at the side.

Intermuscular Spaces (Fig. 13.4)
Three intermuscular spaces (one quadrangular and two triangular) are located under cover of the deltoid muscle in the shoulder region.

Boundaries of Quadrangular Space (from anterior side)
1. Superiorly by subscapularis
2. Inferiorly by teres major
3. Laterally by surgical neck of humerus
4. Medially by long head of triceps brachii

Boundaries of Quadrangular Space (from posterior side)
1. Superiorly by teres minor
2. Inferiorly by teres major
3. Laterally by surgical neck of humerus
4. Medially by long head of triceps brachii

Contents of Quadrangular Space
1. Axillary nerve
2. Posterior circumflex humeral vessels
3. The sagging part of shoulder joint capsule

Boundaries of Upper Triangular Space
1. Superiorly by inferior margin of teres minor
2. Inferiorly by superior margin of teres major
3. The apex (on lateral margin of the scapula) by meeting point of teres major and minor
4. The base by long head of triceps brachii

Contents
The circumflex scapular artery, is the only content (Fig. 13.4).

Boundaries of Lower Triangular Space
1. Superiorly by inferior margin of teres major muscle
2. Medially by the long head of triceps
3. Laterally by shaft of the humerus.

Contents
The radial nerve and profunda brachii vessels pass through this space to reach the spiral groove.
Axillary Nerve

The axillary nerve (C5, C6) is also known as circumflex nerve. It is a mixed nerve containing both sensory and motor fibers. It is a branch of the posterior cord of brachial plexus.

Relations in Axilla

The axillary nerve is located posterior to the third part of axillary artery and anterior to the subscapularis muscle. The radial nerve lies on its medial side.

On reaching the lower border of subscapularis, the nerve passes backwards into the quadrangular space along with posterior circumflex humeral vessels.

Relations in Quadrangular Space

The axillary nerve is related to the boundaries of the quadrangular space, teres minor (posteriorly) and subscapularis (anteriorly) above, teres major below, long head of triceps brachii medially and surgical neck of humerus laterally. It is closely related to the inferomedial part of the fibrous capsule of the shoulder joint.

Distribution (Fig. 13.5)

i. The trunk of axillary nerve gives off an articular twig to the shoulder joint and divides into anterior and posterior branches.

ii. The anterior branch and posterior circumflex humeral vessels wind round the posterior aspect of surgical neck of the humerus to reach the anterior border of the deltoid muscle. Along its course, the anterior branch gives motor branches to deltoid and a few cutaneous branches through the deltoid to the skin over the lower part of the deltoid.

iii. The posterior branch gives a twig to teres minor, which bears a connective tissue swelling called pseudoganglion. After supplying the posterior part of deltoid, the posterior branch continues as the upper lateral cutaneous nerve of the arm, which supplies a patch of skin over the insertion of the deltoid extending up to its lower half.

Since, the axillary nerve gives articular branch to the shoulder joint, supplies the muscles, which act on the joint and supplies the skin in the vicinity of the joint, it is said to obey Hilton’s law.

Clinical insight ...

Lesion of Axillary Nerve

The axillary nerve is liable to injury in fracture of the surgical neck of humerus or in anterior dislocation of humeral head.

Motor Effects

The weakness of deltoid causes inability to abduct the arm. The wasting of deltoid causes loss of rounded contour of the shoulder. The paralysis of teres minor results in weak lateral rotation of arm.

Sensory Loss

There is sensory loss on outer aspect of lower half of deltoid, which is known as regimental badge anesthesia (Fig. 13.6).

Note: A patient with dislocation of shoulder joint, experiences pain on movements of the joint. In order to test the integrity of the axillary nerve in such a patient the abduction cannot be tested. Therefore, sensory loss on the lower half of deltoid is the sign to observe.

Suprascapular Nerve

This nerve arises from the upper trunk (Erb’s point) of the brachial plexus in the posterior triangle of the neck. Its root value is C5, C6.

Cervical Course

The suprascapular nerve runs downwards and laterally posterior and parallel to inferior belly of omohyoid muscle. It leaves the posterior triangle by passing deep to the trapezius. The suprascapular artery, a branch of thyrocervical trunk from the first part of subclavian artery, accompanies the nerve to the scapular region.

Course in Scapular Region (Fig. 9.8)

The suprascapular nerve and vessels reach suprascapular notch of the superior margin of scapula. The suprascapular nerve enters the supraspinous fossa by passing through the foramen formed by the suprascapular notch and the transverse scapular ligament. However, the suprascapular artery passes over the ligament. After supplying the supraspinatus, the nerve passes through the spinoglenoid notch to enter the infraspinous fossa. One interesting feature is
that the spinoglenoid ligament (inferior transverse scapular ligament) bridges the spinoglenoid notch creating a tunnel for the nerve and artery.

**Distribution**

i. Just proximal to suprascapular notch, articular branches are given off to acromioclavicular joint.

ii. Muscular branches to supraspinatus arise in supraspinous fossa.

iii. Articular branches for shoulder joint arise in spinoglenoid notch.

iv. The suprascapular nerve terminates in a handful of motor branches in the infraspinous fossa for the supply of infraspinatus muscle.

**Clinical insight ...**

i. In Erb’s palsy the suprascapular nerve is injured at its origin. The supraspinatus and infraspinatus muscles are paralyzed with resultant loss of initiation of abduction of shoulder joint and weakness of lateral rotation of arm respectively.

ii. Suprascapular nerve entrapment occurs usually in repetitive overuse of arm in overhead abduction as in the case of baseball, volleyball and tennis players besides weight lifters and newsreel cameramen. The suprascapular nerve is liable for entrapment at suprascapular notch and spinoglenoid notch of scapula. If compressed at suprascapular notch both supraspinatus and infraspinatus are weakened. If compressed at spinoglenoid notch only infraspinatus is affected (described as infraspinatus syndrome). The signs of infraspinatus syndrome are atrophy of infraspinatus muscle and difficulty in lateral rotation of arm. The symptom is dull aching pain in shoulder. The infraspinatus syndrome is so common in volleyball players that it is called volleyball shoulder.
The pectoral or shoulder girdle consists of two bones, clavicle and scapula. The clavicle articulates with the axial skeleton by the sternoclavicular joint, which is the only link between the upper limb and the trunk. It articulates with the scapula at the acromioclavicular joint. The pectoral girdle is suspended from the cranium and cervical vertebrae by the trapezius muscle.

**Special Features**

The scapula is a highly mobile bone due to its unique relationship to the posterior thoracic wall. The subscapularis and serratus anterior muscles occupy the interval between the costal surface of scapula and the thoracic wall. There is a loose packing of areolar tissue between serratus anterior and chest wall as well as between the serratus anterior and subscapularis. This unit between the scapula and thoracic wall can be imagined as a scapulothoracic joint. Due to the presence of this pseudo-joint, the scapula slides over the thoracic wall easily. The scapula is supported by the clavicle and reinforced dynamically by the muscles, which insert in to it from the axial skeleton (serratus anterior, trapezius, rhomboideus and levator scapulae). The high mobility of the scapula is responsible for the high mobility of the shoulder joint.

**Girdle Joints (Fig. 14.1)**

There are two joints in the pectoral girdle, sternoclavicular and acromioclavicular joints, where movements of scapula take place.

**Sternoclavicular Joint**

This is a saddle type of synovial joint. The articular disc completely divides the joint cavity.
Articulating Ends
The sternal end of the clavicle and the clavicular notch on the manubrium sterni and the first costal cartilage are the articulating ends.

Ligaments
i. The anterior and posterior sternoclavicular ligaments reinforce the fibrous capsule.
ii. The interclavicular ligament passing through the suprasternal space connects the medial ends of the two clavicles.
iii. The costoclavicular ligament is a powerful ligament that passes from first costochondral junction to the inferior surface of medial end of clavicle. It acts as a fulcrum during the movements of the scapula and prevents dislocation of the joint.

Posterior Relations
The joint is posteriorly related to brachiocephalic veins and trachea on both sides and the brachiocephalic artery (on the right side). These structures are in danger of injury if the joint is dislocated posteriorly.

Acromioclavicular Joint
This is a plane synovial joint. The joint is divided by incomplete articular disc projecting inside from the upper part of the capsule.

Articulating Ends
The acromial end of the clavicle and the medial border of the acromion are the articulating ends.

Ligaments
i. The fibrous capsule covers the joint and is strengthened superiorly by the acromioclavicular ligament.
ii. The coracoclavicular ligament is the main bond between clavicle and scapula. It is a very powerful ligament as it transmits the weight of the upper limb to the medial two-third of the clavicle. Its two parts are conoid and trapezoid. The conoid part is attached above to conoid tubercle of clavicle and below to the root of coracoid process. The trapezoid part is attached above to the trapezoid line of clavicle and below to the upper surface of coracoid process.

The acromioclavicular joint is prone to dislocation or shoulder separation, in which the fibrous capsule and the coracoclavicular ligament are torn. The scapula falls away from the clavicle and weight transmission to the axial skeleton becomes impossible.

Movements of Scapula (Fig. 14.2)
The girdle joints allow free sliding of the scapula on the thoracic wall.

i. The elevation and depression of scapula take place around an anteroposterior axis passing through costoclavicular ligament.

ii. The protraction and retraction of scapula take place around a vertical axis passing through costoclavicular ligament.

iii. Lateral or forward and medial or return rotation of scapula takes place around an axis passing through acromioclavicular joint.

Elevation and Depression
When the lateral end of the clavicle is elevated, the scapula is also elevated along with it and the medial end of the clavicle is depressed. When the lateral end of the clavicle is depressed, the scapula is also depressed.

Muscles Producing Elevation and Depression
i. The elevation of scapula (shrugging movement) is caused by contraction of the upper fibers of trapezius and the levator scapulae.
ii. The depression of the scapula is produced by contraction of pectoralis minor along with lower fibers of trapezius.

**Protraction and Retraction**

During the protraction and retraction, the lateral end of clavicle moves forwards or backwards respectively, along with the scapula. Protraction is the movement used in punching, pushing and reaching forwards.

**Muscles Producing Protraction and Retraction**

i. The protraction of scapula is produced due to combined action of serratus anterior and pectoralis minor muscles.

ii. The retraction of scapula is produced due to combined action of middle fibers of trapezius and rhomboids.

**Rotation of Scapula**

The scapula shows forward or lateral rotation and medial or return rotation. In lateral rotation, as the clavicle rotates upwards along its longitudinal axis, the scapula also rotates so that its acromion is lifted upwards and medially and the inferior angle is turned forwards and laterally. The net effect is on the glenoid cavity, which faces upwards. The forward or lateral rotation of the scapula is an integral part of abduction of shoulder joint above 90°.

**Muscles Producing Rotation**

i. The forward rotation of scapula is produced by the lower five digitations of the serratus anterior along with upper and lower fibers of trapezius.

ii. The medial or return rotation of scapula is due to the action of the muscles attached to the medial border of scapula assisted by gravity. Laterally, the fibrous capsule is attached to the anatomical neck of the humerus except inferomedially, where the capsular attachment shifts one cm or more on the humeral shaft. This is the dependent part of the capsule.

iii. Medially the capsule is attached to the margin of glenoid cavity outside the glenoid labrum. Since, the capsule is attached to the root of the coracoid process, the supraglenoid tubercle of the scapula becomes intracapsular.

iv. The incongruity of articulating surfaces and the laxity of the capsule confer great mobility to the shoulder joint but at the expense of stability. Therefore, the capsule is reinforced with the help of ligaments and tendons of the rotator cuff muscles.

v. There are two constant apertures in the fibrous capsule. The aperture for the long head of the biceps brachii is located on the anteroinferior aspect. The aperture of the subscapular bursa is located on the anterior aspect.

**SHOULDER JOINT**

The shoulder joint or the glenohumeral joint is a multiaxial synovial joint of ball and socket type, between the head of humerus and the glenoid cavity of scapula. The arm can be moved freely in all directions at the shoulder joint.

**Articular Surfaces (Fig. 14.3)**

The large hemispherical head of the humerus articulates with the smaller and shallower glenoid cavity of scapula. Both articular surfaces are covered with articular cartilage. The scapular articular surface is slightly deepened by glenoid labrum, which is a fibrocartilaginous rim attached to the margins of the glenoid cavity. Due to marked disproportion in the sizes of the two articular surfaces only a small part of the head of the humerus comes in contact with the glenoid cavity in any one position of the joint.

**Fibrous Capsule (Fig. 14.4)**

The fibrous capsule envelops the joint on all sides. The capsule is very lax.

i. Laterally, the fibrous capsule is attached to the anatomical neck of the humerus except inferomedially, where the capsular attachment shifts one cm or more on the humeral shaft. This is the dependent part of the capsule.

ii. Medially, the capsule is attached to the margin of glenoid cavity outside the glenoid labrum. Since, the capsule is attached to the root of the coracoid process, the supraglenoid tubercle of the scapula becomes intracapsular.
iii. The incongruity of articulating surfaces and the laxity of the capsule confer great mobility to the shoulder joint but at the expense of stability. Therefore, the capsule is reinforced with the help of ligaments and tendons of the rotator cuff muscles.

iv. There are two constant apertures in the fibrous capsule. The aperture for the long head of the biceps brachii is located on the anteroinferior aspect. The aperture of the subscapular bursa is located on the anterior aspect.

**Glenohumeral Ligaments**

The superior, middle and inferior glenohumeral ligaments are the localized thickenings of the anterior aspect of the capsule.

i. The superior glenohumeral ligament passes from the base of the coracoid process and adjacent glenoid labrum to the upper part of the anatomical neck.

ii. The middle glenohumeral ligament extends from the anterior margin of the glenoid cavity to the lesser tubercle deep to the insertion of subscapularis.

iii. The inferior glenohumeral ligament extends from the anterior and posterior margins of the glenoid cavity to the inferomedial part of the anatomical neck. In traumatic anterior dislocation, the inferior glenohumeral ligament is stretched or its attachment to glenoid labrum is torn. This is known as Bankart lesion, which predisposes to recurrent dislocation of shoulder joint.

**Other Small Ligaments**

i. The coracohumeral ligament extends from the base of coracoid process to the upper surface of greater tubercle of humerus.

ii. The transverse humeral ligament bridges the gap between the greater and lesser tubercles, thus converting the intertubercular sulcus into a canal for the passage of the tendon of long head of the biceps brachii.

**Synovial Membrane**

The synovial membrane lines the fibrous capsule internally and covers the intracapsular part of the anatomical neck of humerus. The intracapsular part of the long tendon of biceps brachii is enveloped in a tubular synovial sheath, which is carried outside the joint through the intertubercular sulcus up to the level of the surgical neck of humerus. The synovial sheath also protrudes through an opening in the anterior part of the capsule to communicate with the subscapular bursa.

**Bursae (Fig. 14.5)**

i. The subscapular bursa is the only communicating bursa, which is always present. Its opening in the joint is located between middle and superior glenohumeral ligaments.

ii. The infraspinatus bursa may occasionally open into the joint.

iii. The subacromial (sub-deltoid) bursa is located between the supraspinatus tendon below and the coracoacromial arch and deltoid muscle above. It is a noncommunicating bursa. It is the largest bursa in the body. This large bursa acts as a secondary socket for humeral head during hyperabduction, when the bursa shifts its position under the acromion. Inflammation of this bursa (subacromial bursitis) causes pain, when pressure is applied just below the acromion.

iv. The supra-acromial bursa lies above the acromion.

v. The subcoracoid bursa is below the coracoid process.

vi. A bursa may be present deep to coracobrachialis tendon.

vii. Occasionally, a bursa is present between teres major and long head of triceps brachii.

**Relations (Fig. 14.5)**

The muscles wrap the shoulder joint snugly on almost all sides. Both communicating and noncommunicating bursae are located close to the joint. These bursae are necessary to facilitate frictionless movements of various musculoskeletal structures around the joint.

The massive deltoid muscle covers the joint anteriorly, superiorly, posteriorly and laterally.

i. Superiorly, the coracoacromial arch covers the joint. The subacromial bursa lies below the arch and the adjoining deltoid muscle. It separates the coracoacromial arch from the underlying supraspinatus tendon.
ii. Posteriorly, the joint is related to the infraspinatus and teres minor muscles.

iii. Immediately anterior to the joint there is the subscapularis tendon. The coracoid process and the origin of conjoint tendon of coracobrachialis and short head of biceps brachii are located in front of the subscapularis.

iv. Inferiorly, the capsule is closely related to the axillary nerve and posterior circumflex humeral vessels in the quadrangular space. The long head of triceps offers the only support for the capsule inferiorly. Hence, the head of humerus is more prone to subglenoid and subcoracoid dislocation.

**Stability**

i. The musculotendinous rotator cuff provides dynamic stability as its component muscles undergo tonic contractions. The rotator cuff is composed of the tendons of supraspinatus above, infraspinatus and teres minor behind and subscapularis in front. The cuff blends with the fibrous capsule. The infero-medial part of the capsule sags down in the quadrangular space, when the arm hangs by the side. This part is the weakest and is maximally stretched during abduction. Rotator cuff syndrome is due to the complete or partial rupture of one or more tendons (usually supraspinatus) of the rotator cuff.

ii. The coracoacromial arch provides a secondary socket for the joint superiorly. The arch is composed of the tip of the acromion, coracoacromial ligament and the lateral surface of coracoid process. The subacromial bursa intervenes between the arch and the tendon of supraspinatus. The movements of the upper end of humerus in abduction of the arm are smoothed by the presence of this bursa. The coracoacromial arch prevents the upward dislocation of shoulder joint during abduction.

**Blood Supply**

The articular branches of the anterior and posterior circumflex humeral, suprascapular and circumflex scapular arteries supply the joint.

**Nerve Supply**

The articular branches of the suprascapular, axillary and lateral pectoral nerves supply the joint.

**Movements**

The shoulder joint is multiaxial, hence movements take place along three mutually perpendicular mechanical axes (Table 14.1).

i. In flexion the arm crosses the front of the chest.

ii. In extension the arm moves backwards and laterally.

iii. In adduction the arm is by the side of the body.

iv. In abduction the arm moves away from the side of the body in lateral and forward direction.
Circumduction is a succession of flexion-extension and abduction-adduction in an order. The rotation of humerus is best seen in flexed elbow. In medial rotation, the hand is carried medially whereas in lateral rotation, the hand is carried laterally.

**Stages in Movement of Abduction (Fig. 14.6)**

In abduction movement, the arm is carried away from the trunk laterally till it comes in horizontal position at right angles to the trunk. The abduction is further continued to raise the arm to a vertical position above the head so that the arm moves a total of 180°.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Muscles responsible for movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Flexion</td>
<td>Clavicular head of pectoralis major, anterior fibers of deltoid and coracobrachialis</td>
</tr>
<tr>
<td>2. Extension</td>
<td>Posterior fibers of deltoid, teres major and latissimus dorsi</td>
</tr>
<tr>
<td>3. Abduction</td>
<td>Supraspinatus and deltoid</td>
</tr>
<tr>
<td>4. Adduction</td>
<td>Pectoralis major, latissimus dorsi and teres major</td>
</tr>
<tr>
<td>5. Medial rotation</td>
<td>Pectoralis major, teres major, latissimus dorsi and subscapularis</td>
</tr>
<tr>
<td>6. Lateral rotation</td>
<td>Infraspinatus, teres minor and posterior fibers of deltoid</td>
</tr>
</tbody>
</table>

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**Clinical insight ...**

i. The painful arc syndrome is also known as impingement syndrome. The condition occurs usually in elderly, who complain of pain in the shoulder (aggravated on attempting certain activities like putting on a jacket). This condition is characterized by midabduction pain. The abduction movement up to 60° is painless. Further abduction up to 120° is acutely painful while beyond it is painless. The pain in mid abduction is due to impingement of the swollen supraspinatus tendon (due to chronic tendonitis) or of the inflamed subacromial bursa under the coracoacromial arch.

ii. The anterior or subglenoid dislocation of head of humerus is common in volleyball players, swimmers and badminton players. When the arm is forcefully abducted and laterally rotated the head is driven through the inferior weak part of capsule and dislocated anterior to the infraglenoid tubercle. This causes intense pain. The axillary nerve is in great danger of injury. The radiograph confirms the dislocation of the head (Fig. 14.7).

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![Fig. 14.6: Movement of abduction of arm at shoulder joint and of hyperabduction at girdle joints](image1)

![Fig. 14.7: Radiograph showing anterior dislocation of head of humerus](image2)
iii. Aspiration of fluid from the joint cavity is done by introducing the needle either anteriorly through the deltopectoral groove lateral to the tip of coracoid process or from lateral aspect between the acromion and greater tubercle of humerus.

iv. The steps in the anterior or deltopectoral approach to the shoulder joint (Fig. 14.8) are easy to follow with the help of the diagram of the relations of the joint. The skin incision is placed along the anterior margin of the deltoid muscle to expose the deltopectoral groove, in which the cephalic vein is isolated. The pectoralis major and deltoid muscles are retracted from each other to expose the coracoid process and the conjoint tendon (pectoralis minor and short head of biceps brachii) attached to its tip. The conjoint tendon is divided about two centimeter below the coracoid process to expose the subscapularis tendon, which is cut to reach the capsule of the shoulder joint.
The upper limb is a segmented lever. It consists of upper arm (arm), elbow, forearm, wrist, hand and digits. It consists of groups of muscles, nerves and blood vessels enclosed within fascial compartments. The deep fascia and the intermuscular septa help in defining the boundaries of the fascial compartments. The superficial fascia contains the cutaneous nerves and the superficial veins.

**Cutaneous Nerves**

There are three sources from which cutaneous nerves originate.

i. Supraclavicular nerves (medial, intermediate and lateral) from the cervical plexus

ii. Intercostobrachial nerve (lateral cutaneous branch of the second intercostal nerve)

iii. Direct cutaneous nerves from brachial plexus and cutaneous nerves from branches of brachial plexus.

**Cutaneous Nerves of Arm**

i. The lateral supraclavicular nerve (C4) supplies the tip of shoulder and the skin overlying the upper part of the deltoid.

ii. The intercostobrachial nerve (T2) gives branches to the skin of the floor of axilla and the upper part of the medial side of arm.

iii. The upper lateral cutaneous nerve of arm (C5, C6), a branch of axillary nerve, supplies the skin overlying the lower half of deltoid.

iv. The lower lateral cutaneous nerve of arm (C5, C6), a branch of radial nerve in spiral groove, supplies the skin on the lateral side of arm below the insertion of deltoid.

v. The posterior cutaneous nerve of arm (C5), branch of radial nerve in the axilla, supplies the skin of the back of arm from the insertion of deltoid to the olecranon.

vi. The medial cutaneous nerve of arm (T1) is a branch of medial cord of brachial plexus. It pierces the deep fascia at the middle of the medial side of arm to supply the skin on the lower half of arm.

**Cutaneous Nerves of Forearm**

i. The posterior cutaneous nerve of forearm (C6, C7, C8), a branch of the radial nerve in the spiral groove, supplies the skin of the lateral side of arm. It travels in the superficial fascia of the middle of the back of the forearm.

ii. The lateral cutaneous nerve of forearm (C5, C6) is the continuation of musculocutaneous nerve. It supplies the skin covering the anterolateral and posterolateral surfaces of the forearm (extending up to the ball of thumb).

iii. The medial cutaneous nerve of forearm (C8, T1) is a branch of medial cord of brachial plexus. It pierces the deep fascia with the basilic vein at the level of insertion of coracobrachialis and supplies the skin of the anteromedial and posteromedial surfaces of the forearm.

**Cutaneous Nerves of Hand**

i. The superficial branch of radial nerve (C6, C7, C8) is one of the terminal branches of radial nerve. It supplies the lateral two-thirds of the dorsum of the hand and dorsal aspects of thumb and of first and part of second phalanges of lateral two and half fingers through five dorsal digital nerves. There is considerable variation in the area of supply of the radial nerve on the dorsum of hand and digits.
ii. The palmar cutaneous and palmar digital branches of median nerve (C6, C7, C8) supply the skin of the palm and the palmar aspect of lateral three and half fingers including the skin on the dorsal aspect of the terminal phalanges of the corresponding fingers.

iii. The dorsal and palmar cutaneous branches of ulnar nerve (C7, C8, T1) supply the medial side of the hand and the medial one and half fingers on both aspects.

From the areas of the cutaneous supply of various nerves, it is evident that the radial nerve supplies the maximum area. However, it is observed that, the areas of sensory loss due to injury to the individual nerve do not coincide with the areas of their cutaneous supply. The reason for this discrepancy is that the cutaneous nerves supplying adjacent areas of skin overlap to a considerable extent. To cite an example, if the radial nerve is injured in the axilla or in the spiral groove, the area of sensory loss is confined to a small area on the dorsum of hand between the thumb and index finger.

Dermatomes

A dermatome is an area of skin supplied by a single spinal segment through its dorsal root. (Table 15.1)

i. In the case of the trunk, the dermatomes extend from the posterior to anterior median lines of the trunk. There is a marked overlap in adjacent dermatomes so that injury to a single spinal nerve produces very little sensory loss in the corresponding dermatome.

ii. In the case of the upper limb, the innervation is through the brachial plexus. So a limb dermatome can be defined as an area of skin supplied by the ventral ramus of a single spinal nerve through the branches of the plexuses. There is marked overlap in the adjacent dermatomes because of the presence of fibers of more than one ventral ramus in different branches of the brachial plexus.

<table>
<thead>
<tr>
<th>Spinal Segment</th>
<th>Dermatomal Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5</td>
<td>Lateral aspect of arm</td>
</tr>
<tr>
<td>C6</td>
<td>Lateral aspect of forearm &amp; thumb</td>
</tr>
<tr>
<td>C7</td>
<td>Middle three fingers</td>
</tr>
<tr>
<td>C8</td>
<td>Little finger &amp; medial side of hand</td>
</tr>
<tr>
<td>T1</td>
<td>Medial aspect of forearm &amp; of lower part of arm</td>
</tr>
<tr>
<td>T2</td>
<td>Medial aspect of upper part of arm &amp; floor of axilla</td>
</tr>
</tbody>
</table>

**Clinical insight ...**

Damage to the cutaneous nerves results in sensory loss in the skin (inability to feel the exteroceptive sensations like touch, pain and temperature). A dermatomal sensory loss results if the dorsal roots of a spinal nerve are damaged. The neurological examination of the patient with nerve root lesion is incomplete without a thorough examination of dermatomes and areas.

**Dermatomes of Upper Limb (Fig. 15.1)**

The dermatomes of the upper limb can be understood better if we know the development of the limb. In the embryo, the upper limb bud carries within it the ventral rami from C5 to T1 segments of the spinal cord. Each limb bud has ventral and dorsal surfaces and preaxial (cranial) and postaxial (caudal) borders. The upper limb bud undergoes lateral rotation as a result of which the preaxial or cranial border becomes the lateral border and postaxial or caudal border becomes the medial border of the limb. Consequently the thumb becomes the preaxial digit and little finger the postaxial digit. The proximal two dermatomes (C5 and C6) are arranged in numerical sequence along the preaxial border up to the preaxial digit. Similarly distal two dermatomes (C8 and T1) are arranged along the postaxial border from the little finger upwards. The middle dermatome (C7) is present only in the hand and it includes the middle three digits. The C4 dermatome overlies the shoulder and T2 dermatome covers the base of axilla. Thus, the dermatomes are arranged in such a way that the discontinuous dermatomes come to lie side by side on the surfaces of the limbs along the ventral and dorsal axial lines.

Contd...
Veins of Upper Limb

The upper limb has two sets of veins, superficial or subcutaneous and deep.

i. The superficial veins are located in the superficial fascia and being easily accessible, are often used for drawing blood sample or for giving intravenous injection.

ii. The deep veins are located deep to deep fascia and they accompany the arteries as venae comitantes.

Superficial Veins (Fig. 15.2)

There are two major superficial or subcutaneous veins in upper limb:

i. Cephalic vein
ii. Basilic vein

These veins begin at the dorsal venous network. Other named veins like median cubital vein and the median vein of the forearm are the tributaries of these major veins.

Dorsal Venous Network (Fig. 15.3)

The dorsal venous network or arch is located in the superficial fascia on the dorsum of the hand. The dorsal digital veins draining the adjacent sides of the four fingers unite to form three dorsal metacarpal veins, which form the dorsal venous network.

Formation of Cephalic Vein

The cephalic vein is formed by the union of dorsal digital vein from the radial side of the index finger and the veins from either side of the thumb with the lateral end of dorsal venous arch.

Extent

The cephalic vein extends from the lateral end of the dorsal venous network to its termination into the axillary vein in the axilla.

Course

i. At the wrist, it lies in the roof of anatomical snuffbox, where it is posterior to the styloid process of radius.

ii. In the forearm, it ascends along the posterolateral side and then turns anteriorly to reach the lateral part of cubital fossa. In this location, the cephalic vein is closely related to lateral cutaneous nerve of forearm.

iii. In the arm, cephalic vein ascends along the lateral side of biceps brachii. At the upper part of the arm (at the level of lower margin of pectoralis major muscle) the...
cephalic vein pierces the deep fascia and enters the deltopectoral groove, where it is related to the deltoid branch of the thoracoacromial artery and the deltopectoral lymph nodes.

iv. At the deltopectoral groove or triangle, the vein takes a sharp turn backwards to pierce the clavipectoral fascia and enters the axilla to terminate in to the axillary vein.

Tributaries
i. A large number of tributaries, which collect blood from the hand, forearm and arm open into the cephalic vein.

ii. The median cubital vein is large and named as tributary. It passes in the superficial fascia of the cubital fossa, upwards and medially from the cephalic vein to the basilic vein (the blood flows from the cephalic to the basilic vein). This venous pattern in front of the elbow resembles the letter H. There may be M pattern of veins, in which the median forearm vein bifurcates just distal to the cubital fossa, one limb passing to the basilic vein and the other to cephalic vein. The median cubital vein rests on the platform provided by the bicipital aponeurosis, which separates it from brachial artery and the median nerve. The deep median vein arising from the deep aspect of the median cubital vein pierces the bicipital aponeurosis and joins the veins accompanying the brachial artery.

iii. Occasionally, a small communicating vein, which crosses the clavicle superficially, may join the terminal part of the cephalic vein to the external jugular vein.

Formation of Basilic Vein
The basilic vein is formed by the union of dorsal digital vein of the ulnar side of the little finger with the medial end of the dorsal venous arch.

Extent
The basilic vein extends from the medial end of the dorsal venous network at the wrist to the lower margin of teres major muscle. It is shorter than cephalic vein.

Course
i. The basilic vein ascends on the medial side of posterior surface of the forearm

ii. Just below the elbow, it moves to the anterior surface of the forearm and courses on the medial part of the front of elbow to enter the arm. The medial cutaneous nerve of the forearm is closely related to it in front of the elbow.

iii. The epitrochlear (supratrochlear) or superficial cubital lymph nodes lie by the side of basilic vein just above the elbow.

iv. In the arm, the basilic vein runs along the medial margin of biceps muscle and at the mid-arm level it pierces the deep fascia of the arm to enter the anterior compartment, where it lies medial to the brachial artery.

Termination
At the lower border of teres major, the basilic vein unites with the brachial veins (venae comitantes of the brachial artery) to form the axillary vein. However, since the basilic vein is more in line with the axillary vein it is observed that basilic vein continues as axillary vein at the lower margin of teres major in some cases. In such cases, the brachial veins open into the axillary vein.

Tributaries
i. The basilic vein collects blood from the medial aspect of hand, forearm and arm by numerous tributaries.

ii. The median cubital vein is its large tributary.

iii. It may receive median forearm vein in cases where the latter does not join the median cubital vein.

Median Vein of Forearm
This vein on the front of the forearm is also called antebrachial vein. It drains the superficial palmar plexus and travels in the superficial fascia of the front of forearm upward to open into the median cubital vein or the basilic vein.

Clinical insight ...

i. For routine purposes like drawing blood sample for laboratory investigations or for giving intravenous medicines or glucose or for blood transfusion the preferred sites for vein puncture are the median cubital vein (Fig. 15.4) in front of the elbow, median vein of forearm and the cephalic vein behind styloid process of radius.

ii. The cephalic vein cut-down at deltopectoral groove is preferred, when superior vena caval infusion is necessary.

iii. The basilic vein is preferred for inserting a cardiac catheter to reach the right side of the heart. To enter the right atrium the catheter passes in succession through the following veins, the basilic, axillary, subclavian, brachiocephalic and finally the superior vena cava. The sharp curve at cephalo axillary junction and presence of valves at this junction are the factors against preferring cephalic vein for this purpose.
Lymphatic Drainage of Upper Limb

The lymphatic vessels are disposed as two groups, superficial and deep.

Superficial Lymph Vessels (Fig. 15.7)

The superficial lymph vessels from the lateral side of the limb and lateral two digits follow the cephalic vein whereas those of the medial side of the limb and medial three digits follow the basilic vein. Some of the medial
vessels terminate in the supratrochlear or epitrochlear lymph nodes, which are situated just above the medial epicondyle. These nodes are palpated in a patient, when enlarged (Fig. 15.8).

Termination of Superficial Lymphatics
i. The lateral group of axillary nodes receive majority of the superficial lymphatics of the upper limb
ii. The deltopectoral nodes receive a few lymphatics that travel along the cephalic vein (draining the thumb and lateral side of upper limb). The lymphatics from deltopectoral nodes pierce the clavipectoral fascia to terminate into the apical group.
iii. A few superficial vessels pierce the clavipectoral fascia to enter directly into the apical group.

Deep Lymph Vessels
The deep lymph vessels travel along the arteries. They drain into the lateral group of axillary lymph nodes.

Clinical insight ...

i. Lymphadenopathy is enlargement of lymph nodes. The infections affecting the medial side of hand and forearm may cause painful enlargement of the supratrochlear lymph nodes at first. The lateral axillary nodes are enlarged and painful in infection of any part of the upper limb.
ii. Lymphedema of upper limb is due to blockage to lymph flow from the upper limb. This gives rise to swelling of the upper limb. A commonly encountered cause is postmastectomy edema due to removal of axillary nodes (Fig. 15.9). Other common cause in tropical countries is obstruction of lymph vessels by filarial microorganisms (Wuchereria Bancrofti) causing elephantiasis.
COMPARTMENTS OF ARM

The arm is the part of the free upper limb. It extends between the shoulder and the elbow. The deep fascia of the arm surrounds it on all sides like a sleeve. The lateral and medial intermuscular septa extend from the deep fascia to the humerus to divide the arm into anterior and posterior compartments (Fig. 16.1). The septa are attached to the margins of supracondylar ridges of the humerus. The ulnar nerve and superior ulnar collateral artery pierce the medial intermuscular septum to enter the posterior compartment of arm. The radial nerve and radial collateral artery pierce the lateral intermuscular septum to enter anterior compartment of arm.

Contents of Anterior Compartment

i. The anterior compartment contains coracobrachialis, brachialis and biceps brachii muscles. In addition, the brachioradialis and extensor carpi radialis longus take origin here.

ii. The musculocutaneous nerve is the nerve of the anterior compartment as it supplies the three main muscles mentioned above. The median nerve passes through the entire extent. The ulnar nerve travels in the upper half medially and the radial nerve travels in the lower half laterally. The medial cutaneous nerves of arm and of forearm travel in the compartment until they pierce the deep fascia of the arm.

iii. The brachial artery and the brachial veins (venae comitantes) are present throughout whereas the basilic vein enters the compartment by piercing the deep fascia at the level of insertion of coracobrachialis.

Coracobrachialis (Fig. 16.2)

The coracobrachialis muscle takes origin from the tip of coracoid process of scapula along with short head of biceps brachii by a conjoint tendon. It is inserted into the middle of medial border of humerus.

Nerve Supply

The coracobrachialis is pierced by musculocutaneous nerve, which supplies it.

Action

The coracobrachialis is a weak flexor of the arm.
Chapter 16

Biceps Brachii
This muscle is a supinator of forearm. It is described in Chapter 19 along with muscles of supination.

Brachialis
The brachialis muscle arises from the lower half of the anteromedial and anterolateral surfaces of the humerus. It passes through the floor of cubital fossa to reach its insertion on the anterior surface of the coronoid process of ulna.

Nerve Supply
The brachialis has dual nerve supply. The musculocutaneous nerve provides motor branches whereas the radial nerve gives proprioceptive (sensory) fibers.

Action
It is the chief flexor of elbow joint. It flexes the elbow joint in any position of the forearm.

Testing Function
The subject is asked to flex the elbow against resistance in any position of the forearm.

Brachial Artery (Fig. 16.3)
The brachial artery begins at the level of lower border of teres major muscle as the continuation of axillary artery. It terminates at the level of the neck of radius in the cubital fossa by dividing into radial and ulnar arteries. Variations in the brachial artery like high division into two or three branches or its absence (when axillary artery itself divides into radial and ulnar arteries) are common.

Relations in Arm
The brachial artery is accompanied by venae comitantes (also called brachial veins), which are connected by transverse channels.

Fig. 16.2: Three muscles of anterior compartment and the musculocutaneous nerve that supplies them

Fig. 16.3: Extent of brachial artery and elbow anastomosis

Fig. 16.4: Median nerve crossing the brachial artery from lateral to medial side
i. Anteriorly, the brachial artery is easily accessible because only the skin and fasciae cover it. At midarm level, the median nerve crosses anterior to the brachial artery from lateral to medial side (Fig. 16.4).

ii. Posteriorly from above downwards, the brachial artery rests on the long head of triceps, medial head of triceps, coracobrachialis and brachialis muscles. The level of insertion of coracobrachialis is the best place to apply pressure by squeezing the artery against the shaft of the humerus (Fig. 16.5). This is necessary if severe hemorrhage takes place from any artery distal to the brachial artery and direct pressure on the bleeding artery fails to stop the hemorrhage (for example in bleeding wounds of the palmar arches).

iii. Laterally, the proximal part of brachial artery is related to the median nerve (before it crosses the artery) and corachobrachialis muscle whereas its distal part is in relation to biceps brachii muscle.

iv. Medially, its proximal part is in relation to the ulnar nerve, medial cutaneous nerve of forearm and the basilic vein whereas its distal part is related to median nerve.

Relations in Cubital Fossa
i. Laterally—Biceps tendon
ii. Medially—Median nerve
iii. Posteriorly—Brachialis muscle
iv. Anteriorly—Bicipital aponeurosis (which separates it from median cubital vein)

Recording Blood Pressure (Figs 16.6A and B)
While taking blood pressure, the cuff of the sphygmomanometer is tied around the arm and is inflated (to compress brachial artery) until the radial pulse disappears. Then the diaphragm of stethoscope is placed on the brachial artery in the cubital fossa and the cuff is gradually deflated until the sound is heard. The reading on the manometer at this point is the systolic pressure. On further deflating, the sound muffles (disappears). The reading at this point is the diastolic pressure.

Brachial Pulse (Fig. 16.7)
The brachial pulse is felt medial to the tendon of biceps in the cubital fossa.

Branches of Brachial Artery (Fig. 16.8)
i. Profunda brachii is the largest and the first branch to arise from the posteromedial aspect of brachial artery just below its beginning. It immediately leaves along with the radial nerve through the lower triangular space to enter the spiral groove on the posterior surface of humerus.

ii. Nutrient artery to the humerus enters the nutrient foramen located near the insertion of coracobrachialis.
It is directed downwards towards the non-growing end of the humerus.

iii. Superior ulnar collateral artery follows the ulnar nerve into the posterior compartment.

iv. Inferior ulnar collateral artery (also known as supratrochlear artery) divides into anterior and posterior branches.

v. Muscular branches supply the muscles in the anterior compartment.

Surface Marking
The brachial artery corresponds to the lower two-third of the line connecting the midclavicular point to the point 1cm below the midpoint of the inter-epicondylar line of humerus (position of arm being abducted to 90 degrees with palm facing upwards).

Clinical insight ...

i. The lack of blood supply to flexor muscles of forearm (due to compression or spasm of brachial artery) leads to necrosis and muscle contracture. In supracondylar fracture of the humerus, the anteriorly displaced upper bony fragment compresses the brachial artery (Fig. 17.7C). This results in inadequate blood supply to the flexor muscles. Initially this gives rise to pallor, pain, puffiness, pulselessness and paralysis. Further reduction in blood supply results in necrosis and fibrosis of the muscles leading to Volkmann’s ischemic contracture, in which there is flexion contracture of the metacarpophalangeal and interphalangeal joints.

ii. Brachial artery aneurysm (Fig. 16.9) is a rare condition. If present, it causes symptoms of vascular insufficiency in the forearm and hand.

iii. The brachial artery is sometimes anastomozed with cephalic vein in the cubital fossa to create an A-V fistula. The brachial artery can also be anastomozed with basilic vein in the arm to create A-V fistula in the arm.

Musculocutaneous Nerve
The musculocutaneous nerve (C5, C6, C7) is the nerve of the anterior compartment of arm.

Course

i. It arises in the axilla as a branch of the lateral cord of the brachial plexus. It leaves the axilla by piercing the coracobrachialis muscle and enter the front of the arm.

ii. It courses down lying between the biceps brachii and brachialis muscles and comes out of the muscular plane laterally. In the lower part of arm it passes in front of the elbow, where it pierces the deep fascia and continues down as the lateral cutaneous nerve of forearm.
Distribution

i. The musculocutaneous nerve supplies the coracobrachialis, biceps brachii, and brachialis muscles.

ii. The lateral cutaneous nerve of forearm supplies the skin along the lateral side of the forearm as low down as the ball of the thumb.

Clinical insight ...

Injury to musculocutaneous nerve though rare, produces inability to flex and supinate the forearm strongly. There is loss of biceps tendon reflex and loss of sensation along the lateral aspect of forearm.

Median Nerve in Arm

The median nerve is formed in the axilla. It enters the arm at the level of the lower margin of the teres major muscle. In its initial course, it is in lateral relation of the brachial artery. The median nerve crosses in front of the brachial artery at the level of insertion of coracobrachialis. Below this level, it travels downwards to the front of the elbow in medial relation to the artery. The median nerve gives vascular branches to the brachial artery and may supply muscular branch to the pronator teres muscle just above the elbow.

Ulnar Nerve in Arm

The ulnar nerve arises in the axilla. After entering the arm, it is in medial relation to the brachial artery till the midshaft level where it pierces the medial intermuscular septum and leaves the anterior compartment (along with superior ulnar collateral branch of brachial artery) to enter the posterior compartment. Here, it descends to reach the back of medial epicondyle. It leaves the arm between the humeral and ulnar heads of flexor carpi ulnaris.

Contents of Posterior Compartment

The triceps brachii is the only muscle in the posterior compartment of arm. In addition, the compartment contains the radial nerve and profunda brachii vessels in the spiral groove and the ulnar nerve in the lower half medially.

Triceps Brachii Muscle

The triceps brachii originates by three heads:

1. The long head takes origin from infraglenoid tubercle of scapula.

2. The lateral head arises from a linear oblique ridge on the posterior surface of the shaft of humerus above the level of spiral groove.

3. The medial head has an extensive origin from the posterior surface of the shaft of humerus below the level of spiral groove. Also,

i. The nerve to anconeus and middle collateral artery pass downwards in the substance of the medial head.

ii. The long, lateral and medial head of triceps brachii unite to form a common tendon.

iii. The common tendon is inserted into the olecranon process of ulna.

iv. A few fibers of the medial head of triceps (which are given separate name as articularis genu or subanconeus) are inserted into the fibrous capsule of the elbow joint.

Actions

i. The triceps brachii is the main extensor of the elbow joint.

ii. The long head provides support to the inferior part of the shoulder joint.

Testing Function

The subject is asked to extend the elbow against resistance.

Nerve Supply

Each head of the triceps receive a separate twig from the radial nerve as follows:

i. The long head receives a branch in the axilla.

ii. Before entering the spiral groove, the radial nerve gives off ulnar collateral nerve that supplies the medial head.

iii. The branches for the medial and lateral heads arise in the spiral groove.

It is to be noted that the medial head receives two separate branches at two levels.

Spiral or Radial Groove (Fig. 16.10)

The spiral groove is present on the back of the shaft of the humerus.

Boundaries

i. Anteriorly by the middle-third of the posterior surface of the shaft of the humerus.

ii. Posteriorly by the lateral head of triceps.

iii. Superiorly by the origin of lateral head.

iv. Inferiorly by the origin of medial head of triceps brachii.
Contents

i. Radial nerve
ii. Profunda brachii vessels.

Profunda Brachii Artery (Fig. 16.8)
The profunda brachii artery is the first and the large branch of the brachial artery. It arises immediately below the lower border of teres major muscle. It enters the spiral groove through the lower triangular space along with the radial nerve and terminates by dividing into middle collateral and radial collateral arteries at the lower end of the spiral groove.

Branches

i. Muscular branches to triceps brachii muscle
ii. Nutrient branch to the humerus.
iii. Deltoid branch ascends to anastomose with a branch of posterior circumflex humeral artery.
iv. Middle collateral artery (posterior descending) descends through the substance of medial head of triceps and takes part in elbow anastomosis behind the lateral epicondyle.
v. The radial collateral artery (anterior descending) pierces the lateral intermuscular septum along with radial nerve to enter the anterior compartment of arm.

Radial Nerve (Fig. 16.10)

i. The radial nerve arises in the axilla.
ii. In the arm, it is in posterior relation to the initial part of the brachial artery. It soon leaves the medial part of the arm accompanying profunda brachii artery to enter the spiral groove at the back of the humerus.
iii. While in the spiral groove (in direct contact with the bone), it lies between the lateral and medial heads of triceps. At the lower end of the spiral groove, it pierces the lateral intermuscular septum along with radial collateral artery to enter the anterior compartment of arm.
iv. In the lower part of anterior compartment, the radial nerve is placed between the brachialis medially and brachioradialis and extensor carpi radialis longus muscles laterally. The radial nerve passes in front of the lateral epicondyle under cover of brachioradialis to enter the cubital fossa.

Branches in Arm

1. In the spiral groove, the radial nerve gives following branches:
   i. Lower lateral cutaneous nerve of arm
   ii. Posterior cutaneous nerve of forearm
   iii. Muscular branch to the lateral head of triceps
   iv. Muscular branch to medial head of triceps
   v. Muscular branch to anconeus through the substance of medial head.

2. In the lower lateral part of anterior compartment, the radial nerve gives following branches.
   i. Muscular branch to brachioradialis
   ii. Muscular branch to extensor carpi radialis longus
   iii. Proprioceptive fibers to brachialis.

Fig. 16.10: Distribution of radial nerve in spiral groove

Fig. 16.11: Wrist drop deformity in the patient showing swelling in posterior aspect of arm (due to pathology of radial nerve)
Clinical insight ...

Effects of Lesion in Spiral Groove
The common causes of injury are fracture of humeral shaft, inadvertent intramuscular injection in the triceps muscle and compression of radial nerve while a drunken person hangs the upper limb from bed or chair during deep sleep (Saturday night palsy).

i. Wrist drop (Fig. 16.11) deformity is the one in which wrist assumes flexed position due to paralysis of all the extensors of wrist, namely, extensor carpi radialis longus, extensor carpi radialis brevis and extensor carpi ulnaris muscles. These muscles are supplied by branches distal to its course in spiral groove.

ii. Finger drop (fingers in flexed position at metacarpophalangeal joints due to paralysis of extensor digitorum muscle)

iii. Thumb drop (due to paralysis of extensor pollicis longus and extensor pollicis brevis).

iv. Sensory loss on the dorsum of hand at the first interosseous space.

Clinical insight ...

Surgical Exposure of Radial Nerve
The radial nerve is surgically exposed at spiral groove by dividing the lateral head of triceps as shown in the intraoperative photograph (Fig. 16.12) in a patient who had pathology of radial nerve at spiral groove.
CUBITAL FOSSA

The cubital fossa is a triangular intermuscular space seen as a shallow surface depression in front of the elbow.

Boundaries (Fig. 17.1)

i. The base of the cubital fossa is the imaginary line passing through the medial and lateral epicondyles of humerus.
ii. The medial boundary is formed by the lateral margin of pronator teres muscle.
iii. The lateral boundary is formed by medial margin of brachioradialis muscle.
iv. The apex is located at the crossing of pronator teres and brachioradialis muscles.
v. The floor consists of brachialis in the upper part and supinator in the lower part.
vi. The roof consists of skin, superficial fascia and deep fascia, which is strengthened by the bicipital aponeurosis. The latter is crossed superficially by median cubital vein. The bicipital aponeurosis provides a firm platform to steady this vein during venipuncture (Fig. 17.2) and to protect the underlying brachial artery and median nerve.

Contents (Fig. 17.3)

i. The three main contents from lateral-to-medial side are the tendon of biceps brachii, brachial artery and median nerve (TAN).
ii. The radial nerve is present in the superolateral part of the fossa under cover of brachioradialis.

Exit of Neurovascular Contents

The brachial artery divides into its terminal branches (radial and ulnar) at the level of neck of radius.

i. The radial artery leaves the cubital fossa through its apex to enter the front of forearm.
It gives one branch called radial recurrent that takes part in elbow anastomosis.

ii. The ulnar artery leaves the cubital fossa deep to the deep (ulnar) head of pronator teres. It gives off...
following important branches in the cubital fossa. There are two branches that take part in elbow anastomosis, anterior ulnar recurrent and posterior ulnar recurrent. The common interosseous artery is another very important branch which divides into anterior and posterior interosseous arteries. The interosseous recurrent branch (taking part in elbow anastomosis) arises from posterior interosseous artery.

iii. The median nerve gives medially directed muscular branches to pronator teres, flexor carpi radialis, palmaris longus and flexor digitorum superficialis muscles. It leaves the fossa between the ulnar (deep) and humeral (superficial) heads of pronator teres.

iv. The radial nerve is located in the superolateral part of the fossa under cover of the brachioradialis muscle. At the level of lateral epicondyle, it divides into superficial and deep branches. The deep branch gives a muscular twig to extensor carpi radialis brevis and supinator before entering the substance of supinator muscle (the deep branch is also described as posterior interosseous nerve). The superficial branch of radial nerve passes downwards under cover of the brachioradialis to enter the front of forearm.

**Anastomosis around Elbow (Fig. 16.3)**

The articular branches of following four arteries (brachial, profunda brachii, ulnar and radial) take part in this anastomosis.

i. The articular branches of brachial and profunda brachii arteries are given off in the arm and are referred to as collateral arteries.

ii. The articular branches of radial and ulnar arteries are given off in cubital fossa and are referred to as recurrent arteries.

The collateral and recurrent arteries anastomose with each other in front and behind the epicondyles of the humerus as follows:

**Anterior Anastomosis Medially**

i. Anterior branch of inferior ulnar collateral (branch of brachial artery)

ii. Anterior ulnar recurrent (branch of ulnar artery)

**Posterior Anastomosis Medially**

i. Superior ulnar collateral (branch of brachial artery)

ii. Posterior ulnar recurrent (branch of ulnar artery)

**Anterior Anastomosis Laterally**

i. Radial collateral (branch of profunda brachii artery)

ii. Radial recurrent (branch of radial artery)

**Posterior Anastomosis Laterally**

i. Middle collateral (branch of profunda brachii artery)

ii. Interosseous recurrent (branch of posterior interosseous artery)

**Functional Importance**

This arterial anastomosis ensures the normal circulation to forearm and hand when the elbow is flexed and the brachial artery is compressed temporarily.

**ELBOW JOINT**

The elbow joint is a hinge variety of synovial joint permitting movements of flexion and extension around a transverse
Articulating Bones (Figs 17.4 and 17.5)

The lower end of humerus presents laterally placed capitulum and medially placed trochlea (pulley like in shape). Both are covered with articular cartilage.

i. The capitulum articulates with the disc-shaped head of the radius to form humeroradial articulation.

ii. The trochlea articulates with the trochlear notch of the ulna (formed by articular areas of coronoid and olecranon processes) to form humeroulnar articulation. Thus, elbow joint consists of two articulations.

Articular Surfaces

i. The articular surfaces of the humeroradial articulation are reciprocally curved. The closest contact between the head of radius and capitulum of humerus occurs in semiflexed and midprone position of the forearm.

ii. The articular surfaces of humeroulnar articulation are not reciprocally congruent because the trochlea of the humerus is not a simple uniform pulley as its medial flange projects downwards for a longer distance than its lateral counterpart. Moreover, the trochlea is widest posteriorly, where its lateral edge is sharp. This is the reason why the humerus and ulna are not in the same plane in extended and supinated position of forearm.

The angulation between the arm and forearm is called carrying angle. On the contrary, in pronated position of extended forearm they are in the same plane. This is for functional needs of human hand, as extended and semi prone forearm and hand are essential for optimum precision.

Fibrous Capsule (Figs 17.4A and B)

Being a hinge joint, the articular capsule is lax and thin anteriorly and posteriorly but strengthened by collateral ligaments on either side.
Upper Attachment

i. Anteriorly, it is attached to the margins of articular surfaces covering capitulum and trochlea and to the margins of radial and coronoid fossae.

ii. Posteriorly, it is attached to the lateral trochlear margin and to the edge of olecranon fossa.

Lower Attachment

i. Anteriorly, it is attached to the edges of coronoid process of the ulna and to the front of the annular ligament of radius.

ii. Posteriorly, it is attached to the superior and lateral margin of olecranon process and to the back of annular ligament.

Intra-articular Fossae

At the lower end of the humerus there are three fat filled intra-articular fossae.

i. The coronoid fossa lies above the trochlea on the anterior aspect.

ii. The radial fossa lies above the capitulum on the anterior aspect. During flexion of elbow, coronoid and radial fossae are occupied with upper border of coronoid process and head of radius, respectively.

iii. The olecranon fossa lies on posterior aspect. During extension of elbow, the tip of the olecranon process occupies the olecranon fossa.

Synovial Membrane

It lines the fibrous capsule and all the intraarticular parts of the joint, which are not covered with articular cartilage. The fat pads in the fossae are intracapsular but extrasynovial. The synovial membrane projects under the annular ligament to surround the neck of the radius. Thus the elbow and superior radioulnar joints share a common synovial sheath.

Collateral Ligaments (Figs 17.6A and B)

i. The ulnar collateral ligament is triangular in shape. It extends from medial epicondyle of humerus to the upper end of ulna. It consists of three parts, anterior, posterior and oblique (inferior). These parts share a common upper attachment to the medial epicondyle. However, their lower attachments are separate. The anterior thick band is attached to the medial border of the coronoid process. The posterior band is attached to the medial border of olecranon process. The oblique band stretches between coronoid and olecranon processes connecting the lower ends of the anterior and posterior bands. The ligament gives origin to few fibers of flexor carpi ulnaris. The ulnar nerve lies in contact with the medial surface of this ligament.

ii. The radial collateral ligament extends from lateral epicondyle of humerus to the lateral part of annular ligament surrounding the head of radius. Some of its posterior fibers cross the annular ligament to get attached to upper end of supinator crest of ulna.

Relations of Joint

i. The anterior relations are the structures in the cubital fossa, namely, brachialis, biceps tendon, median nerve and brachial artery.

ii. Posteriorly, the joint is related to insertion of the triceps brachii with olecranon bursa between the tendon and joint capsule.

iii. Medially, the ulnar nerve is closely related to the posterior aspect of medial epicondyle and to the ulnar collateral ligament. In addition, it is related to the common origin of superficial flexor muscles of forearm.

iv. The common origin of the extensor muscles from the anterior aspect of the lateral epicondyle is related to the joint laterally.

Arterial Supply

The arterial anastomosis around the elbow provides twigs to the joint.

Nerve Supply

The articular branches are given from the radial nerve (through its branch to anconeus), musculocutaneous nerve (through a branch to brachialis), ulnar nerve and median nerve.
Movements

i. Flexion is produced by brachialis, biceps brachii and brachioradialis muscles. The biceps brachii flexes the elbow in the supinated position of forearm and the brachioradialis in the midprone position.

ii. Extension is produced by triceps brachii and anconeus assisted by gravity.

Clinical insight ...

i. At the back of the elbow there are three palpable bony points (Figs 17.7A and B) namely, medial epicondyle of humerus, lateral epicondyle of humerus and the tip of olecranon process of ulna. In the extended elbow, these points lie in a straight horizontal line. In flexed elbow, they form an equilateral triangle. These bony points are examined to differentiate posterior dislocation of the elbow joint and the supracondylar fracture of humerus. In posterior dislocation (Fig. 17.8), the olecranon process moves backwards from the lower end of humerus resulting in loss of the normal shape of the triangle. In supracondylar fracture, the normal bony relation is retained (since the olecranon shifts backward along with lower end of humerus). The brachial artery is in danger of compression by the proximal fragment in supracondylar fracture of humerus as this fragment is displaced forwards as shown in Figure 17.7C.

ii. Pulled elbow is the condition in which the radial head escapes downward from the annular ligament. Children are more prone to pulled elbow (nursemaid’s elbow) because the shape of annular ligament is tubular and the head of radius is not fully developed.

iii. Tennis elbow is due to inflammation of the radial collateral ligament and of the periosteum around its attachment to the lateral epicondyle.

iv. Golfer’s elbow is due to inflammation at the site of common flexor origin from the anterior surface of medial epicondyle.

v. Students elbow is due to inflammation of the subcutaneous olecranon bursa, caused by friction between the overlying skin and the hard surface of the desk.

vi. In acute synovitis of the elbow joint, the swelling is more conspicuous around the olecranon.

vii. The carrying angle is the angulation between the long axis of arm and forearm, when the forearm is extended and supinated. The angle obliterates in pronated and extended forearm because in this position the human hand has optimum functional capacity. It also obliterates in flexed forearm. The carrying angle facilitates the movements of the forearm in relation to the hip and thigh. It is present mainly because the medial flange of trochlea of humerus projects downward 6mm longer than the lateral flange.

Contd...

Fig. 17.8: Radiograph of a dislocated elbow joint (as indicated by arrow)
In cubitus valgus deformity, the forearm is deviated laterally more than normal due to increase in the carrying angle. The cubitus valgus may gradually stretch the ulnar nerve behind the medial epicondyle leading to a clinical condition called tardy ulnar palsy.

In cubitus varus deformity, the forearm is deviated medially due to reduction in the carrying angle as a consequence of which the ulnar side of the forearm touches the thigh.

There are differing views regarding normal value of carrying angle. If one defines carrying angle as angle of deviation of forearm from the axis of arm then its normal value ranges from 10 to 15° (slightly more in female). If one defines the carrying angle as the angulation (which is open laterally) between the long axis of the arm and that of the forearm then the normal value ranges from 160 to 170°.
The forearm extends from the elbow to the wrist. Like the arm, it is enclosed in a sleeve of deep fascia. The two bones (radius and ulna) of the forearm and the intervening interosseous membrane divide the forearm into flexor compartment anteriorly and the extensor compartment posteriorly.

Anterior Compartment (Fig. 18.1) of Forearm
This compartment contains muscles, vessels and nerves. The muscles are arranged in three strata.

Superficial Group
The muscles in this group have common origin from anterior aspect of medial epicondyle and they consist of pronator teres, flexor carpi radialis, palmaris longus and flexor carpi ulnaris.

Intermediate Group
This group consists of only the flexor digitorum superficialis (arising from common origin of medial epicondyle).

Deep Group
This group has three muscles consisting of flexor pollicis longus, flexor digitorum profundus and pronator quadratus.

Pronator Teres
The pronator teres muscle is described in Chapter 19.

Flexor Carpi Radialis
i. The flexor carpi radialis muscle has a common origin from the anterior aspect of the medial epicondyle of humerus.
ii. The muscle belly ends in a tendon about halfway down the middle of forearm.

Fig. 18.1: Superficial muscles in the anterior compartment of forearm (Note that at wrist, the radial artery is lateral to the tendon of flexor carpi radialis)
iii. Near the wrist, its tendon is related medially to the radial artery (Fig. 18.1).
iv. The tendon passes deep to the flexor retinaculum in a separate osseofibrous canal, produced by the groove on the trapezium and the flexor retinaculum. (Note that the tendon of flexor carpi radialis is located outside the carpal tunnel)
v. It is inserted into the palmar surfaces of the bases of second and third metacarpal bones.

Nerve Supply
This muscle receives branches from the median nerve in the cubital fossa.

Actions
Acting singly, it is the flexor of wrist joint but acting synergistically with radial extensors of the carpus (extensor carpi radialis longus and brevis) it produces abduction of wrist (radial deviation).

Palmaris Longus
This muscle is not always present. It has a short belly and a long tendon.
i. The palmaris longus has a common origin from medial epicondyle of humerus. Distally, its tendon passes in front of the flexor retinaculum with which its fibers mingle and beyond this it becomes continuous with the apex of palmar aponeurosis.
ii. The median nerve lies just behind the thin palmaris longus tendon above the wrist and hence is likely to be mistaken for a tendon.
iii. The palmaris longus tendon is used as a graft in surgical repair of damaged flexor tendons in the hand.

Nerve Supply
The muscle receives nerve supply from the median nerve in the cubital fossa.

Action
It is a weak flexor of elbow joint.

Flexor Carpi Ulnaris
This muscle takes origin by two heads.
i. The humeral head arises from common flexor origin on medial epicondyle.
ii. The ulnar head arises from the medial margin of olecranon process and the upper two-thirds of the posterior margin of ulna.
iii. The ulnar nerve enters the forearm between the two heads of this muscle. The compression of ulnar nerve in this location is known as cubital tunnel syndrome.
iv. At the wrist, the tendon of flexor carpi ulnaris lies medial to the ulnar nerve (Fig. 18.1).
v. The muscle is inserted into pisiform bone, which is the sesamoid bone in its tendon. The insertion is prolonged through the pisohamate ligament to the hamate and through pisometacarpal ligament to the base of fifth metacarpal bone.

Nerve Supply
The muscle receives branches from ulnar nerve (It is the only muscle of common flexor origin not supplied by median nerve).

Actions
Acting singly, it is a flexor of wrist but acting synergistically with extensor carpi ulnaris it produces adduction of wrist (ulnar deviation).

Flexor Digitorum Superficialis (FDS)
This is a broad muscle takes origin by two heads (Fig. 18.2).
i. The humeroulnar head arises from common flexor origin, ulnar collateral ligament and medial margin of olecranon process of ulna.

Fig. 18.2: Deeper contents of anterior compartment of forearm (Note the posterior relations of radial artery from above downwards)
ii. The radial head arises from the anterior oblique line of radius.

iii. A fibrous band connects the two heads and the median nerve and ulnar artery pass underneath this band.

iv. The muscle ends into four tendons, which are bunched together, so that the tendons for middle and ring fingers lie anterior to those for index and little fingers.

v. The tendons pass deep to the flexor retinaculum within the carpal tunnel, where they are enclosed in a common synovial sheath (ulnar bursa) along with the flexor digitorum profundus tendons.

vi. On reaching the bases of proximal phalanges, each digital tendon enters the fibrous flexor sheath along with respective tendon of flexor digitorum profundus. The superficialis tendon splits into two slips, which pass posteriorly around the profundus tendon (Fig. 18.3). Behind the profundus tendon, the two slips join (Chiasma of Camper) and then insert into the palmar aspect of the sides of middle phalanx of the medial four digits.

Nerve Supply
The median nerve supplies a branch (in cubital fossa) to that part of flexor digitorum superficialis, which gives origin to the tendons for the medial three digits. It supplies the part of muscle giving origin to the tendon of index finger in the forearm.

Actions
It produces flexion of middle phalanx at the proximal interphalangeal joint.

Testing Function (Figs 18.4A and B)
The subject is asked to flex the middle phalanx of the finger (to be examined) while holding down the adjoining fingers in extension (to eliminate action of flexor digitorum profundus). If the subject is able to flex the middle phalanx, the FDS is intact.

Flexor Digitorum Profundus
i. The flexor digitorum profundus (FDP) takes origin from the anterior and medial surfaces of the upper three-fourths of the shaft of ulna, from adjacent interosseous membrane and upper three-fourths of the posterior border of ulna by an aponeurosis.

ii. About halfway down the forearm, four tendons are formed.

Fig. 18.3: Mode of insertion of flexor digitorum superficialis and profundus tendons into the phalanges

Figs 18.4A and B: Methods of testing the function of flexor digitorum superficialis and of profundus muscles
iii. The tendons pass deep to the flexor retinaculum in the carpal tunnel and are enclosed in a common synovial sheath (ulnar bursa) with the tendons of flexor digitorum superficialis.

iv. After entering the palm, the tendons diverge towards respective digits.

v. Each tendon gives origin to the lumbrical muscle.

vi. Each tendon enters the fibrous flexor sheath, where it perforates the tendon of flexor digitorum superficialis. Finally each tendon is inserted into the base of respective terminal phalanx.

**Nerve Supply**
The medial half of the muscle receives branches from the ulnar nerve and the lateral half by the anterior interosseous branch of the median nerve.

**Actions**
Its main action is to flex the terminal phalanx of the digit.

**Testing Function (Figs 18.4A and B)**
The subject is asked to flex the finger (to be examined) while holding down the proximal and middle phalanges of the same finger. If the subject can flex the terminal phalanx, the FDP is intact.

**Flexor Pollicis Longus**

i. This muscle takes origin from the anterior surface of the radius (below the anterior oblique line up to the upper attachment of pronator quadratus) and the adjacent interosseous membrane.

ii. It ends in a tendon just above the wrist.

iii. The tendon (wrapped in a separate synovial sheath called radial bursa) passes deep to the flexor retinaculum in the carpal tunnel.

iv. In the palm, it passes distally between the opponens pollicis and oblique head of adductor pollicis.

v. It enters the fibrous flexor sheath at the base of the proximal phalanx and is inserted into the base of distal phalanx of thumb.

**Nerve Supply**
The anterior interosseous branch of median nerve supplies the muscle in the forearm.

**Action**
It flexes the terminal phalanx of thumb.

**Testing Function**
The subject is asked to flex the distal phalanx of thumb against resistance, while the proximal phalanx is held stationary.

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### Clinical Conditions of Flexor Tendons

i. In traumatic injuries to the distal forearm, the cut tendons are often repaired surgically. The tendon grafting can be done using the tendon of palmaris longus muscle.

ii. Avascular necrosis of the tendon is a complication of suppurative tenosynovitis (inflammation of synovial sheath surrounding the tendon). This results due to pressure on the arteries supplying the tendons by accumulated pus. These delicate arteries reach the tendons inside the digital synovial sheath via the vincula brevia (seen near the insertion of the tendon) and vincula longa (seen closer to the base of the finger).

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### Pronator Quadratus
This muscle is described in chapter 19 along with muscles of supination and pronation.

### Superficial Branch of Radial Nerve

i. It is one of the terminal branches of the radial nerve given off in the cubital fossa under cover of brachioradialis muscle.

ii. During its downward course in the lateral part of the forearm it is placed successively on the supinator, pronator teres, radial head of flexor digitorum superficialis and flexor pollicis longus muscles.

iii. The radial nerve is in close lateral relation to the radial artery in the middle-third of its course. It leaves the radial artery about seven centimeter above the wrist, passes deep to the tendon of brachioradialis and curves round the lateral side of radius as it descends.

iv. On the dorsum of the hand, the nerve gives four to five digital branches after piercing the deep fascia.

**Distribution**
The superficial branch of the radial nerve is purely sensory. It supplies a variable area of the dorsum of hand and its digital branches supply the lateral three and half digits (excluding the nail beds). Therefore, there will be sensory loss on the dorsum of the hand if the nerve is cut in the forearm.

### Ulnar Nerve

i. The ulnar nerve enters the forearm from the back of the medial epicondyle between the humeral and ulnar heads of flexor carpi ulnaris.

ii. It descends along the medial side of forearm lying on flexor digitorum profundus and covered with flexor carpi ulnaris.
III. In the lower part of forearm, it becomes superficial, covered only by skin and fasciae. Anterior or superficial to flexor retinaculum, it is inside a fascial canal called Guyon’s canal lateral to the pisiform bone. (Note: The ulnar nerve and artery are vulnerable to injury at the superficial location at the wrist)

IV. The ulnar artery is separated from it in the upper-third of its course in forearm but in the distal two-third they form a close neurovascular unit.

V. The ulnar nerve terminates under cover of the palmaris brevis muscle into superficial and deep branches.

Surface Marking
A line joining the back of the medial epicondyle of the humerus to the pisiform bone represents the ulnar nerve in the forearm.

Branches in Forearm
- Articular branch to the elbow joint.
- Muscular branches to the flexor carpi ulnaris and medial-half of flexor digitorum profundus.
- Palmar cutaneous and dorsal cutaneous branches nearer the wrist.

Median Nerve
- The median nerve leaves the cubital fossa to enter the forearm between the humeral and ulnar heads of pronator teres muscle.
- It passes downward behind the tendinous bridge connecting the humeroulnar and radial heads of flexor digitorum superficialis and remains closely adherent to the deep surface of the same muscle.
- The median nerve and median artery (which supplies blood to median nerve and is a branch of anterior interosseous artery) form a neurovascular bundle in the middle part of forearm.
- About five centimeter proximal to the flexor retinaculum, the median nerve comes to lie anterior to the tendons of flexor digitorum superficialis. Here, it is very close to the surface being posterior to palmaris longus tendon (Fig. 18.1). It enters the carpal tunnel along with the long flexor tendons of digits.

Branches in Cubital Fossa
- Articular branches to elbow and superior radioulnar joints.
- Muscular branches to pronator teres, palmaris longus, flexor carpi radialis and flexor digitorum superficialis (FDS).

Branches in Forearm
- The anterior interosseous nerve
- A muscular branch to part of FDS giving origin to tendon of index finger.
- Palmar cutaneous branch just proximal to the flexor retinaculum (it supplies the skin of the palm overlying the thenar eminence).

Anterior Interosseous Nerve
- This nerve arises, as the median nerve leaves the cubital fossa. It soon joins company with the anterior interosseous artery and the two descend on the anterior surface of the interosseous membrane. It passes posterior to the pronator quadratus muscle to end in front of the wrist.
- The anterior interosseous nerve supplies lateral half of the flexor digitorum profundus, flexor pollicis longus and pronator quadratus muscles.
- Its articular branches supply the distal radioulnar, radiocarpal (wrist) and intercarpal joints.

Clinical insight ...

**Anterior Interosseous Nerve Syndrome**
There is paralysis of flexor pollicis longus, flexor digitorum profundus for index and middle fingers and pronator quadratus in the lesion of this nerve. There is inability to pinch the thumb and index finger together to make OK sign (Fig. 18.5A). Instead the patient will make triangular sign (Fig. 18.5B) in which the terminal phalanges of thumb and index finger are in close approximation due to inability to flex distal IP joints. The patient will have difficulty in picking up small objects (like coin, needle or grain) from the flat surface.

Radial Artery
The radial artery is one of the terminal branches of the brachial artery.

Extent in Forearm and Dorsum
It extends from the level of the neck of the radius in the cubital fossa to the proximal end of the first intermetacarpal space on the dorsum of the hand.

Exit from Dorsum
The artery enters the palm between the heads of first dorsal interosseous muscle to continue as the deep palmar arch. The course of the radial artery can be divided into three parts, in the forearm, at the wrist and in the palm.
Relations in Forearm

i. Anteriorly in the proximal part, the radial artery is related to the fleshy belly of brachioradialis and in the distal part to the skin and fasciae. Therefore, in the distal forearm.

ii. Posteriorly the radial artery is related from above downwards (Fig. 18.2) to tendon of biceps brachii, supinator, pronator teres, flexor digitorum superficialis, flexor pollicis longus, pronator quadratus and the lower end of radius.

iii. Laterally it is related proximally to the fleshy belly of brachioradialis and distally to the tendon of brachioradialis. In its middle-third-radial nerve comes in close lateral relation of the radial artery.

iv. It is related medially to pronator teres muscle proximally and to tendon of flexor carpi radialis distally (where the radial pulse is felt lateral to this tendon).

Course at Wrist

i. The radial artery takes a curve from the styloid process of radius backwards across the anatomical snuffbox.

ii. At first it passes deep to the two tendons (abductor pollicis longus and extensor pollicis brevis), which form the anterior boundary of the anatomical snuffbox.

iii. Then the artery lies on the scaphoid and the trapezium in the floor of the snuffbox where the cephalic vein is superficial to the radial artery.

iv. Lastly the artery passes deep to the extensor pollicis longus tendon and approaches the proximal end of the first inter metacarpal space.

Relations in Palm

After reaching the palm, it takes a transverse course medially across the palm. It anastomoses with the deep branch of the ulnar artery to complete the deep palmar arch at the base of fifth metacarpal bone.

Surface Marking in Forearm

A line drawn from a point one centimeter below the midpoint of the inter-epicondylar line at the elbow to the point of radial pulse (lateral to the tendon of flexor carpi radialis against the lateral aspect of lower radius) represents the radial artery.

Branches of Radial artery

i. In the cubital fossa, the radial artery gives the radial recurrent artery.

ii. In the forearm its branches are, the muscular, anterior radial carpal or palmar carpal branches and superficial palmar branch.

iii. At the wrist, it gives the posterior radial carpal branches or dorsal carpal and the first dorsal metacarpal artery.

iv. In the palm, it gives radialis indicis, princeps pollicis and deep palmar arch.

Radial Pulse

The radial pulse is felt on the anterior surface of the distal end of radius lateral to the tendon of flexor carpi radialis (Fig. 18.6).

Clinical insight ...

i. For arterial puncture (Figs 18.7A and B), the radial artery is chosen since it is superficial in the distal forearm. In this procedure blood is withdrawn for the purpose of Arterial Blood Gas (ABG) analysis.

ii. The radial artery graft is used in coronary artery bypass surgery.

Contd...
Ulnar Artery
The ulnar artery is the larger of the two terminal branches of the brachial artery.

Extent
It begins at the level of neck of radius in the cubital fossa.

Exit from Cubital Fossa
The ulnar artery leaves the cubital fossa deep to the deep (ulnar) head of pronator teres, to enter the forearm.

Course in Forearm
i. Its course in the forearm can be divided into upper oblique part and lower vertical part.
ii. In the upper-third of the forearm, the ulnar artery takes as oblique course to reach the medial margin of the forearm.
iii. In the lower two-thirds, the artery passes vertically down along the medial margin of forearm to reach the wrist.
iv. At the wrist, it crosses the flexor retinaculum superficially (Fig. 18.2) and at the pisiform it divides into deep and superficial branches.

Surface Marking in Forearm
The oblique part of ulnar artery is indicated by a line joining the point (one cm below the midpoint of inter-epicondylar line) to a point coinciding with the junction of upper one-third and lower two-third of a line from medial epicondyle to the pisiform. The vertical part is indicated by a line starting from the lower end of the oblique part to the pisiform bone.
Relations

The oblique part is situated deeply compared to the vertical part of the artery.

i. The anterior relations of the oblique part are the muscles that arise from medial epicondyle, namely, pronator teres, flexor carpi radialis, palmaris longus and flexor digitorum superficialis. The deep head of pronator teres intervenes between the ulnar artery and median nerve at the apex of cubital fossa.

ii. The anterior relations of the vertical part are, the flexor carpi ulnaris in upper extent but towards the wrist it is covered with the skin and fasciae. Distally it lies between flexor carpi ulnaris medially and flexor digitorum superficialis laterally before piercing the deep fascia along with the ulnar nerve. Thus, it passes in front of the flexor retinaculum.

iii. Posteriorly, it is related from above downward, to brachialis, flexor digitorum profundus and flexor retinaculum.

iv. Medially, the ulnar nerve is in close relation in its lower two-thirds.
Posterior Compartment of Forearm
The posterior compartment of the forearm contains extensor muscles, posterior interosseous nerve and both posterior and anterior interosseous arteries. A total of twelve muscles belong to the posterior compartment. They are divided into two sets (superficial and deep).

Superficial Muscles
The superficial set of muscles consists of following muscles.

i. Anconeus
ii. Brachioradialis
iii. Extensor carpi radialis longus
iv. Extensor carpi radialis brevis
v. Extensor digitorum
vi. Extensor digitii minimi
vii. Extensor carpi ulnaris.

Anconeus (Fig. 18.9A)
This is a triangular muscle with narrow origin and broad insertion. It takes origin from the posterior surface of lateral epicondyle of humerus and is inserted into olecranon process and posterior surface of upper-fourth of ulna.

Nerve Supply
The nerve to anconeus is a branch of radial nerve in the spiral groove. It reaches the anconeus through the substance of the medial head of triceps brachii.

Action
It is an extensor of the elbow joint.

Brachioradialis (Fig. 18.1)
This is regarded as a borderline muscle since developmentally it is an extensor muscle but functionally and topographically it is the flexor muscle.

It takes origin from the upper two-thirds of the lateral supracondylar ridge of humerus (above the elbow) and is inserted into the radius just above the styloid process (above the wrist).

Nerve Supply
The brachioradialis is supplied by the radial nerve in the anterior compartment of arm.

Actions
i. It is the flexor of the elbow joint in midprone position of forearm.
ii. It is believed to bring the supinated forearm to midprone position and supinate the fully pronated forearm to midprone position.

Testing Function of Brachioradialis
The elbow of the subject is flexed to 90 degrees and the forearm is kept in midprone position. Now the subject is instructed to flex the elbow against resistance. A normal muscle can be seen and felt.

Supinator Jerk or Reflex
When the distal end of radius is tapped, there is reflex flexion of the forearm. Positive response indicates integrity of spinal segments C7-C8. It is the brachioradialis that contracts and not the supinator.

Extensor Carpi Radialis Longus (ECRL)
This muscle takes origin from the lower third of the lateral supracondylar ridge of humerus. It passes downward under cover of brachioradialis and superficial to the extensor carpi radialis brevis. At the wrist, its tendon passes deep to extensor retinaculum for insertion into the base of second metacarpal bone.

Nerve Supply
The radial nerve supplies the ECRL in the arm just above the elbow.

Extensor Carpi Radialis Brevis (ECRB)
This muscle takes origin from common extensor origin on anterior aspect of lateral epicondyle of humerus. It passes downward deep to the corresponding longus muscle lying in direct contact with radial shaft. It is inserted into the bases of second and third metacarpal bones.

Nerve Supply
The deep branch of the radial nerve (posterior interosseous nerve) supplies the ECRB above the proximal margin of supinator in the cubital fossa.

Actions of Radial Extensors of Carpus
i. Both ECRL and ECRB along with extensor carpi ulnaris produce extension or dorsiflexion of the wrist.
ii. Both ECRL and ECRB muscles along with flexor carpi radialis act synergistically to produce abduction or radial deviation of wrist.

Testing Function of ECRL and ECRB
The subject clenches the fist and dorsiflexes the wrist on radial side against resistance. The ECRL and ECRB muscles can be palpated and their tendons can be felt near the insertion.

Extensor Digitorum
This muscle arises from the common extensor origin on anterior aspect of lateral epicondyle of humerus. It ends into four tendons in mid-forearm. The tendons of extensor digitorum and the tendon of extensor indicis are lodged in the fourth compartment deep to the extensor retinaculum. On the dorsum of the hand, the tendons are connected by tendinous interconnections, which restrict the independent actions on the fingers.
Each tendon expands in to the extensor expansion over the proximal phalanx and is inserted through it into the base of the middle phalanx and that of terminal phalanx. The parts and attachments of the extensor expansion are described with the interossei and lumbrical muscles of the hand (Fig. 20.7).

**Nerve Supply**
The posterior interosseous nerve supplies the muscle.

**Actions**
The extensor digitorum acts on the metacarpophalangeal joints to produce extension. (Note: The extension at interphalangeal joints takes place by action of lumbricals and interossei).

**Testing Function of Extensor Digitorum**
The subject is asked to keep the elbow and the anterior aspect of forearm and the palm on the table. After the examiner stabilizes the wrist of the subject with one hand, the subject extends the MCP joint of each finger against resistance.

**Extensor Digiti Minimi**
This is a separate extensor of the little finger. It arises from common extensor origin on the front of lateral epicondyle and passes downwards along the medial side of extensor digitorum. It passes deep to the extensor retinaculum in the fifth compartment. On the dorsum of the hand, it usually splits in to two slips. It is inserted into the extensor expansion of little finger.

**Nerve Supply**
The extensor digiti minimi receives twigs from posterior interosseous nerve.

**Action**
The extensor digiti minimi helps in extension of the metacarpophalangeal joint of the little finger.

**Extensor Carpi Ulnaris**
This muscle takes origin from the common extensor origin on the front of lateral epicondyle and from the posterior subcutaneous border of ulna in common with the origin of flexor carpi ulnaris. Its tendon passes deep to the extensor retinaculum in the sixth compartment, where it lies in a groove between head and styloid process of ulna. It is inserted into the base of the fifth metacarpal bone.

**Nerve Supply**
The posterior interosseous nerve supplies it.

**Actions**

i. Along with the two radial extensors of the carpus (ECRB and ECRL), it produces extension of wrist.

ii. The synergistic action with flexor carpi ulnaris produces adduction or ulnar deviation of wrist.

**Testing Function of ECU**
The subject is asked to keep the closed fist in position of ulnar deviation against resistance.

**Deep Muscles (Figs 18.9A and B)**
The deep set of muscles consists of (from above downward) the following.

i. Supinator

ii. Abductor pollicis longus

iii. Extensor pollicis longus

iv. Extensor pollicis brevis

v. Extensor indicis.

**Supinator**
This muscle is described in chapter 19 along with muscles of supination and pronation.

**Abductor Pollicis Longus**
This muscle takes origin from posterior surface of both radius and ulna and from the interosseous membrane. Its long tendon spirals round the tendons of brachioradialis and the radial extensors of the carpus. The tendons of abductor pollicis longus (APL) and extensor pollicis brevis enclosed in common synovial sheath pass deep to the extensor retinaculum. The tendon of abductor pollicis longus is inserted into the radial side of the base of first metacarpal bone.

**Nerve Supply**
The posterior interosseous nerve supplies it.

**Actions**
The APL abducts and extends the thumb at the first carpometacarpal joint of thumb.

**Testing Function**
The subject holds the forearm in midprone position and is then asked to abduct the thumb against resistance. The tendon of APL stands out in the margin of anatomical snuffbox.

**Extensor Pollicis Brevis**
This muscle takes origin from the posterior surface of radius below the origin of abductor pollicis longus as well as from the adjacent interosseous membrane. Its tendon closely follows the tendon of abductor pollicis longus. The extensor pollicis brevis (EPB) is inserted into the dorsal surface of proximal phalanx of thumb.

**Nerve Supply**
The posterior interosseous nerve supplies it.
**Actions**
It extends the proximal phalanx of the thumb and the first metacarpal bone.

**Testing Function of EPB**
Ask the subject to extend the proximal phalanx of thumb at the MCP joint against resistance (the forearm is resting on the table in prone position).

**De Quervain’s Tenosynovitis**
It is the inflammatory condition of the common synovial sheath around the tendons of abductor pollicis longus and extensor pollicis brevis. This produces swelling and pain along the lateral aspect of the wrist. Symptoms usually subside after incising the tendon sheath.

**Extensor Pollicis Longus (EPL)**
This muscle takes origin from the posterior surface of ulna below the origin of abductor pollicis longus and from the interosseous membrane. Its long tendon hooks round the Lister’s tubercle of radius deep to the extensor retinaculum. It is inserted into the base of the terminal phalanx of thumb. On the dorsum of the proximal phalanx (in the absence of extensor expansion proper), the sides of the extensor pollicis longus tendon receive connections from the tendon of extensor pollicis brevis on the lateral side and from the insertion of adductor pollicis and first palmar interosseous muscles on the medial side.

**Nerve Supply**
The posterior interosseous nerve supplies the muscle.

**Arterial Supply**
The muscle belly receives arterial twigs from posterior interosseous artery but its tendon receives twigs mainly from anterior interosseous artery.

**Actions**
The EPL extends the thumb at the interphalangeal and first carpometacarpal joints.

**Testing Function**
The subject is asked to extend the distal phalanx of thumb against resistance.

**Rupture of EPL Tendon**
The spontaneous rupture of EPL tendon may occur due to ischemia as a result of injury to anterior interosseous artery. This artery or its branches may be injured in Colle’s fracture. The tendon ruptures, where it changes direction around the Lister’s tubercle. The patient feels that the thumb has “dropped” as the interphalangeal joint of the thumb cannot extend (hammer thumb deformity).
Extensor Indicis
This muscle takes origin from posterior surface of ulna below the origin of extensor pollicis longus. Its tendon passes along with the extensor digitorum tendons deep to the extensor retinaculum in the fourth compartment. It is inserted into the dorsal digital expansion of index finger.

Nerve Supply
The posterior interosseous nerve supplies it.

Action
It helps in extension of index finger.

Posterior Interosseous Nerve
This is the only nerve inside the posterior compartment of forearm. It is a purely motor nerve. It is the continuation of the deep branch of radial nerve in the cubital fossa.

As the nerve passes through the supinator, it is closely related to the lateral aspect of the neck of radius (Fig. 19.6B). Then it enters the back of forearm by piercing the distal part of the supinator.

Course
i. At first the posterior interosseous nerve lies between the superficial and deep extensor muscles.
ii. At the distal border of extensor pollicis brevis, it passes deep to extensor pollicis longus and directly rests on the interosseous membrane.
iii. In its upper part the posterior interosseous artery accompanies the nerve but distally the anterior interosseous artery accompanies it.
iv. The posterior interosseous nerve and anterior interosseous artery reach the dorsum of the carpus, where they occupy the fourth compartment deep to the extensor retinaculum. Here, the nerve terminates in a pseudoganglion.

Branches (Fig. 18.10)

i. Before the posterior interosseous nerve enters the supinator, it supplies extensor carpi radialis brevis and supinator in the cubital fossa.
ii. While passing through the supinator it gives additional branches to supinator.
iii. In its initial course at the back of forearm, it gives three short branches to the extensor digitorum, extensor digiti minimi and extensor carpi ulnaris.
iv. Then it gives longer branches to extensor pollicis longus, extensor indicis, abductor pollicis longus and extensor pollicis brevis.
v. The branches from the pseudoganglion are given to the carpal articulations.

Clinical insight ...

PIN Syndrome
Posterior interosseous nerve (PIN) syndrome occurs if the nerve is compressed deep to the arcade of Frohse (Fig. 19.6B), which is a musculotendinous structure at the proximal edge of supinator muscle. The extensor carpi ulnaris is usually affected first so wrist extension causes radial deviation due to overaction of radial extensors. There is weakness of extension and abduction of thumb (thumb drop) besides weak extension of fingers (finger drop).

Posterior Interosseous Artery
It is one of the terminal branches of the common interosseous artery, which arises from the ulnar artery in cubital fossa. It enters the posterior compartment through the gap between the upper margin of interosseous membrane and the oblique cord. It passes downwards between the supinator and abductor pollicis longus. On the surface of the abductor pollicis longus, it accompanies the posterior interosseous nerve. It ends by anastomosing with the terminal part of anterior interosseous artery and dorsal carpal arch.

Branches
In cubital fossa, it gives the interosseous recurrent artery, which anastomoses with the radial collateral branch of profunda artery and in the posterior compartment it mainly gives muscular branches.
**RADIOULNAR JOINTS**

The radius and ulna articulate with each other by two synovial joints, the superior and inferior radioulnar joints and by the middle radioulnar joint, which is of fibrous variety (Fig. 19.1).

### Superior Radioulnar Joint

This is the pivot type of synovial joint between the disc-like head of the radius and the radial notch on the upper end of the ulna.

The fibrous capsule of the elbow joint covers the superior radioulnar joint. The synovial membrane lines the annular ligament and the fibrous capsule internally and is continuous with that of the elbow joint.

#### Ligaments

1. The head of the radius is held against the radial notch of ulna by a strong band called the annular ligament. This ligament encircles the head of the radius and is attached to anterior and posterior margins of the radial notch of ulna. The annular ligament and the radial notch together form an osseofibrous ring (Fig. 19.2) for the head of the radius to rotate during pronation and supination.

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**Fig. 19.1:** Superior, middle and inferior radioulnar joints
ii. The quadrate ligament is a weak bond between the neck of radius and lower margin of radial notch of ulna.

Clinical insight ...

Pulled Elbow
There is a difference in the shape of the annular ligament in adults and children. In adults, the cup-shaped ligament firmly grips the neck of radius (thus preventing its downward displacement). On the contrary, in children (below five years) the head tends to slip out of the ring due to the tubular shape of ligament and the smaller circumference of the head of radius resulting in a nursemaid’s elbow or pulled elbow.

Inferior Radioulnar Joint
This is the pivot type of synovial joint between the head of ulna and the ulnar notch on the lower end of radius. The fibrous capsule surrounds the joint cavity. The synovial membrane lines the capsule and projects upwards between the interosseous membrane and the pronator quadratus as a narrow recess. The articular disc is attached medially to a pit between the styloid process and the head of ulna and laterally to the inferior margin of the ulnar notch of the radius. The disc excludes the ulna from the wrist joint and provides the ulnar head a platform to rotate during movements of supination and pronation (Fig. 19.3).

Middle Radioulnar Joint
This is a longitudinally-oriented joint between the shafts of the radius and ulna. This is a syndesmosis type of fibrous joint. The oblique cord and the interosseous membrane are the connecting bonds between the two bones.

i. The oblique cord extends from the lateral side of ulnar tuberosity to the lower limit of radial tuberosity.

ii. The interosseous membrane is a thick sheet of collagenous tissue between the interosseous borders of radius and ulna. The fibers in the membrane are directed downwards and medially from radius to ulna. Proximally, the membrane starts about two to three centimeters below the radial tuberosity and distally it reaches up to the level of distal radioulnar joint, where it fuses with the capsule of this joint.

Relations of Anterior Surface
i. The three deep muscles of the front of forearm, flexor digitorum profundus, flexor pollicis longus and pronator quadratus take origin from the anterior surface.

ii. The anterior interosseous nerve and vessels are closely related to this surface.

iii. The anterior interosseous vessels pass through the interosseous membrane at the upper limit of the pronator quadratus to enter the posterior compartment. The anterior interosseous nerve descends up to the lower limit of the membrane.

Relations of Posterior Surface
i. The four deep muscles of the back of forearm, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus and extensor indicis take origin from the posterior surface.

ii. The lower part of the posterior surface is closely related to the posterior interosseous nerve and anterior interosseous vessels.
Functions

i. The interosseous membrane transmits the compression forces from radius to ulna.

ii. It increases the area of origin of deep muscles of the forearm.

Supination and Pronation (Fig. 19.3)

The superior and inferior radioulnar joints permit the movements of supination and pronation. The movements take place around a mobile vertical axis passing through the center of the head of the radius and the lower end of ulna. The head of the radius rotates within the osseofibrous ring.

i. In the movement of pronation, the radius carrying the hand with it, turns anteromedially across the ulna with the result that the lower part of radius comes to lie medial to ulna and the palm faces posteriorly.

ii. During the supination, the radius comes back to its position lateral to ulna so that the palm faces anteriorly. The supination, is a more powerful movement as is evident from the design of the screws. The supination is equated to the screwing movement while pronation to the unscrewing movement. The opening of a lock with the key in right hand is an example of supination while the action of locking with the key in right hand is an example of pronation.

Muscles of Pronation (Fig. 19.4)

Pronator Teres

The pronator teres takes origin by two heads. The humeral head is larger and more superficial than the ulnar head.

i. The humeral head arises from the lower part of the medial supracondylar ridge and from the common flexor origin on the front of medial epicondyle.

ii. The ulnar head arises from the medial border of coronoid process of ulna.

iii. The two heads unite with each other and the combined muscle passes obliquely across the proximal forearm for insertion into the area of maximum convexity on the lateral surface of radius.

iv. The median nerve leaves the cubital fossa between the two heads of pronator teres. The ulnar artery passes deep to the deep head. Thus, its ulnar head is sandwiched between the median nerve and ulnar artery.

Nerve Supply

The median nerve gives branch to pronator teres in the lower part of the arm and also in the cubital fossa.

Actions

The pronator teres assists the pronator quadratus in rapid pronation movements of forearm. It is also a weak flexor of elbow.

Testing Function of Pronator Teres

After flexing the elbow roughly to 20 degrees, the subject is asked to supinate the forearm fully. After this, the subject attempts to pronate the forearm against resistance. If normal, the contraction of the muscle is felt in upper part of forearm.

Pronator Quadratus

The pronator quadratus is a quadrilateral and flat muscle, which is located deeply in the distal part of the forearm.

i. It arises from the bony ridge on the anterior surface of the lower one-fourth of the shaft of ulna. The fibers pass laterally and downward for insertion on the anterior surface of lower-fourth of radius.

ii. The muscle lies in contact with the anterior surface of the lower part of the interosseous membrane.
The anterior interosseous nerve descends behind the posterior surface of the muscle.

iii. The space of Parona or deep forearm space lies between the long flexor tendons and the anterior surface of the pronator quadratus.

**Nerve Supply**
The anterior interosseous branch of the median nerve supplies the muscle.

**Actions**
It is the chief pronator of the forearm. It is assisted by the pronator teres only in rapid and forceful pronation.

**Muscles of Supination (Fig. 19.4)**

**Biceps Brachii**
The biceps brachii is a powerful supinator. It is a muscle of the anterior compartment of arm (Fig. 16.2). It takes origin by two tendinous heads from the scapula.

i. The short head takes origin from the tip of the coracoid process of scapula along with coracobrachialis.

ii. The long head takes origin from the supraglenoid tubercle of scapula. The tendon of the long head is intracapsular but extrasynovial in position. It leaves the shoulder joint by passing beneath the transverse humeral ligament to enter the intertubercular sulcus. The synovial sheath covers the tendon up to the level of surgical neck of humerus.

iii. The two heads of the biceps fuse to form a fusiform belly, which ends in a flat tendon about six to seven centimeter above the elbow. In the cubital fossa, the tendon is in lateral relation to the brachial artery. It is inserted into the posterior part of radial tuberosity.

iv. The extension from the medial border of the tendon is called bicipital aponeurosis. This extends medially in front of the brachial artery and median nerve to get attached to the deep fascia of the forearm and through it to the subcutaneous posterior border of ulna.

**Nerve Supply**
The biceps brachii is supplied by musculocutaneous nerve.

**Actions**
The biceps brachii acts on three joints (shoulder, elbow and superior radioulnar) since it crosses all the three joints.

i. On the radioulnar joint, it acts as powerful supinator of the forearm. The biceps has its maximum supination power, when the elbow is flexed at right angle. In this position of the elbow, the insertion of the biceps is in line with the rest of the muscle.

ii. The action of the biceps on the elbow joint is flexion.

iii. Its action on shoulder joint is flexion. The long head of biceps helps in stabilizing the head of humerus during movements of the shoulder joint.

**Testing Function**
The subject flexes the elbow against resistance, when the forearm is supinated and extended.

**Biceps Reflex**
A tap on the tendon of biceps at the cubital fossa by a tendon hammer produces brisk flexion of elbow joint. This tests the C5 spinal segment.

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**Clinical insight ...**

**Popeye Sign and Deformity**
When the biceps contracts to flex the elbow joint, there is a prominent bulge of muscle belly (specially in body builders). This is called Popeye sign. When the tendon of long head of biceps ruptures (as in weight lifters or in swimmers) it causes a sudden appearance of a swelling in the lower part of the front of arm (Fig. 19.5). This is due to the detached muscle belly taking the shape of a ball. This appearance resembles the arm of a cartoon character named Popeye (hence called Popeye deformity).

**Supinator**
This muscle belongs to the extensor compartment of forearm (Figs 18.9 and 19.6A).
The supinator is composed of two laminae (superficial and deep).

ii. The superficial lamina arises by tendinous fibers from the lateral aspect of lateral epicondyle of humerus, radial collateral ligament of elbow joint and annular ligament of superior radioulnar joint.

iii. The deep lamina arises by muscular fibers from the supinator crest of ulna and a small area in front of it.

iv. The fibers of both laminae spiral round, as they are inserted into the lateral surface of proximal-third of radius between the anterior and posterior oblique lines.

Relations
The supinator muscle lies deep in the distal part of the floor of cubital fossa. The deep branch of the radial nerve (posterior interosseous nerve) leaves the cubital fossa by entering the substance of the supinator at its proximal edge (Fig. 19.6B). The nerve travels between the two laminae and enters the posterior compartment just above the distal border of the supinator. The proximal edge of the superficial lamina is fibrotendinous (called arcade of Frohse) in some percentage of population. This is a site of compression of the nerve, producing posterior interosseous nerve (PIN) syndrome.

Nerve Supply
The supinator is supplied by the posterior interosseous nerve usually before it enters the muscle and also as it passes through the muscle.

Actions
i. The action of the supinator is to rotate the shaft of the radius laterally and thereby bring about supination of the forearm.

ii. In the flexed forearm, the role of supinator is to fix the radius (the prime supinator being biceps brachii) but in extended forearm the supinator is the prime supinator.

Testing Function
The subject is asked to supinate forearm against resistance in extended and fully pronated position.

WRIST JOINT (FIG. 19.7)

The wrist joint is an ellipsoid type of synovial joint permitting movements along two axes. The wrist joint is a radio-carpal joint suggestive of the fact that among the forearm bones only the radius (and not the ulna) articulates with carpus. This is a functional necessity as the radius can carry the hand with it during pronation and supination.
The proximal articular surface is concave. The concavity is formed by the articular area on the inferior surface of the lower end of the radius and the inferior surface of the articular disc of the inferior radioulnar joint.

The distal articular surface is reciprocally convex. It is formed by proximal surfaces of the scaphoid, lunate and triquetral bones from lateral to medial side.

The joint is surrounded by the fibrous capsule, which is strengthened by the palmar and dorsal radiocarpal ligaments and the carpal collateral ligaments.

The fibrous capsule is attached to the articular margins of the proximal and distal articular areas, including the articular disc. It is lined by synovial membrane.

The palmar radiocarpal ligament is the thickening of anterolateral part of the capsule.

The palmar ulnocarpal ligament is the thickening of anteromedial part of the capsule.

Posteriorly, the capsule is strengthened to form dorsal radiocarpal ligament.

These ligaments are attached distally mainly to the proximal row of carpal bones and also to the capitate (a bone of distal row).

The radial artery in the anatomical snuffbox is related laterally.

The articular branches of anterior and posterior interosseous nerves supply the joint.

The palmar and dorsal carpal arches are the source of arterial supply. The carpal arches are the arterial anastomoses on the front and back of the wrist deep to the long tendons.

i. Palmar carpal branch of radial artery
ii. Palmar carpal branch of ulnar artery
iii. Descending branch of anterior interosseous artery
iv. Recurrent branches of deep palmar arch

Arteries Forming Dorsal Carpal Arch
i. Dorsal carpal branch of radial artery
ii. Dorsal carpal branch of ulnar artery
iii. Carpal branches of anterior interosseous artery
iv. Carpal branches of posterior interosseous artery

i. Flexion (palmar flexion)
ii. Extension (dorsal flexion)
iii. Adduction (ulnar deviation)
iv. Abduction (radial deviation)
v. Circumduction (sequential combination of the above movements)

The main flexors of wrist joint are the flexor carpi radialis and flexor carpi ulnaris. They are assisted by flexor digitorum superficialis, flexor digitorum profundus and flexor pollicis longus muscles.
ii. The main extensors of wrist joint are the extensor carpi radialis longus, extensor carpi radialis brevis and extensor carpi ulnaris. They are assisted by extensor digitorum, extensor digiti minimi, extensor indicis, and extensor pollicis longus.

iii. The adduction is the combined action of extensor carpi ulnaris and flexor carpi ulnaris muscles.

iv. The abduction is the combined action of extensor carpi radialis longus and brevis and flexor carpi radialis muscles. The abductor pollicis longus and extensor pollicis brevis also assist.

Anatomical Snuffbox (Fig. 19.8)
This is a hollow space, which appears on the lateral side of the posterolateral side of the wrist in the fully extended position of the thumb.

Boundaries
i. On the ulnar side (posteriorly), by the extensor pollicis longus tendon
ii. On the radial side (anteriorly), by the tendons of abductor pollicis longus and extensor pollicis brevis.
iii. The floor consists of four bony parts. In the proximal to distal order the bones are styloid process of radius, scaphoid, trapezium and base of the first metacarpal (Fig. 19.7).
iv. The fascial roof contains the cephalic vein and superficial branch of radial nerve.

Content
The radial artery passes via the anatomical snuffbox to the dorsum of the hand. On light pressure applied in the floor, pulsations of the radial artery are felt.

Retinacula at the Wrist
The wrist is a junctional zone between the forearm and the hand. The tendons of the extensor muscles of the forearm cross the wrist from behind while the tendons of the flexor muscles cross in front. Since the tendons cross a series of joints at the carpus, they are held tightly against the carpus, to prevent their bow stringing. The deep fascia of the wrist is modified to form flexor and extensor retinacula to strap down these tendons.

Flexor Retinaculum (Fig. 19.9)
It is a square-shaped dense thickening of the deep fascia. Its size is 2.5 × 2.5 cm.

Attachments
i. Medially, to the pisiform bone and hook of the hamate
ii. Laterally, to the tubercle of scaphoid and the crest of trapezium

Ganglion of Wrist Joint
The ganglion is a localized cystic swelling on the dorsum of the wrist arising from either the capsule of the joint or from the synovial sheath surrounding the extensor tendons or of the intercarpal joints. It usually presents as a painful lump and causes discomfort during the movements of the wrist.
iii. Proximally, it is continuous with the deep fascia of forearm
iv. Distally, it is continuous with the palmar aponeurosis.

**Surface Marking**
Cup the palm of the hand by spreading the fingers (as though to grasp a large ball). The hollow between the proximal parts of the thenar and hypothenar eminences marks the position of flexor retinaculum distal to the distal flexure crease of the wrist.

**Special Note**
The flexor retinaculum is quite deep from the skin because its anterior surface is covered with origin of thenar and hypothenar muscles. The surgeon operating on flexor retinaculum for the first time must be aware of this fact.

**Relations**
1. Anterior or superficial to the retinaculum five structures are related from medial to lateral, the ulnar nerve and vessels, the palmar cutaneous branch of ulnar nerve, the palmaris longus tendon and the palmar cutaneous branch of median nerve. The ulnar nerve and vessels are protected in Guyon’s canal inside the substance of the flexor retinaculum. The thenar and hypothenar muscles take origin from the anterior surface of the retinaculum.
2. Posterior or deep to the retinaculum are the contents of the carpal tunnel (9 flexor tendons comprising 4 of FDS, 4 of FDP and 1 of FPL and median nerve) and the tendon of flexor carpi radialis in a separate tunnel formed by the groove of trapezium.

**Clinical insight ...**

**Carpal Tunnel syndrome (CTS)**
This syndrome results due to compression of median nerve in the carpal tunnel. A few causes of CTS are chronic tenosynovitis (inflammation of the tendons in the carpal tunnel), myxedema and anterior dislocation of lunate bone.

**Effects of Median Nerve Compression**
- i. The early symptoms are numbness, tingling and burning pain in lateral three and half fingers. The sensory loss develops in the same fingers in due course of time.
- ii. Weakness of thenar muscles and flattening of thenar eminence are the symptoms and signs of loss of motor function. Gradually, it will lead to ape thumb deformity if left untreated.

**Surgical Treatment**
Cutting of flexor retinaculum is one of the methods of relieving pressure on the median nerve.

**Extensor Retinaculum (Fig. 19.10)**
This is the rectangular shaped thickening of deep fascia (about 3.5 cm long) on the back of the wrist.

**Attachments**
- i. It is attached medially to pisiform and triquetral
- ii. Laterally, it is attached to the anterior border of lower end of radius.
- iii. Proximally, it is continuous with the deep fascia at the back of forearm
- iv. Distally, it is continuous with the deep fascia on the dorsum of hand.

**Relations**
- i. The posterior or superficial relations are the superficial branch of radial nerve and dorsal cutaneous branch of ulnar nerve superficial to retinaculum.
- ii. From the anterior or deep aspect of the extensor retinaculum septa arise, which attach to the back of radius and ulna so that six osseofibrous compartments are formed for the passage of the extensor tendons. The compartments are numbered from lateral to medial side.

**Contents of Compartments**
- i. Abductor pollicis longus and extensor pollicis brevis
- ii. ECRL and ECRB
- iii. Extensor pollicis longus
- iv. Extensor digitorum and extensor indicis, posterior interosseous nerve and anterior interosseous artery.
- v. Extensor digitii minimi
- vi. Extensor carpi ulnaris

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**Fig. 19.10:** Attachments and deep relations of extensor retinaculum
(Note the superficial branch of radial nerve and dorsal cutaneous branch of ulnar nerve superficial to retinaculum)
FEATURES OF HAND

The hand is the most functional part of the upper limb distal to the forearm. The skeleton of hand consists of the carpal bones, metacarpal bones and the phalanges in the digits. The digits are numbered from lateral to medial side. So the thumb is the first digit and little finger is the fifth digit. The dorsal and palmar aspects of hand have characteristic features.

Dorsum of Hand

In striking contrast to the skin of palm, the skin on the dorsum is very thin and can be very easily pinched. The subcutaneous veins including the dorsal venous arch show through it clearly. If there is a deep-seated abscess in the palm, its outer sign in the form of swelling appears on the dorsum. This is due to availability of subcutaneous space on the dorsum for the lymph to accumulate. It is noteworthy that lymph flows from palmar to the dorsal aspect.

Spaces on Dorsum

The deep fascia of the dorsum is extremely thin and is attached to the extensor tendons, which are devoid of the synovial sheaths here. An aponeurotic layer is formed under the skin by intertendinous connections. So, the dorsum presents dorsal subcutaneous space and dorsal subaponeurotic space. The infection of the subaponeurotic space usually results from laceration of the knuckles, as for example in tooth-bite on the fist.

Structures on Dorsum

i. Dorsal venous network or arch
ii. Cutaneous nerves and vessels
iii. Long extensor tendons of the digits.

Dorsal Venous Arch (Fig. 15.3)

For description of dorsal venous arch refer to Chapter 15.

Sensory Nerves on Dorsum (Fig. 20.1)

i. Dorsal digital branches of superficial branch of radial nerve supply the skin of the radial side of the hand as well as the lateral three and half digits up to the level of approximately the middle of middle phalanx.

ii. Dorsal cutaneous branches of ulnar nerve supply the ulnar side of dorsum and medial one and half digits up to the level of distal interphalangeal joint.

Fig. 20.1: Sensory innervation of dorsum of hand
iii. Palmar digital branches of median nerve reach the dorsal aspect over the tips of digits to supply the nail beds of lateral three and half digits.
iv. Palmar digital branches of ulnar nerve supply the nail beds of medial one and half digits.

Arteries of Dorsum
The dorsal metacarpal arteries are the main supply of the dorsum. Corresponding to the four interosseous spaces there are four metacarpal arteries. On reaching the bases of the digits, the metacarpal arteries divide into dorsal digital arteries for the supply of the adjacent fingers
i. The first dorsal metacarpal artery is a branch of radial artery, which is given off before leaving the dorsum between the two heads of first dorsal interosseous muscle.
ii. The second, third and fourth dorsal metacarpal arteries are the branches of dorsal carpal arch.

Connections of Dorsal Metacarpal Arteries
i. Proximally, the proximal perforating arteries from the deep palmar arch reinforce the medial three metacarpal arteries.
ii. Distally, the distal perforating arteries connect the dorsal metacarpal arteries to the common palmar digital arteries (arising from superficial palmar arch).

Extensor Tendons on Dorsum (Fig. 20.2)
The long extensor tendons enter the dorsum after passing deep to the extensor retinaculum. All the tendons are covered with synovial sheath. They cross the dorsum to reach the digits for insertion.

i. The extensor digitorum tendons of the medial four digits are connected by tendinous interconnections, which restrict the independent movements of the digits.
ii. The tendon of extensor digit minimi usually splits in two on the dorsum. The extensor digiti minimi and extensor indicis tendons fuse with the respective tendons of the extensor digitorum distal to the tendinous interconnection.
iii. The extensor tendons form a dorsal expansion over the respective metacarpophalangeal (MCP) joints and the proximal phalanges. The extensor expansion provides insertion not only to the extensor tendons but also to the interosseous and lumbrical muscles. The details of the parts of extensor expansion are described along with interossei and lumbral muscles.
iv. The extensor expansion is not present in the thumb. The abductor pollicis longus does not reach the thumb phalanx. The tendon of extensor pollicis longus reaches the terminal phalanx. The tendon of extensor pollicis brevis sends a connection to the tendon of extensor pollicis longus on the proximal phalanx from the lateral aspect. The tendon of extensor pollicis longus receives similar connection from the insertion of first palmar interosseous and the adductor pollicis on medial aspect.

The Palm
The palm houses twenty intrinsic muscles of the hand, nine long flexor tendons, ulnar and median nerves and the palmar arterial arches. These structures are wrapped in fascial layers of palm in four definite compartments.

External Appearance of Palm
The skin of the palmar aspect of hand is of thick glabrous type with abundant sweat glands. The skin presents characteristic papillary ridges, which are responsible for the fingerprints.
The palmar skin is firmly anchored to the deep fascia at the skin creases (flexure lines) of palm.

Transverse Palmar Creases
i. The distal palmar crease (heart line) lies just proximal to the metacarpophalangeal joints (MCP joints).
ii. The proximal palmar crease is called the headline.
In Down syndrome (trisomy 21), there is a single transverse crease on the palm simian crease).

Longitudinal Palmar Crease
There is one longitudinally-oriented crease laterally. On its lateral side, there is an elevated area called thenar eminence. A less well-marked area on the medial side is known as hypothenar eminence.

There are flexure creases on fingers also

Superficial Fascia of Palm
The superficial fascia contains subcutaneous fat interspersed with dense fibrous tissue. This connects the skin of palm firmly to palmar aponeurosis (modified deep fascia). The superficial transverse metacarpal ligament at the web margins of the hand is a modification of superficial fascia. The palmaris brevis muscle is located in the superficial fascia.

Palmaris Brevis (Fig. 20.3)
The palmaris brevis is a subcutaneous muscle (representing panniculus carnosus of quadrupeds) seen on the medial side across the base of hypothenar eminence. It takes origin from the flexor retinaculum and the palmar aponeurosis near its apex. It is inserted into the dermis of the medial margin of hand. The muscle is supplied by, superficial branch of ulnar nerve. Its contraction improves the grip of the hand.

Palmar Aponeurosis (Fig. 20.3)
The palmar aponeurosis is a triangular thickening of deep fascia in the central region of the palm. It has an apex pointed proximally and a base pointed distally.

i. The apex is continuous with flexor retinaculum and the tendon of palmaris longus.
ii. The base extends distally to the level of distal palmar crease, where it splits into four digital slips for the medial four digits. Each slip divides into two slips.
iii. The deep slip is attached to deep transverse metacarpal ligament, capsule of corresponding MCP joint, base of proximal phalanx and to fibrous flexor sheath of corresponding digit.
iv. The superficial slip is attached to the superficial transverse metacarpal ligament and the skin.
v. The medial palmar septum connects the medial margin of palmar aponeurosis to the fifth metacarpal bone.
vi. The lateral palmar septum arises from lateral margin of palmar aponeurosis and is attached to first metacarpal bone.

These septa divide the palm into fascial compartments.

Functions
i. The palmar aponeurosis protects the nerves and vessels inside the palm.
ii. It helps to improve the grip of the hand.

Fibrous Flexor Sheath (Fig. 20.3)
The fibrous flexor sheath is the thickened deep fascia on all five digits. It has a very thick and unique structure (consisting of five dense and stiff annular pulleys and three thin and lax cruciform pulleys). The sheath is attached to the margins of the phalanges.

Extent
The sheath extends from the level of head of metacarpal bone to the base of distal phalanx. Thus, the phalanges and the sheath together form an osseofibrous tunnel in each digit. The tunnel is closed distally by the attachment of the...
sheath to the phalanx beyond the insertion of flexor pollicis longus in thumb and flexor digitorum profundus in other fingers.

Contents
The sheath for the thumb houses one tendon of flexor pollicis longus whereas the sheaths for the other digits house two tendons, one each of flexor digitorum superficialis and flexor digitorum profundus. The tendons are surrounded by synovial sheath to allow their frictionless movements inside the tunnel. The arteries are carried to the tendon by the synovial folds, the vincula longa and brevia. The vincula longa are located near the roots of the fingers whereas the vincula brevia are found closer to the insertion of the tendons.

Fascial Compartments of Palm (Fig. 20.4)
The deep fascia of the palm is disposed in two layers, which wrap the intrinsic muscles, the long flexor tendons, the nerves and vessels of the palm. The deep fascia of palm covering the thenar and hypothenar areas turns posteriorly around the margins of these areas to become continuous with the deeper layer of fascia covering the anterior surfaces of the metacarpals, the interosseous muscles between them, and the adductor pollicis muscle. These two layers (superficial and deep) of deep fascia are connected to each other by means of medial and lateral palmar septa. In this way the palm is divided into four fascial compartments, thenar, hypothenar, intermediate and adductor.

i. The thenar compartment contains abductor pollicis brevis, flexor pollicis brevis and opponens pollicis.

ii. The hypothenar compartment contains abductor digiti minimi, flexor digiti minimi, and opponens digiti minimi.

iii. The intermediate compartment contains the long flexor tendons surrounded by synovial sheaths, lumbricals, palmar arterial arches and the branches of median and ulnar nerves.

iv. The adductor compartment contains only the adductor pollicis muscle.

Palmar Spaces (Fig. 20.4)
The palmar spaces are known as the fascial spaces of palm. Under normal conditions, there are no well-defined fascial spaces inside the fascial compartments of palm. However, these fascial spaces become apparent in the intermediate fascial compartment only if there is collection of pus. A new septum called midpalmar septum (or intermediate palmar septum) develops in this compartment to divide it into thenar and midpalmar spaces.

The following spaces are included under the term palmar spaces.

i. Midpalmar space

ii. Thenar space

iii. Web spaces

iv. Pulp spaces

v. Forearm space of Parona.

Boundaries of Midpalmar Space

i. Anteriorly (from superficial to deep), the structures are, palmar aponeurosis, superficial palmar arch, flexor tendons of medial three digits covered with common synovial sheath (ulnar bursa) and medial three lumbrical muscles.

ii. Posteriorly, there is deep layer of deep fascia covering the third and fourth interossei and the metacarpal bones.

iii. Medially, there is medial palmar septum.

iv. Laterally, there is midpalmar septum.
v. Proximally, the space extends up to the level of distal margin of flexor retinaculum, where normally it is closed (but sometimes may extend deep to the retinaculum).

vi. Distally, the space extends up to the level of distal palmar crease beyond which it communicates with fourth and third lumbrical canals.

**Boundaries of Thenar Space**

i. Anteriorly (from superficial to deep), the structures are, palmar aponeurosis, superficial palmar arch, flexor tendons of index finger covered with a synovial sheath (radial bursa) and the first lumbrical muscle.

ii. Posteriorly, there is deep layer of deep fascia covering the adductor pollicis muscle.

iii. Medially, there is midpalmar septum.

iv. Laterally, there is lateral palmar septum.

v. Proximally, the space extends up to the level of distal margin of flexor retinaculum, where normally it is closed (but sometimes may extend deep to the retinaculum).

vi. Distally, the space extends up to the level of distal palmar crease beyond which it communicates with first lumbrical canal.

**Relation of Palmar Spaces to Radial and Ulnar Bursae (Fig. 20.5)**

i. The radial bursa is the synovial sheath surrounding the flexor pollicis longus tendon. It extends from the forearm (two centimeter proximal to the proximal margin of flexor retinaculum) to the level of the base of terminal phalanx of thumb. The radial bursa is closely related to thenar space.

ii. The ulnar bursa is the common synovial sheath surrounding the tendons of flexor digitorum superficialis and profundus. It extends from the forearm (two centimeter proximal to proximal margin of flexor retinaculum) to the mid-palm level where the ulnar bursa ends as a cul de-sac but retains its continuity with the digital sheath around the flexor tendons of the little finger. The ulnar bursa and its distal extension in the little finger are closely related anteriorly to midpalmar space. Beyond the cul-de-sac, the tendons of index, middle and ring fingers are devoid of synovial sheath until they enter the fibrous flexor sheath.

**Clinical insight ...**

i. Tenosynovitis means inflammation of synovial sheath surrounding a tendon. The tenosynovitis of little finger can infect the ulnar bursa. Similarly, tenosynovitis of thumb can infect the radial bursa. The inflamed ulnar bursa can burst into the midpalmar space and the inflamed radial bursa can burst into thenar space causing abscesses in these spaces.

ii. With the current trend of liberal use of antibiotics to control infections, the occurrence of abscesses in palmar spaces is much reduced.

**Lumbrical Canals**

If pus collects in the thenar or midpalmar spaces it is drained through lumbrical canals, which are spaces around lumbrical muscles. They open distally into web spaces.

i. The midpalmar space communicates with third and fourth web spaces via corresponding lumbrical canals. Hence, incision may be placed in the third or fourth web space to open the lumbrical canal to let out the pus.

ii. The thenar space communicates with first web space via first lumbrical canal. Hence, first web space is incised to open the first lumbrical canal to let out the pus.

(Note: If midpalmar and thenar spaces are analogous to “pus tanks” then lumbrical canals are the “pus taps”, which can be opened in web spaces to let out the pus).

**Web Spaces**

There are four subcutaneous spaces within the folds of skin connecting the bases of the proximal phalanges. Each web space has a free margin. The web space extends from its free margin up to the level of metacarpophalangeal joint. The web space contains subcutaneous fat, superficial transverse metacarpal ligament, tendon of interosseous and lumbrical and digital nerves and vessels.
Upper Extremity

Pulp Space (Fig. 20.6)
The pulp space is a subcutaneous space between the distal phalanx and the skin of the terminal digit. It is closed proximally by the fusion of the fibrous flexor sheath (deep fascia) to the skin of the digit at the distal crease on the anterior aspect and by fusion of the deep fascia to the periosteum of terminal phalanx on the posterior aspect.

Contents
The pulp space contains subcutaneous fatty tissue (which is loculated by tough fibrous septa) and digital nerves and vessels.

Arterial Supply of Distal Phalanx
Before entering the pulp space, the digital artery gives off its epiphyseal branch to the proximal one-fifth of the distal phalanx. After entering the space, the diaphyseal branches arise. They supply the distal four-fifth of the phalanx.

Clinical insight ...
Whitlow or Felon
An abscess in the pulp space is called whitlow or Felon. Being the most exposed part of the finger the pulp space is frequently injured and infected. When abscess forms in it, there is throbbing pain due to increased tension in the closed space. The complication of Whitlow is avascular necrosis of the distal four-fifth of the distal phalanx due to thrombosis of the diaphyseal branches of the digital artery. This complication can be avoided if the abscess is drained at the right time by placing a small incision on the point of maximum tenderness.

Forearm Space or Space of Parona
Though it is located in the forearm, the space of Parona is included under palmar spaces because it is in continuity with the palmar spaces behind the flexor tendons through the carpal tunnel.

Boundaries
i. Anteriorly, it is bounded by long flexor tendons wrapped in synovial sheaths.
ii. Posteriorly, it is bounded by pronator quadratus muscle.

Very rarely this space is filled with pus if the inflamed radial or ulnar bursa bursts here.

Arteries of Hand
The hand is provided with abundant blood supply through branches of the radial and ulnar arteries, which form the superficial and deep palmar arterial arches.

Superficial Palmar Arch (Fig. 20.7)
This arterial arch is located between the palmar aponeurosis and the long flexor tendons.

Modes of Completion of Superficial Palmar Arch
The superficial branch of the ulnar artery continues in the palm as superficial palmar arch. The completion of the arch on the lateral side is variable.

i. In the most usual mode, superficial palmar branch of radial artery joins the superficial branch of ulnar artery.
ii. Sometimes either the princeps pollicis or the radialis indicis (branches of radial artery) may complete the arch.

iii. Rarely the median artery, a branch of anterior interosseous artery completes the arch.

Branches

Three common palmar digital arteries and one proper digital artery arise from the convexity of the arch.

i. The common palmar digital arteries are reinforced by palmar metacarpal arteries (branches of deep palmar arch), which join them nearer the webs. Each artery divides into two proper digital arteries. The six proper digital arteries thus formed supply the adjacent sides of the medial four fingers.

ii. The proper digital artery (arising directly from the arch) supplies the medial side of the little finger.

Surface Marking

A distally convex line drawn from the distal border of fully extended thumb across the palm to meet the hook of the hamate represents the superficial arch.

Deep Palmar Arch (Fig. 20.8)

This arterial arch is located deep in the palm between the flexor tendons in front and the interossei muscles and the metacarpal bones behind.

Formation: The continuation of the radial artery in the palm mainly forms the deep palmar arch, which is completed on the medial side by the deep branch of ulnar artery. The deep branch of the ulnar nerve lies in the concavity of the arch.

Branches

i. Three palmar metacarpal arteries join the common palmar digital arteries (branches of superficial palmar arch).

ii. Three perforating arteries pass through the second, third and fourth interosseous spaces to anastomose with the dorsal metacarpal arteries.

iii. Recurrent arteries turn proximally and pass in front of the carpus to take part in the formation of palmar carpal arch.

Surface Marking

A four centimeter long horizontal line drawn across the palm from a point just distal to the hook of hamate represents the deep palmar arch. It is 1 to 1.5 cm proximal to the superficial palmar arch.

Clinical insight...

Bleeding Injury of Palmar Arterial Arches

Injury to palmar arterial arches causes uncontrollable bleeding. The compression of the brachial artery against the humerus (Fig. 16.5) is the most effective method to arrest bleeding. Tying or clamping the radial or ulnar or both radial and ulnar arteries proximal to the wrist fails to control the bleeding because of the communications between the palmar and dorsal carpal arches with the palmar arches. (Note: The interosseous arteries arising from proximal part of ulnar artery contribute to carpal arches)

Nerves of Palm

1. The median nerve (Fig. 20.9) enters the palm under the distal margin of flexor retinaculum. It divides almost
immediately into six branches (recurrent nerve, three proper palmar digital nerves and two common palmar digital nerves).

i. The short and thick recurrent branch is the lateral most. It turns proximally on the distal margin of the flexor retinaculum to enter the thenar muscles. It supplies abductor pollicis brevis, opponens pollicis and the superficial head of flexor pollicis brevis.

ii. The first proper palmar digital nerve supplies the radial side of the thumb.

iii. The second proper palmar digital nerve supplies the medial side of the thumb.

iv. The third proper palmar digital nerve supplies the radial side of the index finger and also gives a motor branch to the first lumbrical muscle (motor twig enters muscle from its superficial aspect).

v. The lateral common palmar digital nerve gives a motor twig to the second lumbrical muscle (motor twig enters the muscle from its superficial aspect). Then it divides into two proper palmar digital nerves for the adjacent sides of index and middle fingers.

vi. The medial common palmar digital nerve divides into two branches for the adjacent sides of middle and ring fingers.

All the proper palmar digital branches cross over the tips of the respective digits and supply the nail bed as well some variable area on the dorsal aspect of digits beyond the nail bed.

2. The ulnar nerve terminates on the anterior surface of the flexor retinaculum in close relation to the pisiform bone into a smaller superficial and a larger deep branch.

i. The superficial branch of ulnar nerve (Fig. 20.10) enters the palm under cover of the palmaris brevis muscle, which it supplies and then divides into one proper digital and one common digital branch. The proper digital nerve supplies the medial side of little finger and the common digital branch divides to supply adjacent sides of little and ring fingers.

The digital nerves cross over the tips of digits to supply the nail bed and adjacent area of terminal digit.

**Clinical insight ...**

**Digital Nerve Block (Fig. 20.11)**

This procedure is necessary while draining abscesses on digits or repairing the tendons in digits to name a few. There are four digital nerves per digit (two palmar and two dorsal). To achieve, full anesthesia needle is inserted on either side of the base of the digit from dorsal aspect to inject the anesthesia.

**Intrinsic Muscles of Hand**

There are twenty intrinsic muscles located inside the palm. They are described into four groups, subcutaneous (palmaris brevis), hypothenar muscles (muscles acting on
little finger), thenar muscles (muscles acting on thumb) including adductor pollicis and muscles acting on fingers (interossei and lumbricals).

**Hypothenar Muscles**

The hypothenar muscles consist of three short muscles, the abductor digiti minimi medially and the flexor digiti minimi laterally, on a superficial plane. The opponens digiti minimi lies on a deeper plane.

**Abductor Digiti Minimi**

This muscle originates from the pisiform bone, pisohamate ligament and the tendon of flexor carpi ulnaris. It is inserted into the ulnar side of the base of proximal phalanx of little finger. It abducts the little finger away from the fourth finger.

**Testing Function of Abductor Digiti Minimi**

This is the first muscle to show weakness in ulnar nerve lesion, hence it is essential to know to test its function.

The subject is asked to place the back of the hand on the table and to abduct the little finger against resistance.

**Flexor Digiti Minimi**

Flexor digiti minimi (flexor digiti minimi brevis) takes origin from the hook of hamate and adjacent flexor retinaculum. It is inserted into the ulnar side of the base of proximal phalanx of little finger. It flexes the little finger at MCP joint.

**Testing Function of Flexor Digiti Minimi**

The subject is asked to flex the MCP joint of little finger against resistance.

This muscle is tested clinically in suspected cases of ulnar nerve lesion, since the loss of function of this muscle may be the only sign initially.

**Opponens Digiti Minimi**

This muscle has a common origin with the flexor digiti minimi and is inserted into the ulnar side of the shaft of fifth metacarpal bone. It causes flexion of fifth metacarpal bone. It draws the bone anteriorly and laterally, thus deepening the hollow of the palm.

**Nerve Supply of Hypothenar Muscles**

All the three muscles receive branches from the deep branch of the ulnar nerve.

**Thenar Muscles**

The thenar muscles consist of three short muscles, the abductor pollicis brevis laterally and flexor pollicis brevis medially, in the superficial plane and opponens pollicis on a deeper plane.

**Abductor Pollicis Brevis**

This muscle takes origin from the tubercle of scaphoid, trapezium and the adjoining part of flexor retinaculum. It is inserted into the lateral side of the base of proximal phalanx of thumb. The muscle abducts the thumb.

**Testing Function of Abductor Pollicis Brevis**

The subject is asked to abduct the thumb in a plane at right angle to the palmar aspect of index finger against the resistance of examiner’s own thumb.

This muscle is tested clinically, in case of median nerve compression in the carpal tunnel. It is the first muscle to show weakness in carpal tunnel syndrome.
Flexor Pollicis Brevis
This muscle has two heads. The superficial head takes origin from the tubercle of trapezium and the deep head takes origin from the capitate and trapezoid bones. It is inserted into the lateral side of the base of the proximal phalanx of thumb. There is usually a sesamoid bone at the site of its insertion.

This muscle is a flexor of the thumb.

Opponens Pollicis
This muscle takes origin from the tubercle of trapezium and the adjacent part of flexor retinaculum. It is inserted into the lateral half of the palmar surface of first metacarpal bone.

It flexes and medially rotates the first metacarpal bone so as to help in opposition of the thumb.

Testing Function of Opponens Pollicis
This muscle is tested by asking the subject to touch the tip of little finger with the point of thumb or by asking the subject to make a circle with the thumb and index finger.

Nerve Supply of Thenar Muscles
i. The recurrent branch of median nerve supplies abductor pollicis brevis, opponens pollicis and superficial head of flexor pollicis brevis.
ii. The deep branch of ulnar nerve supplies the deep head of flexor pollicis brevis.

Adductor Pollicis (Fig. 20.12)
This muscle has two heads of origin. The oblique head arises from the capitate bone and bases of the second and third metacarpal bones. The transverse head takes origin from the palmar aspect of third metacarpal bone. The adductor pollicis is inserted into the medial side of the base of the proximal phalanx of thumb. It adducts the thumb from the abducted position.

Nerve Supply
The deep branch of the ulnar nerve supplies it with its terminal branches.

Testing Function of Adductor Pollicis
Froment’s test is performed to assess the strength of the adductor pollicis muscle. With both palms held together a card is kept between the thumbs and index fingers of the patient. Then the patient is asked to grip the card tightly. Thumb on the affected side flexes at the IP joint due to action of flexor pollicis longus, which compensates the action of adductor pollicis.

Lumbral Muscles (Fig. 20.13)
Lumbral is a Latin word, which means earthworm. The shape of the lumbral muscle is like that of earthworm. The lumbricals are four tiny muscles, which are numbered one to four from lateral to medial side.

Origin and Insertion
The first lumbrical arises from tendon of FDS going to index finger, the second from tendon of FDS going to middle
finger, the third from adjacent sides of tendons of FDS going to the middle and ring fingers and the fourth from adjacent sides of FDS tendons going to ring and little fingers. Each lumbrical ends in a tendon which enters the web space and turns dorsally along the lateral side of MCP joint. It is inserted into the lateral basal angle of corresponding extensor expansion. Thus, lumbricals are the connecting link between the flexor and extensor tendons of the digits (Fig. 20.14). A connective tissue sheath called lumbrical canal surrounds each lumbrical tendon (for clinical importance of these canals read palmar spaces) (Table 20.1).
Adduction of Fingers
The palmar interossei are adductors of the fingers from the central axis passing through the middle finger. The second palmar interosseous adducts the index finger, the third adducts the ring finger, and the fourth adducts the little finger. There is no adduction movement of the middle finger, hence no palmar interosseous is attached to it.

Abduction of Fingers
The dorsal interossei are abductors of the middle three fingers. The first dorsal interosseous abducts the index finger away from the middle finger, the second abducts the middle finger on the radial side, the third abducts the middle finger on the ulnar side and the ring finger is abducted away from the middle finger by the fourth muscle. This explains why there are two dorsal interossei for the middle finger. Since the little finger has its own abductor no dorsal interosseous muscle is attached to it.

Deep Branch of Ulnar Nerve (Fig. 20.16)
The deep branch of ulnar nerve begins near the pisiform bone and enters the hypothenar compartment of palm. It gives motor twigs to abductor digiti minimi, flexor digiti minimi and opponens digiti minimi. Accompanied by deep branch of ulnar artery, the nerve turns laterally around the hook of the hamate and crosses the palm. In this mediolateral course it courses posterior to the flexor tendons. It supplies all the interossei muscles and medial two lumbrical muscles. It ends by supplying the adductor pollicis and the deep head of flexor pollicis brevis muscles. The deep branch of ulnar nerve supplies muscles involved in precision and fine movements of digits. Therefore, it is aptly called the musician’s nerve.

Extensor Expansion (Fig. 20.17)
Each extensor digitorum tendon flattens in to the extensor expansion over the MCP joint.

Parts of Extensor Expansion
The extensor expansion is triangular in shape. Its base encircles the MCP joint on all sides except the palmar aspect. Each basal angle is fixed to the deep palmar metacarpal ligament. Its thickened lateral margin receives the insertion of lumbricals and interossei. Its thick axial part carries the insertion of the extensor tendon or tendons. The axial part and the margins are interconnected by fibrous tissue nearer the base, so as to ensure the firm anchorage of the extensor expansion to the back of MCP joint. Closer to thePIP joint, the axial slip splits in to three slips of which the central one is attached to the base of the middle phalanx. Each collateral slip joins the lateral margin of its side and then unites with the fellow of the other side on the dorsal aspect of the middle phalanx. The united collateral slips cross the DIP joint and gain attachment to the base of the terminal phalanx. The central and collateral slips function independently. The central slip carrying the insertion of the extensor tendon acts on the MCP joint while the collateral slips carrying the insertion of lumbricals and interossei act on MCP, PIP and DIP joints.

The slips of extensor expansion are closely applied to the dorsal aspects of the interphalangeal joints. In fact, they replace the fibrous capsule of IP and MCP joints on the dorsal aspect.

Combined Actions of Interossei and Lumbricals
The interossei and lumbricals together flex the metacarpophalangeal joints and simultaneously extend the
interphalangeal joints. They can perform this unusual combination of actions due to their relations to the axes of movements of MCP and IP joints (Fig. 20.14). These muscles cross the metacarpophalangeal joints on palmar aspect therefore they are able to flex MCP joints. Through the extensor expansion, the muscles cross the interphalangeal joints on dorsal aspect. Accordingly the pull of the muscles is transferred to the dorsal side of the axes of the interphalangeal joints, which they extend.

Testing Function of Dorsal Interossei

The principle of testing the dorsal interossei is to assess the capacity of middle three fingers to adduct against resistance.

i. To test first dorsal interosseous, the index finger is abducted. The examiner can feel the contracted muscle in the first intermetacarpal space.

ii. To test the second muscle, the extended middle finger is crossed dorsally over the extended index finger (good luck sign).

iii. To test the third muscle, the middle finger is abducted towards the ring finger.

iv. To test the fourth muscle, ring finger is abducted.

Testing Function of Palmar Interossei

The principle of testing the palmar interossei is to assess the capacity of index, ring and little fingers to adduct against resistance.

i. To test the second palmar interosseous, muscle, the index finger is adducted towards the middle, finger.

ii. To test the third muscle, the ring finger is adducted.

iii. To test the fourth muscle, the little finger is adducted.

**Complete Claw Hand**

Paralysis of all the interossei and lumbricals produces complete or true claw hand deformity (Fig. 12.5) in which there is hyperextension of MCP and hyperflexion of PIP and DIP joints of all fingers.

**Movements of Thumb and Fingers**

The thumb enjoys free mobility compared to the other fingers, hence functionally it is regarded as one half of the hand. An opposable thumb is a human character. It is designed for grasping objects. The anatomical peculiarity of the thumb is that it has two phalanges and one modified metacarpal bone. Its metacarpal is at right angles to the plane of other metacarpals. The base of this metacarpal articulates with the trapezium to form the first carpometacarpal joint. It is a saddle variety of synovial joint, which confers great mobility to the thumb. Following movements take place in this joint (Fig. 20.18).

i. In flexion, the palmar surface of the thumb moves across the palm towards the ulnar border till the thumb comes in contact with the palm. Flexion is always accompanied by conjunct (automatic) medial rotation.

ii. In extension, the thumb moves away from the palm so that its dorsal surface comes to face the dorsum of hand. Extension is necessarily accompanied by lateral rotation of thumb.

iii. In abduction, the thumb moves away from the index finger at right angles to the plane of the palm.

iv. In adduction, the thumb is brought back to the resting position (in front of and in contact with the palmar surface of the index finger).

v. In opposition, the tip of the thumb is brought in contact with the base or tip of any other finger. It is a composite movement consisting of abduction, flexion and medial rotation. It can be defined as the movement of flexion with medial rotation of abducted thumb.

vi. In reposition, the opposed thumb is brought back to the resting position. In this movement there is
extension, lateral rotation and adduction of abducted thumb.

vii. Circumduction is an angular motion of the thumb consisting of flexion, abduction, extension and adduction.

**First Carpometacarpal Joint**

It is the trapezio-metacarpal joint. It is a saddle type of synovial joint. The articulating ends consist of the distal articular surface of trapezium and the proximal articular surface of the base of first metacarpal bone. Both the articulating surfaces are reciprocally concavoconvex. The fibrous capsule lined with synovial membrane encircles the joint. The carpometacarpal ligaments reinforce the joint.

**Muscles Acting on Thumb**

A total of nine muscles act on the thumb. The long muscles are extensor pollicis longus, extensor pollicis brevis, abductor pollicis longus and flexor pollicis longus. The short muscles are the three thenar muscles, adductor pollicis and the first palmar interosseous.

i. The flexion is produced by flexor pollicis longus and flexor pollicis brevis.

ii. The extension is produced by extensor pollicis brevis, extensor pollicis longus and abductor pollicis longus.

iii. The adduction is produced mainly by adductor pollicis assisted by first palmar interosseous muscle.

iv. The abduction is produced mainly by abductor pollicis brevis, which is assisted by abductor pollicis longus.

v. The opposition movement is the result of synergistic actions of abductor pollicis longus and brevis, opponens pollicis and flexor pollicis brevis.

vi. The reposition (reverse of opposition) is by synergistic actions of extensor pollicis brevis and longus, abductor pollicis longus and brevis (for extension and lateral rotation) and adductor pollicis muscles.

**Metacarpophalangeal (MCP) Joints**

The knuckles indicate the positions of the MCP joints. These joints are condyloid types of synovial joints. The articulating ends are the convex metacarpal head and the spherical fossa on the base of the proximal phalanx. The fibrous capsule covers the joint except dorsally where it is replaced by extensor expansion. The collateral ligaments support the joints on either side. The palmar ligament is very strong. It is in the form of a fibrous plate attached firmly to the base of proximal phalanx, but loosely to the neck of the metacarpal. This plate undergoes excursions relative to the movements of the joint. The margins of the palmar ligament give attachment to deep transverse ligament, fibrous flexor sheath, and slips of palmar aponeurosis, collateral ligaments and transverse fibers of extensor expansion.

**Movements**

The movements of flexion-extension and adduction-abduction take place at these joints.

**Flexion**

i. The flexor digitorum superficialis assisted by flexor digitorum profundus flex the joints in power grip.

ii. The interossei and lumbricals flex these joints in precision grip.

**Extension**

The extensor digitorum is the main extensor. In the case of little finger extensor digiti minimi assists likewise, extensor indicis assists the extension of index finger.

**Interphalangeal (IP) Joints**

These joints consist of two rows, the proximal interphalangeal (PIP) joints and the distal interphalangeal (DIP)
joints. The PIP and DIP joints are simple hinge types of synovial joints. The thumb has only one interphalangeal joint. On the dorsal aspect, the capsule of these joints is replaced by the extensor expansion. Collateral ligaments, which are slack, support the joints, when the fingers are extended.

**Movements**

IP joints permit movements of flexion-extension.

i. The flexor digitorum superficialis is the main flexor at the PIP joint.

ii. The flexor digitorum profundus alone causes flexion of DIP joint.

iii. The interossei and lumbricals produce the extension at PIP and DIP joints.

In fully extended position of MCP joints, the distal part of extensor digitorum is slackened, so that it becomes ineffective at IP joints. This can be understood from the claw hand deformity, in which MCP joints are hyperextended and IP joints are hyperflexed in spite of normal extensor digitorum. In other words, the extensor digitorum can extend the MCP joints only.

### Clinical insight ...

<table>
<thead>
<tr>
<th>Deformities of Fingers</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. In swan neck finger, there is hyperextension of PIP and flexion at DIP joints due to degeneration of the flexor digitorum superficialis tendon and of the insertion of extensor expansion in the terminal digit.</td>
</tr>
<tr>
<td>ii. In buttonhole finger (Boutonniere deformity), there is flexion at PIP and hyperextension at DIP joint due to rupture of the central slip of extensor expansion.</td>
</tr>
<tr>
<td>iii. The mallet finger (baseball finger) is due to injury to attachment of extensor expansion in distal phalanx so the terminal phalanx is flexed.</td>
</tr>
</tbody>
</table>
The median nerve originates from the brachial plexus in axilla by two roots.

i. The lateral root arises from the lateral cord and carries C5, C6, and C7 fibers in it.

ii. The medial root arises from the medial cord and carries C8 and T1 fibers in it.

**Union of Roots**
The medial root crosses the third part of the axillary artery and unites with the lateral root either in front of or on the lateral side of the artery to form the median nerve. So, the root value of the median nerve is C5, C6, C7, C8 and T1.

**Course and Relations (Fig. 21.1)**

i. In the axilla, the median nerve lies on the lateral side of the third part of the axillary artery. It enters the arm at the lower border of teres major muscle along with other nerves and the vessels in the axilla.

ii. In the arm initially, the median nerve lies in lateral relation to the brachial artery. It crosses in front of the brachial artery at the level of insertion of the coraco-brachialis and travels downwards in medial relation to the artery to the cubital fossa.

iii. In the cubital fossa, the median nerve is located medial to the brachial artery. The nerve and the artery are protected anteriorly by the bicipital aponeurosis (which provides a platform for the median cubital vein). The median nerve leaves the cubital fossa between the humeral (superficial) and ulnar (deep) heads of pronator teres.

iv. In the forearm, the median nerve passes downwards behind the tendinous bridge between the humeroulnar and radial heads of flexor digitorum superficialis. During its descent in the forearm, it remains adherent to the deep surface of flexor digitorum superficialis. About five centimeter proximal to the flexor retinaculum the median nerve becomes superficial (hence vulnerable to laceration injuries) lying along the lateral edge of flexor digitorum superficialis tendons and immediately posterior to the palmaris longus tendon as it approaches the flexor retinaculum.

v. In the carpal tunnel, the median nerve lies deep to flexor retinaculum. It is anterior to the tendons of long flexors of digits and the tendon of flexor pollicis longus. There is tight packing of nine tendons, their synovial sheaths and the median nerve in the carpal tunnel. Therefore, in case of narrowing of the carpal tunnel due to any cause median nerve is liable to compression.

**Branches**

*Branches in Arm:* The median nerve supplies a twig to the pronator teres just above the elbow in addition to supplying sympathetic fibers to the brachial artery.

*Branches in cubital fossa:* It gives muscular branches from its medial side to pronator teres, flexor carpi radialis, palmaris longus and flexor digitorum superficialis. It also gives articular branches to elbow and superior radio-ulnar
joints. At its point of exit the anterior interosseous branch arises from the median nerve.

Branches in forearm: It supplies the part of flexor digitorum superficialis, which continues as the tendon for index finger. Before entering the carpal tunnel its palmar cutaneous branch arises. This cutaneous branch supplies the skin overlying the thenar eminence and the lateral part of the palm.

Branches in palm: The median nerve flattens at the distal border of the flexor retinaculum and divides into six branches (Fig. 20.9) as follows:

i. The recurrent branch is the most lateral branch. It is thick and short. It doubles back on the free margin of flexor retinaculum to gain entry into the thenar compartment. It supplies flexor pollicis brevis (superficial head), abductor pollicis brevis and opponens pollicis.

ii. The lateral three proper digital branches supply the sides of the thumb and radial side of index finger. The digital branch for the radial side of index finger also supplies the first lumbral.

iii. There are two common digital branches. The lateral common digital branch after supplying second lumbral divides into two proper digital branches for the adjacent sides of index and middle fingers. The medial common digital branch divides into two proper digital branches, which go to the adjacent sides of middle and ring fingers. All palmar digital branches supply the dorsal aspect of the distal one and half to two digits of the fingers including the nail beds.

(Note: The median nerve is called laborer’s nerve because it supplies flexor muscles that are responsible for baggage or hook grip)

**Clinical insight ...**

**Effects of Lesion or Injury**

The effects of the lesion of the median nerve depend on the level of the site of lesion.

**Injury at Elbow**

The median nerve may be injured due to supracondylar fracture of humerus or pronator syndrome (entrapment of median nerve between two heads of pronator teres). This results in paralysis of all the muscles supplied by median nerve in forearm and palm and also the sensory loss.

**Motor Effects**

i. Loss of pronation

ii. Hand of Benediction deformity (Fig. 21.2A), which is due to paralysis of both superficial and deep flexors of the middle and index fingers (loss of flexion at proximal IP and distal IP joints). The ring and little fingers can be flexed due to retention of the nerve supply of their FDP.

iii. Paralysis of flexor pollicis longus results in loss of flexion of thumb.
iv. Paralysis of lateral two lumbricals results in inability to flex lateral two MCP joints.

v. Ape thumb or Simian hand deformity (Fig. 21.2B) is due to paralysis of thenar muscles. In this deformity, the thumb comes to lie in line with other fingers and there is thenar atrophy producing ape thumb deformity.

**Sensory Effects (Figs 21.3A and B)**

Injury above the origin of palmar cutaneous branch results in loss of sensation over the central part of palm, lateral half of palm and the lateral three and half digits in addition to loss of sensation on the dorsal aspects of the same digits (Figs 21.3A and B).

**Injury at Mid-forearm**

i. It manifests as pointing index deformity (Fig. 21.2C) due to paralysis of only the part of FDS that continues as the tendon of index finger and ape thumb deformity.

ii. The sensory loss is similar to that seen in lesion at previous level.

**Injury at Wrist**

The superficial laceration at wrist, usually, due to cut may damage the palmar cutaneous branch only. This results in sensory loss over the skin of lateral palm including the thenar eminence.

**Injury at Carpal Tunnel**

**Sensory Effects**

Initially the patient experiences symptoms like, numbness, tingling and pins and needles sensations in the lateral three and half digits. In due course, there may be total sensory loss in lateral three and half digits and also on the dorsal aspects of the same digits. (There is no sensory loss on the lateral part of palmar skin because of the sparing of palmar cutaneous branch in lesion at this level).

**Motor Effects**

There is ape thumb deformity due to paralysis of thenar muscles. There is loss of flexion of proximal IP joints of fingers and weakness of flexion of lateral two MCP joints. (Injury to recurrent branch of the median nerve alone produces paralysis of thenar muscles, causing ape thumb but no sensory loss)

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**ULNAR NERVE**

The ulnar nerve arises in the axilla from the medial cord of brachial plexus. Its root value is C8 and T1.

**Course and Relations (Fig. 21.4)**

i. In the axilla, the ulnar nerve lies medial to the third part of axillary artery between it and the axillary vein.
Chapter

It enters the arm as part of the main neurovascular bundle.

ii. In the arm, the ulnar nerve is related medially to the brachial artery up to the level of insertion of coracobrachialis, where it pierces the medial intermuscular septum to enter the posterior compartment of the arm. Here, it courses downward on the medial head of the triceps along with the superior ulnar collateral artery. At the back of the medial epicondyle, the ulnar nerve is lodged in a groove. The pressure on the ulnar nerve at this site produces “funny bone” symptoms, with tingling along the hypothenar eminence and little finger. In leprosy, the ulnar nerve is thickened and hence palpable at this site in the early stages of the disease. The ulnar nerve leaves the arm between the humeral and ulnar heads of flexor carpi ulnaris, superficial to and in intimate contact with ulnar collateral ligament of the elbow joint.

iii. In the forearm, the ulnar nerve lies on the flexor digitorum profundus and is covered with flexor carpi ulnaris in the upper-third of forearm. In its initial course in the forearm, the ulnar nerve and ulnar artery are widely separated from each other. In the lower two-thirds of forearm, the ulnar nerve becomes superficial. It is lateral to the flexor carpi ulnaris tendon. In this part of its course, the ulnar nerve and the ulnar artery descend together (the artery being on the lateral side of the nerve).

iv. At the wrist, the ulnar nerve passes anterior to the flexor retinaculum (in Guyon’s canal) on the lateral side of pisiform bone and medial to the ulnar artery.

v. In the palm, the ulnar nerve divides under cover of palmaris brevis into its terminal branches namely superficial and deep.

Branches in Forearm

i. Articular branch to elbow joint.

ii. Muscular branches to medial half of flexor digitorum profundus and to the flexor carpi ulnaris.

iii. Palmar cutaneous branch arises at the mid-forearm level.

iv. Dorsal cutaneous branch arises five centimeter proximal to flexor retinaculum.

Distribution in Palm

i. The superficial terminal branch of ulnar nerve supplies palmaris brevis and divides into one proper palmar digital branch for the medial side of little finger and the other common palmar digital branch for the adjacent sides of little and ring fingers. The palmar digital branches cross over to the dorsal side to supply the nail bed of the medial one and half digits.

ii. The deep terminal branch supplies the hypothenar muscles and turns deeply between the abductor digitii minimi and flexor digitii minimi muscles. The nerve accompanied by deep branch of the ulnar artery turn laterally on the base of the hook of hamate. While crossing the palm in mediolateral direction, the nerve lies in the concavity of the deep palmar arch. It supplies the dorsal and palmar interossei, medial two lumbricals (3rd and 4th lumbricals) and deep head of flexor pollicis brevis before it enters the adductor pollicis muscle to supply it.

(Note: The deep branch of the ulnar nerve is called ‘musician’s nerve’ because it innervates all the small muscles of the hand involved in fine movements of hand)
Effects of Lesion

The effects of the lesion of the ulnar nerve depend on the level of the site of lesion.

Injury at Elbow

Being in exposed position, the ulnar nerve is injured in cubital tunnel syndrome (compression between two heads of flexor carpi ulnaris), fracture of medial epicondyle, cubitus valgus, etc.

Motor Effects

i. The weakness of flexor digitorum profundus muscle of the ring and little fingers causes inability to flex the terminal phalanx of these fingers.

ii. There is marked clawing at the medial two fingers due to paralysis of interossei and medial two lumbricals (Fig. 21.5).

iii. The atrophy of all interossei results in guttering on the dorsum of hand.

iv. There is loss of adduction of thumb. Froment’s sign is positive.

Sensory Effects

There is sensory loss in the medial half of palmar and dorsal aspects of hand and medial one and half fingers (Figs 21.6A and B).

Tardy or late ulnar nerve palsy occurs in valgus deformity of the elbow, in which the ulnar nerve is subjected to a gradual stretch leading to a late or gradual palsy.

Injury at Wrist

The ulnar nerve is superficial to flexor retinaculum and hence vulnerable to compression (Guyon’s canal syndrome) or laceration.

i. This usually results in claw hand deformity of medial two digits and guttering of interosseous spaces.

ii. The sensory loss is limited only to medial one and half digits (palmar and dorsal cutaneous branches are spared).

Injury in the Palm

In the palm, the deep branch of ulnar nerve may be compressed against the hamate bone, when the hand is used as a mallet or if a vibrating tool rubs against it. This gives rise to ulnar clawing of the hand but no sensory loss.

Froment’s Sign

The Froment’s sign is positive in ulnar nerve injury. When the patient pinches a piece of paper between thumb and index finger, the thumb on the affected side flexes. This is due to weakness of adductor pollicis muscle (supplied by ulnar nerve), which permits uncontrolled contraction of flexor pollicis longus.

Clinical insight ...

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Know More ...

The claw hand due to injury at the wrist is more obvious compared to the injury at elbow. This is known as ulnar nerve paradox. The lesion at the wrist spares the flexor digitorum profundus, which brings about powerful flexion at the interphalangeal joints causing marked clawing.
**RADIAL NERVE**

The radial nerve arises from the posterior cord of brachial plexus in the axilla. It is the largest branch of the brachial plexus. Theoretically, the nerve carries fibers from all the roots of brachial plexus but T1 fibers are not constant (C5, C6, C7, C8, T1).

**Course and Relations**

i. In the axilla, the radial nerve lies posterior to third part of the axillary artery and anterior to the three muscles forming the posterior wall of the axilla (subscapularis, teres major and latissimus dorsi). The radial nerve leaves axilla as a part of the principal neurovascular bundle to enter the arm at the level of lower border of teres major muscle.

ii. In the arm, the radial nerve is posterior to the brachial artery. Here it gives medial muscular branches to long and medial heads of the triceps brachii. The branch for the medial head of triceps lies very close to the ulnar nerve and hence is called the ulnar collateral nerve.

iii. The radial nerve soon passes between the long and medial heads of triceps to enter the lower triangular space, through which it reaches the spiral groove along with the profunda brachii vessels. This neurovascular bundle in the spiral groove lies in direct contact with the humerus, between the lateral and the medial heads of triceps.

iv. At the lower end of the spiral groove, the radial nerve is accompanied by radial collateral branch of the profunda artery. The two together pierce the lateral intermuscular septum of the arm and enter the anterior compartment, where they descend between the brachialis and brachioradialis and more distally between the brachialis and extensor carpi radialis longus muscles. In this location, the radial nerve supplies branches to brachioradialis and extensor carpi radialis longus. It also gives a few proprioceptive fibers to the brachialis.

v. At the elbow, the radial nerve is hidden under cover of the brachioradialis muscle. At the level of lateral epicondyle of humerus, it terminates into superficial and deep branches in the lateral part of cubital fossa. The deep terminal branch (also otherwise described as posterior interosseous nerve) gives branches to supinator and extensor carpi radialis brevis before entering the substance of supinator on way to the posterior compartment of forearm.

**Branches of Radial Nerve in Axilla**

i. Posterior cutaneous nerve of arm

ii. A branch to long head of triceps brachii

**Branches of Radial Nerve in Spiral Groove**

i. The muscular branches supply the medial and lateral heads of triceps and the anconeus. The branch to anconeus lies in direct contact with the humerus as it passes downwards through the substance of the medial head (along with the middle collateral branch of profunda brachii artery).

ii. The cutaneous branches are posterior cutaneous nerve of forearm and lower lateral cutaneous nerve of arm.

**Terminal Branches of Radial Nerve**

Further course of the posterior intersosseous nerve is described in posterior compartment of the forearm (Chapter 18).

**Superficial Branch of Radial Nerve**

The superficial branch of radial nerve is entirely sensory. It travels in the anterolateral part of the forearm under cover of brachioradialis. During its downward course it lies successively on the pronator teres, flexor digitorum superficialis and flexor pollicis longus. The radial artery is on its medial side. About seven centimeter above the wrist the superficial branch of radial nerve passes deep to the tendon of brachioradialis and turns dorsally in the direction of the anatomical snuffbox. In this relatively unprotected position, the nerve is liable to be compressed by tight bracelets or watch straps. As it courses in the superficial fascia of the anatomical snuffbox the radial nerve divides into dorsal digital branches. It supplies a variable area of skin over the lateral side of the dorsum and lateral three and half digits. It may supply the proximal and middle phalanges or the proximal and half of the middle phalanges of the above digits.

**Surface Marking of Superficial Branch**

Mark the following three points. The first point is one centimeter lateral to the tendon of biceps brachii. The second point is at the junction of upper two-thirds and lower one-third of the lateral margin of the forearm. The third point is the anatomical snuffbox. A line joining the marked points represents the radial nerve in the forearm.

**Clinical insight ...**

**Effects of Lesion**

The effects of lesion of radial nerve depend on the level of site of the lesion.

*Contd...*
Injury at Axilla

In the axilla, the radial nerve is injured due to pressure of the crutch (crutch palsy).

Motor Effects

All the muscles supplied by the radial nerve directly or indirectly through its posterior interosseous branch are paralyzed.

- Loss of extension at elbow (paralysis of triceps brachii)
- Wrist drop (Fig. 21.7) is due to paralysis of wrist extensors (extensor carpi radialis longus, extensor carpi radialis brevis and extensor carpi ulnaris)
- Loss of extension at metacarpophalangeal joints of fingers (finger drop due to paralysis of extensor digitorum) and thumb drop due to paralysis of extensor pollicis longus and brevis.

Sensory Effects

More often there is an isolated sensory loss on the dorsum of the hand at the base of the thumb (Fig. 21.8).

Injury in Mid-arm

The radial nerve may be injured due to fracture of shaft of humerus, inadvertent intramuscular injection in the triceps brachii or direct pressure on radial nerve as in saturday-night palsy. The long head of the triceps is spared, hence extension of the elbow is not totally lost. Otherwise the effects of injury are similar to those found at injury in the axilla.
CASE 1
An elderly man came to the hospital with the complaint of a pulsatile soft swelling in the left axilla. On examination it was found that abduction movement of his left arm was restricted and there was sensory loss on the skin over lower half of deltoid muscle. There was slight edema (swelling) of the upper limb.

Questions and Solutions

1. Which large blood vessel in the axilla is likely to give rise to a pulsatile swelling?
   Axillary artery

2. What is dilatation of a blood vessel called?
   Aneurysm

3. Give the extent and surface marking of this vessel.
   The axillary artery extends from outer border of first rib to lower margin of teres major.
   For surface marking of axillary artery refer to chapter 12.

4. Name the muscle that crosses this vessel anteriorly.
   Pectoralis minor muscle

5. Describe with the help of diagrams the relations of this vessel.
   Refer to chapter 12 for relations of the vessel.

6. Name the branches of this vessel in order.
   First part - Superior thoracic artery
   Second part - Acromiothoracic and lateral thoracic arteries
   Third part - Subscapular artery, anterior circumflex humeral artery and posterior circumflex humeral artery

7. Compression of which adjacent blood vessel will cause edema of the upper limb. Give the formation and termination of this vessel.
   Compression of axillary vein leads to swelling of upper limb. This vein is formed at the lower margin of teres major muscle in the anterior compartment of arm by the union of basilic vein and venae comitantes of brachial artery (in some cases the basilic vein continues as axillary vein at the lower margin of teres major). The axillary vein continues as the subclavian vein at the outer margin of first rib.

8. Explain sensory loss over the lower half of deltoid and restricted abduction in this case.
   The aneurysm of axillary artery compresses the axillary nerve, which is located posterior to the third part of axillary artery. The compression of motor fibers of axillary nerve results in weakness of deltoid and restricted abduction. Compression of sensory fibers carried in upper lateral cutaneous nerve of arm (a branch of axillary nerve) results in sensory loss in the skin over the lower half of deltoid (regimental badge anesthesia).

CASE 2
A baby with a history of forceps delivery was brought to the pediatrician after four weeks for a routine check up. On examination, it was observed that the baby’s left arm was medially rotated and adducted and the left forearm was pronated and extended.

Questions and Solutions

1. Name the position of the upper limb seen in this baby.
   Porter’s tip position

2. Lesion at which site in the brachial plexus causes this position of the upper limb?
   Lesion at upper trunk or Erb’s point gives rise to Erb’s palsy which causes this position of upper limb.
3. Paralysis of which muscles results in medial rotation of arm?
   Infraspinatus and teres minor (lateral rotators of arm)

4. Paralysis of which muscles results in extended forearm?
   Biceps brachii, brachialis and brachioradialis (flexors of forearm)

5. Paralysis of which muscles results in adducted arm?
   Supraspinatus and deltoid (abductors of arm)

CASE 3

A 35-year-old woman came to the surgeon with complaint of hard, painless lump in the upper outer quadrant of the right breast. Examination revealed enlarged axillary lymph nodes on the right side and loss of mobility of the breast. X-ray of vertebral column showed irregular shadows in the bodies of L4 and L5 vertebrae.

Questions and Solutions

1. What is the probable diagnosis?
   Malignancy or cancer of right breast

2. Name the three muscles related to the base of the breast.
   Pectoralis major, serratus anterior and aponeurosis of external oblique muscle

3. How is the fixity of the breast tested?
   The patient is asked to press the hand on the hip forcibly to contract pectoralis major. After this the clinician moves the breast over the pectoral fascia in the direction of muscle fibers of pectoralis major. Loss of normal mobility or fixity of breast indicates spread of cancer cells in underlying pectoral muscle and fascia.

4. Which part of the breast is in contact with the pectoral group of lymph nodes and how does this part enter the axilla?
   Axillary tail of Spence enters the axilla by passing through foramen of Langer in axillary fascia.

5. What is the reason of irregular shadows in the lumbar vertebrae in the above case?
   The cancer cells detach and enter the veins of the breast, which drain into posterior intercostal veins (into which open the intervertebral veins). During rise in intra-thoracic pressure (in acts like coughing, straining, etc) there is reversal of blood flow in the intervertebral veins, which facilitates the entry of cancer cells into the internal vertebral venous plexus and into the vertebral bodies. For this reason, radiological examination of the vertebral column is mandatory in cases of breast cancer.

6. Describe lymphatic drainage of breast.
   Refer chapter 10 for lymphatic drainage of breast.

7. Describe the arterial supply of breast.
   i. Branches of lateral thoracic artery supply the lateral part of the breast.
   ii. Twigs from the perforating cutaneous branches of internal mammary artery in the second, third and fourth intercostal spaces supply its medial part.
   iii. Pectoral branches of acromiothoracic and superior thoracic arteries provide additional supply to the upper part of breast.
   iv. Posterior intercostal arteries in the second, third and fourth spaces supply the breast from its base.

CASE 4

A man involved in automobile accident was brought to the casualty. On examination, it was found that his left shoulder was flattened and the head of humerus was palpable in the infraclavicular fossa. An AP X-ray of the shoulder confirmed the diagnosis of anterior dislocation of shoulder joint. For the operation of reduction of the head of humerus, the orthopedic surgeon used the anterior approach for which skin incision was placed along the deltopectoral groove.

Questions and Solutions

1. Which long blood vessel is located in the deltopectoral groove?
   Cephalic vein

2. After retracting the deltoid and pectoralis major muscles from each other, which bony part of scapula is exposed?
   Coracoid process

3. Name the two muscles, which are attached to this bony part by a conjoint tendon.
   Short head of biceps brachii and coracobrachialis
4. Draw a diagram to show the relations of the shoulder joint.
   Refer to Fig. 14.5

5. Which nerve is in danger of injury in anterior dislocation of shoulder joint?
   Axillary nerve

6. Describe the origin and distribution of this nerve.
   The axillary nerve arises from posterior cord of brachial plexus in the axilla. Its root value is C5, C6. Axillary nerve provides following branches.
   i. Articular to shoulder joint
   ii. Sensory branches to upper lateral cutaneous nerve of arm (which supplies skin over lower half of deltoid muscle).
   iii. Motor branches to deltoid and teres minor

7. Name the muscles in the rotator cuff and give nerve supply of each.
   The rotator cuff muscles are supraspinatus, infraspinatus, teres minor and subscapularis (subscapularis - suprascapular nerve, teres minor - axillary nerve, supraspinatus and infraspinatus - suprascapular nerve)

CASE 5
A head load worker, experienced difficulty in raising the right arm vertically upwards. The examining physician asked the man to press his hands against the wall in front. It was found that the medial border and inferior angle of his right scapula became prominent.

Questions and Solutions
1. Which muscle is tested in this man to detect the injury to which nerve?
   The serratus anterior is tested to detect injury to long thoracic nerve.

2. Name the deformity of scapula caused by injury to this nerve.
   Winging of scapula

3. Where does this nerve originate?
   The long thoracic nerve originated in the neck from the C5, C6, C7 roots of branchial plexus.

4. How does this nerve enter the axilla?
   Through the apex of axilla

5. Name the muscle in the medial wall of axilla to which this nerve is intimately related. Give the attachments of the muscle.
   Serratus anterior is the muscle in the medial wall of axilla. The long thoracic nerve lies on its lateral surface. The serratus anterior takes origin from upper eight ribs. It passes backwards around the chest wall for insertion into the medial border of the ventral (costal) surface of scapula. The first digitation arises from the outer border of the first rib and from the second rib. It is inserted in the superior angle of scapula. The second, third and fourth digitations arise from respective ribs and spread out to be inserted along the entire medial border. The lower four digitations arise from the respective ribs and converge for insertion in the inferior angle of scapula.

6. What is the action of this muscle in hyperabduction of arm? Does it act alone or in combination with other muscle?
   The serratus anterior causes forward or lateral rotation of scapula along with upper and lower fibers of trapezius.

CASE 6
A gardener cut his right ring finger by a sharp edge of broken glass while digging soil. After about 3 to 4 days he developed fever and his entire ring finger was swollen and painful.

Questions and Solutions
1. Name the structure in the ring finger that is likely to be inflamed.
   Synovial sheath around flexor tendons (digital synovial sheath)

2. What is the clinical condition called?
   Tenosynovitis

3. In what tubular structure is the digital synovial sheath protected?
   Fibrous flexor sheath
4. Name the palmar spaces in the intermediate compartment of palm giving boundaries of each.
   Midpalmar and thenar spaces (refer to chapter 20)

5. Name the canals that connect the palmar spaces to the web spaces.
   Lumbrical canals

6. What is the surgical importance of these canals?
   Lumbrical canals are opened up surgically in corresponding web spaces to drain the pus from palmar spaces.

**CASE 7**
An elderly woman with a history of fall on the outstretched hand developed localized pain and swelling on the dorsal aspect of the wrist. When movements of wrist became painful she came to the hospital. X-ray showed the fracture of the lower end of radius.

**Questions and Solutions**

1. What is the name of the fracture of the lower end of the radius and the typical deformity of the hand as a result of this fracture?
   Colles’ fracture - dinner fork deformity

2. Does the normal relationship of the styloid process of radius and ulna change consequent to this fracture?
   Normally, the radial styloid process is longer than the ulnar styloid process. In Colles’ fracture the distal fragment of radius shifts posteriorly and upward carrying with it the styloid process. Hence both ulnar and radial styloid processes are either at the same level or the radial styloid process may be higher.

3. Name the space in which the styloid process of radius is felt.
   Anatomical snuffbox

4. Which bones form the floor of this space?
   From proximal to distal - styloid process of radius, scaphoid, trapezium, base of first metacarpal bone.

5. Give the anterior and posterior boundaries of this space.
   Anterior - Abductor pollicis longus and extensor pollicis brevis

   Posterior - Extensor pollicis longus

6. Which nerve crosses the roof of this space?
   Superficial branch of radial nerve

7. Name the articulations of radius.
   i. Elbow joint
   ii. Proximal (superior) radioulnar joint
   iii. Middle radioulnar joint
   iv. Inferior radioulnar joint
   v. Wrist joint

**CASE 8**
While drawing a blood sample from the median cubital vein, the trainee nurse observed that blood in the syringe was bright red. She immediately withdrew the needle. Then she reinserted the needle slightly medial to the previous puncture site. Her patient experienced sharp pain, which radiated to the lateral three and half digits.

**Questions and Solutions**

1. Name the superficial veins that are connected by the median cubital vein giving direction of blood flow in this vein.
   Cephalic vein laterally and basilic vein medially are connected by median cubital vein, in which blood flows from cephalic vein to basilic vein

2. Which aponeurotic structure forms a platform for the median cubital vein?
   Bicipital aponeurosis

3. What are the attachments of this structure?
   The bicipital aponeurosis is an extension from the insertion of biceps brachii tendon (into posterior part of radial tuberosity). It is attached to the deep fascia of forearm and to the posterior subcutaneous margin of ulna.

4. Which nerve and artery lie deep to the aponeurotic structure?
   Median nerve and brachial artery

5. Name the nerve, which on irritation by needle causes radiating pain to lateral three and half digits?
   Median nerve
6. Name the muscles of the forearm and palm, which are paralyzed if this nerve is cut in the cubital fossa.

In the cubital fossa, median nerve supplies four muscles namely pronator teres, flexor carpi radialis, palmaris longus and flexor digitorum superficialis.
In the forearm, the median nerve supplies two and half muscles via its anterior interosseous branch namely flexor pollicis longus, pronator quadratus and lateral half of flexor digitorum profundus.
In the palm, the median nerve supplies four and half muscles namely first and second lumbricals, abductor pollicis brevis, opponens pollicis and superficial head of flexor pollicis brevis.

CASE 9

An obese elderly woman with history of myxedema (deficiency of thyroxine) complained of pins and needles sensation in the index and middle fingers of her right hand. On examination, it was found that the thenar eminence of right hand was flattened and the patient was unable to bring the tips of the thumb and little finger together. On flexing the wrist pain was aggravated.

Questions and Solutions

1. Name the clinical condition from the symptoms and signs
   
   Carpal Tunnel syndrome

2. Name the boundaries of the carpal tunnel and enumerate its contents.
   
   Anteriorly, by flexor retinaculum
   Posteriorly, by carpal bones
   Contents, Medial nerve and long flexor tendons of FDS, FDP and FPL covered with synovial sheaths

3. Compression of which content is responsible for the above condition?
   
   Compression of median nerve is the cause of this condition.

4. Weakness or paralysis of which muscle leads to inability to touch the thumb and little finger?
   
   Opponens pollicis

5. Which structure is surgically cut to relieve symptoms in this condition?
   
   Flexor retinaculum

6. Mention the attachments and anterior relations of this structure.

   Flexor retinaculum is attached medially to pisiform and hook of hamate and laterally to scaphoid and trapezium. Anteriorly it is crossed by (from lateral to medial side) palmar cutaneous branch of median nerve, palmaris longus tendon, palmar cutaneous branch of ulnar nerve, ulnar artery and ulnar nerve.

7. Anterior dislocation of which carpal bone produces similar condition?

   Lunate bone

CASE 10

A patient suffering from Hensen’s disease (leprosy) came to the hospital with complaints of loss of sensation in the left hand. Examination revealed sensory loss in medial one and half fingers and medial side of palmar and dorsal aspects of hand. In addition there was flattening of hypothenar eminence and difficulty in holding a card between thumb and index finger.

Questions and Solutions

1. Name the nerve that is affected in this patient.
   
   Ulnar nerve

2. Describe the course and branches of this nerve in the palm.

   Refer to description of ulnar nerve in chapter 21.


   This is due to paralysis of muscles of hypothenar eminence (abductor digiti minimi, flexor digiti minimi and opponens digiti minimi).

4. Explain the inability of the patient to hold the card between thumb and index finger.

   To hold the card between thumb and index finger, the adduction of thumb is necessary. The adduction of thumb is lost due to paralysis of adductor pollicis in this patient.

5. Name the branches (giving the level of their origin) of this nerve that supply the skin of the dorsal and palmar aspects of the hand.

   The palmar cutaneous branch takes origin from ulnar nerve in the middle of the forearm. It passes superficial...
to the flexor retinaculum to enter the palm. The dorsal cutaneous branch arises from the ulnar nerve a little above the wrist and enters the dorsum of hand to supply the skin of medial side.

6. Name the deformity that results if the roots of above nerve are damaged.

Damage to C8 and T1 roots will cause paralysis of all intrinsic muscles of hand resulting in complete claw hand.

CASE 11

A 40-year-old auto driver involved in street fight received a deep cut in the middle of the back of his left arm. There was profuse bleeding from the wound when he was rushed to the hospital.

Questions and Solutions

1. Which nerve and artery at this site are in danger of injury?

The radial nerve and profunda brachi artery are in danger of injury as they travel together in the radial groove of humerus.

2. What is the origin and termination of the artery?

The profunda brachi artery takes origin from brachial artery in the front of arm. It enters the radial groove and terminated at the lower end of the groove by dividing into radial collateral and middle collateral arteries.

3. How will you assess the functional integrity of the nerve in this case?

Since the upper arm is injured, we can test the extension of the wrist joint and of metacarpophalangeal joints for assessing functional integrity of the radial nerve. The sensory function is assessed by looking for sensory loss in the first interosseous space on the dorsum of hand.

4. Which part of the brachial plexus gives origin to this nerve and which other nerves arise from the same part?

The posterior cord of brachial plexus gives origin to radial nerve. The axillary, upper subscapular, lower subscapular and thoracodorsal nerves are the other branches of posterior cord.

5. Give the motor distribution of this nerve.

In the axilla, the radial nerve supplies long head of triceps brachii.

In the radial groove, it supplies lateral and medial heads of triceps and anconeus.

In the lower lateral part of anterior compartment (after piercing the lateral intermuscular septum), the radial nerve supplies brachioradialis, extensor carpi radialis longus and proprioreceptive fibers to brachialis. In the forearm, the radial nerve terminates at the lateral end of cubital fossa under cover of brachioradialis, into two branches, superficial and deep. The deep branch of radial nerve supplies extensor carpi radialis brevis and supinator in the cubital fossa. It leaves the cubital fossa by passing through the supinator to enter the posterior compartment of forearm.

In the posterior compartment of forearm, the posterior interosseous nerve supplies extensor digitorum, extensor digiti minimi, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis brevis, extensor pollicis longus and extensor indicis.

6. Name the cutaneous branches of this nerve.

i. The posterior cutaneous nerve of arm arises in axilla.

ii. The lower lateral cutaneous nerve of arm and posterior cutaneous nerve of forearm arise in spiral groove.

iii. The superficial branch of radial nerve (which is one of the terminal branches) is a purely sensory branch. It supplies the lateral part of dorsum of hand and lateral three digits.

CASE 12

A 53-year-old man while riding on motor cycle met with a head on collision with the truck on a national highway. He was thrown off the motorcycle and fell with an impact on his back some distance away from the site of accident. On being rushed to the casualty, radiological examination revealed multiple fractures of left scapula.

1. Name the nerve that is in intimate contact with the scapula.

Suprascapular nerve

2. Describe the origin, course and distribution of the nerve.

The suprascapular nerve arises from the upper trunk (Erb’s point) of the brachial plexus in the posterior triangle of neck. Its root value is C5, C6.

Cervical Course

The suprascapular nerve runs downwards and laterally posterior and parallel to inferior belly of omohyoid
muscle. It leaves the posterior triangle by passing deep to the trapezius. The suprascapular artery, a branch of thyrocervical trunk from the first part of subclavian artery, accompanies the nerve to the scapular region.

Course in Scapular Region

The suprascapular nerve and vessels reach suprascapular notch of the superior margin of scapula. The suprascapular nerve enters the supraspinous fossa by passing through the foramen formed by the suprascapular notch and the transverse scapular ligament. However, the suprascapular artery passes over the ligament. After giving branches to supraspinatus muscle the nerve passes through the spinoglenoid notch to enter the infraspinous fossa. It is commonly observed that the spinoglenoid ligament (inferior transverse scapular ligament) bridges the spinoglenoid notch creating a tunnel for the neurovascular bundle.

Distribution

i. Just proximal to suprascapular notch, articular branches are given off to acromioclavicular joint.
ii. Muscular branches to supraspinatus arise in supraspinous fossa.
iii. Articular branches for shoulder joint arise in spinoglenoid notch.
iv. The suprascapular nerve terminates in a handful of motor branches in the infraspinous fossa for the supply infraspinatus muscle.

3. What is volleyball shoulder?

If the suprascapular nerve is compressed at spinoglenoid notch only infraspinatus muscle is affected (described as infraspinatus syndrome). The sign of infraspinatus syndrome is atrophy of infraspinatus muscle and difficulty in lateral rotation of arm. The symptom is dull aching pain in shoulder. This syndrome is so common in volleyball players, that it is called volleyball shoulder.

4. Enumerate movements of scapula mentioning the muscles producing them.

i. The elevation and depression of scapula take place around an anteroposterior axis passing through costoclavicular ligament.
ii. The protraction and retraction of scapula take place around a vertical axis passing through costoclavicular ligament.
iii. Lateral or forward and medial or return rotation of scapula takes place around an axis passing through acromioclavicular joint.

Muscles of Elevation and Depression

The elevation of scapula (shrugging movement) is caused by contraction of the upper fibers of trapezius and the levator scapulae.

The depression of the scapula is produced by contraction of pectoralis minor along with lower fibers of trapezius.

Muscles of Protraction and Retraction

The protraction of scapula is produced due to combined action of serratus anterior and pectoralis minor muscles.

The retraction of scapula is produced due to combined action of middle fibers of trapezius and rhomboids.

Muscles Producing Rotation of Scapula

The forward rotation of scapula is produced by the lower five digitations of the serratus anterior along with upper and lower fibers of trapezius.

The medial or return rotation of scapula is due to the action of the muscles attached to the medial border of scapula assisted by gravity.

5. Which arteries are liable to injury in scapular fracture?

i. Suprascapular artery (a branch of thyrocervical trunk of subclavian artery) along the superior margin.
ii. Deep branch of transverse cervical artery (arising from thyrocervical trunk of subclavian artery) along medial margin
iii. Subscapular artery (branch of third part of axillary artery) and its continuation as thoracodorsal artery along lateral margin

6. What is the importance of scapular anastomosis?

The above mentioned arteries anastomose with other on both the costal and dorsal surfaces of scapula. This anastomosis communicates the first part of subclavian artery with third part of axillary artery. The anastomosis opens up if there is arterial block anywhere between first part of subclavian and third part of axillary arteries. In this way, an adequate blood supply is ensured for the upper limb.
CASE 13

A patient was scheduled for cardiac bypass surgery. Preparatory to the operation, a venous line was cannulated at the wrist in a vein in the anatomical snuff box.

1. **Name the vein which is used for cannulation.**
   
   Cephalic vein

2. **Give the origin, course and termination of this vein.**
   **Origin**
   
   The cephalic vein begins at the lateral end of dorsal venous arch by the union of dorsal digital vein from the radial side of index finger, veins from either side of the thumb and the lateral end of al venous arch.

   **Course**
   
   i. At the wrist, it lies in the roof of anatomical snuffbox, where it is posterior to the styloid process of radius.
   
   ii. In the forearm, it ascends along the posterolateral side and then turns anteriorly to reach the lateral part of cubital fossa.
   
   iii. In the arm, cephalic vein ascends along the lateral side of biceps brachii. At the upper part of the arm (at the level of lower margin of pectoralis major muscle), the cephalic vein pierces the deep fascia and enters the deltopectoral groove, where it is related to the deltoid branch of the thoracoacromial artery and the deltopectoral lymph nodes.

   **Termination**
   
   The cephalic vein opens into the axillary vein inside the axilla.

3. **Which nerve is closely related to this vein at elbow?**
   
   Lateral cutaneous nerve of forearm, which is the continuation of musculocutaneous nerve.

4. **How is this vein arterialized?**
   
   Arterialization of cephalic vein is useful in dialysis in renal failure patients. The cephalic vein can also be anastomozed with brachial artery in cubital fossa for the same purpose.

CASE 14

A 49-year-old woman with chronic renal failure was admitted to dialysis unit of a hospital. On examination, it was found that there were two scars indicative of previously performed arteriovenous fistulae on her left forearm (one at wrist and another in front of the elbow). The one at wrist was radiocephalic fistula and the other at the elbow was brachiocephalic fistula. Both procedures failed to successfully arterialize the cephalic vein. Therefore, a third fistula was created on the right forearm on the medial side at the junction of middle-third and lower-third. This was a successful fistula as on auscultation on the prominent vein on the medial side of the forearm a distinct bruit was heard.

**Questions and Solutions**

1. **Name the superficial vein on medial side of forearm which is successfully arterialized in this patient.**
   
   Basilic vein

2. **Which artery on medial side is anastomozed with the above vein?**
   
   Ulnar artery

3. **Write a brief note on the above artery.**
   
   The ulnar artery is one of the terminal branches of brachial artery in the cubital fossa.
   
   The ulnar artery leaves the cubital fossa deep to the deep (ulnar) head of pronator teres, to enter the forearm. Its course in the forearm can be divided into two parts. In the upper-third of the forearm the ulnar artery takes as oblique course to reach the medial margin of the forearm. In the lower two-thirds, the artery passes vertically down along the medial margin of forearm to reach the wrist. Then it crosses the flexor retinaculum superficially and at the pisiform bone it divides into deep and superficial branches.
1. The following part of scapula forms the lateral most palpable landmark on the shoulder?
   a. Superior angle
   b. Glenoid cavity
   c. Coracoid process
   d. Acromion

2. Which of the following can extend, adduct and medially rotate the arm?
   a. Teres minor
   b. Subscapularis
   c. Latissimus dorsi
   d. Deltoid

3. What is the continuation of ventral ramus of 7th cervical spinal nerve called?
   a. Medial cord
   b. Upper trunk
   c. Middle trunk
   d. Lateral cord

4. A patient presents with loss of abduction and weakness of lateral rotation of arm. This is due to an injury to a nerve caused by fracture of humerus at
   a. Anatomical neck
   b. Midshaft
   c. Surgical neck
   d. Medial epicondyle

5. Subacromial bursa separates coracoacromial arch from the tendon of
   a. Subscapularis
   b. Teres minor
   c. Supraspinatus
   d. Infraspinatus

6. Which one of the following has action similar to that of teres minor?
   a. Supraspinatus
   b. Infraspinatus
   c. Subscapularis
   d. Teres major

7. On which aspect are the interphalangeal joints in hand devoid of capsule?
   a. Posterior
   b. Anterior

8. Which of the following forms the anterior fold of axilla?
   a. Pectoralis major
   b. Pectoralis major and pectoralis minor
   c. Pectoral muscles and subclavius
   d. Clavipectoral fascia

9. Epitrochlear lymph nodes are located along
   a. Median cubital vein
   b. Cephalic vein above elbow
   c. Basilic vein above elbow
   d. Brachial artery

10. Which nerve is injured if on trying to make a circle by touching the tips of index finger and thumb, the approximation of palmar surfaces of distal phalanges occurs (as in pinching)?
    a. Median nerve at wrist
    b. Anterior interosseous nerve
    c. Recurrent branch of median nerve
    d. Deep branch of ulnar nerve

11. In climbing a tree, the following two muscles contract together
    a. Teres major and teres minor
    b. Latissimus dorsi and teres major
    c. Pectoralis major and latissimus dorsi
    d. Teres major and pectoralis major

12. Ligaments of Cooper are modifications of
    a. Axillary fascia
    b. Pectoral fascia
    c. Fatty tissue of breast
    d. Fibrous stroma of breast

13. Which is not a branch of deep palmar arch
    a. Proximal perforating
    b. Recurrent
    c. Palmar metacarpal
    d. Common palmar digital

14. In which of the following at elbow region the secondary center of ossification appears first?
    a. Head of radius
    b. Capitulum
15. Froment’s test tests the integrity of
   a. Second palmar interosseous
   b. Second dorsal interosseous
   c. Adductor pollicis
   d. First lumbrical

16. A sportsman with severe injury to right leg had to use crutches for several months. Subsequently his doctor found that he had restricted abduction of shoulder and extension of elbow. What is the site of injury in the brachial plexus?
   a. Middle trunk
   b. Posterior cord
   c. Lateral cord
   d. Medial cord

17. Which of the following does not connect radius and ulna?
   a. Annular ligament
   b. Interosseous membrane
   c. Oblique cord
   d. Quadratar ligament

18. Which of the following is not the modification of deep fascia?
   a. Extensor retinaculum
   b. Palmar aponeurosis
   c. Extensor expansion
   d. Fibrous flexor sheath

19. Hammer thumb deformity is due to the rupture of the tendon of
   a. Flexor pollicis longus
   b. Abductor pollicis longus
   c. Extensor pollicis brevis
   d. Extensor pollicis longus

20. Abduction of the middle finger is brought about by
   a. Third dorsal interosseous
   b. Third lumbrical

21. Ulnar collateral ligament of elbow joint is related to
   a. Median nerve
   b. Basilic vein
   c. Ulnar nerve
   d. Ulnar artery

22. The artery supplying the scaphoid usually enters the bone at
   a. Waist
   b. Distal half
   c. Proximal half
   d. Proximal end

23. Which dermatome overlies the thumb?
   a. T1
   b. C8
   c. C7
   d. C6

24. Which of the following pierces the interosseous membrane?
   a. Posterior interosseous artery
   b. Anterior interosseous artery
   c. Common interosseous artery
   d. All of the above

25. The skin overlying the thenar eminence is supplied by
   a. Recurrent branch of median nerve
   b. Palmar cutaneous branch of ulnar nerve
   c. Palmar cutaneous branch of median nerve
   d. Lateral proper digital branch of median nerve

**KEY TO MCQs**

1-d, 2-c, 3-c, 4-c, 5-c, 6-b, 7-a, 8-a, 9-c, 10-b, 11-c, 12-d, 13-d, 14-b, 15-c, 16-b, 17-a, 18-c, 19-d, 20-c, 21-c, 22-b, 23-d, 24-b, 25-c
THORAX
THORACIC CAGE

The thoracic cage (Fig. 23.1) is formed by thoracic vertebrae and intervening discs posteriorly, twelve pairs of ribs posterolaterally and anterolaterally and the sternum in the midline anteriorly. Its upper end is called thoracic inlet, which communicates the thoracic cavity with neck. Its lower end is called thoracic outlet, which is closed in living state by diaphragm. The thoracic cavity provides protection to the main organs of respiration and circulation. As the lungs are constantly moving, the thoracic cage has to be resilient. The thoracic cage provides attachments to the muscles of respiration, which increase its volume during inspiration and decrease its volumes during expiration.

Sternum

The sternum or the breast-bone is the axial bone located in the midline of the front of the chest. It is a flat bone consisting of spongy marrow.

Parts of Sternum

The sternum consists of three parts. From above downwards they are manubrium sterni, body and a pointed xiphoid process, which projects in the epigastrium of anterior abdominal wall.

Manubrium

The manubrium is the upper broadest and thickest piece of sternum. The concave center of its upper margin is called suprasternal notch. The manubrium is usually selected for marrow puncture (to withdraw red bone marrow for hematological examination).

Body

It is formed by the union of four sterna. It is longer, narrower and thinner than manubrium. It presents anterior surface and a posterior surface. Its lateral margin is irregular due to presence of costal notches.

Xiphoid Process

It is the lower part of sternum, which is thin and tapering. It is cartilaginous in young age but by the age of forty it ossifies.

Vertebral Levels

i. Upper margin of manubrium corresponds to third thoracic vertebra.
ii. Lower margin of manubrium corresponds to lower margin of fourth thoracic vertebra.

iii. The sternal body lies opposite to the fifth to ninth thoracic vertebrae.

iv. The xiphisternal joint corresponds to ninth thoracic vertebra.

**Joints of Sternum**

i. Sternoclavicular joint is a synovial joint between manubrium and medial end of the clavicle.

ii. Manubriosternal joint between the manubrium and body of sternum is a secondary cartilaginous joint or symphysis. This joint is called angle of Louis or sternal angle, which is an important surface landmark for counting ribs in a patient.

iii. Xiphisternal joint is secondary cartilaginous joint, which turns into synostosis by 40th year.

iv. Manubriocostal joint (first sternocostal joint) is between the first costal cartilage and the manubrium. It is a synchondrosis or primary cartilaginous joint.

v. Other sternocostal joints (from second to seventh) between the costal cartilages and side of the body of sternum are synovial joints. The second costal cartilage is attached to the costal notch at angle of Louis.

**Posterior Relations (Fig. 23.2B)**

i. Posterior surface of manubrium forms the anterior wall of superior mediastinum. The arch of aorta and its three branches are related to it. The left brachiocephalic vein crosses in front of the three branches, hence this vein is in danger of injury during sternal puncture. The anterior margins of lungs and anterior lines of pleural reflections are related to lateral aspect of posterior surface.

ii. The posterior surface of the body of sternum forms the anterior boundary of anterior mediastinum, which is a very narrow space. This brings the pericardium and heart in close relation of the body of sternum. In head-on collision, the steering wheel of the car pushes through the body of sternum into the pericardium of the driver causing rupture of the heart and ascending aorta. (The anterior attachments are shown in Figure 23.2A).

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**Clinical insight ...**

**External Cardiac Massage**

In a patient with cardiac arrest, the cardiopulmonary resuscitation (CPR) provides the basic life support. This is done by a technique called external cardiac massage. A firm pressure is applied to the chest vertically downwards on the lower part of the sternum, which should move posteriorly for four to five centimeter. This may force the blood out of the heart into the ascending aorta and may act as a stimulant for contraction of the heart.

**Midline Sternotomy**

The heart is usually approached for coronary bypass surgery by placing a midline sternum-splitting incision from the jugular notch to the xiphoid process. The split sternum is joined by steel wires after the surgery.

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**Figs 23.2A and B:** (A) Anterior; (B) Posterior attachments of sternum
Ribs or Costae

The ribs are twelve pairs of arched bones in the thoracic cage. Eleven pairs of intercostal spaces are bounded by the adjacent margin of twelve pairs of ribs. The ribs extend from vertebral column posteriorly to the sternum and costal margin anteriorly. The rib and its cartilage are united to each other by the continuity of the periosteum of the rib with the perichondrium of its costal cartilage. The costal cartilages impart elasticity to the rib cage. The ribs contain spongy hemopoetic marrow.

Length of Ribs

The length increases from the first rib to the seventh and decreases from seventh rib to the twelfth. Therefore, seventh rib is the longest.

Classifications of Ribs

Depending on Articulation with Sternum

i. True ribs (first to seventh ribs) articulate with sternum directly.
ii. False ribs (eighth to twelfth ribs) do not articulate with sternum directly.

Depending on Anterior Attachments

i. Vertebrosternal ribs are the ones that connect with the sternum through their costal cartilages. The first seven ribs are vertebrosternal ribs or true ribs.
ii. Vertebrochondral ribs or false ribs are connected to each other by cartilage (eight to tenth ribs).
iii. Floating or vertebral ribs (eleventh and twelfth ribs) present free anterior ends.

Depending on Morphological Features

i. Typical ribs (third to ninth ribs, which have similar features)
ii. Atypical ribs (first, second, tenth, eleventh and twelfth) have special features.

Articulations of Typical Rib

i. Costovertebral joint in which head of the rib articulates with the body of numerically corresponding thoracic vertebra and with the body of the vertebra above.
ii. Costotransverse joint in which the tubercle of the rib articulates with the transverse process of numerically corresponding thoracic vertebra.
iii. The sternocostal joints of typical ribs are of synovial type.

Movements of Ribs

The movements of the ribs are responsible for increasing the anteroposterior and transverse diameters of thoracic cage during inspiration. The ribs are obliquely placed one below the other in the thoracic cage in the adult. In the children up to the age of four to six year, the ribs are horizontally disposed. As a result of this, the child has abdominal breathing. Afterwards when the ribs become oblique, the respiration becomes thoracic.

Typical Rib (Fig. 23.3)

Each typical rib presents posterior end, shaft and anterior end from behind forwards.

Features of Posterior End

i. The head has two facets. The upper smaller facet articulates with the body of the vertebra above and the lower larger one articulates with the numerically corresponding vertebra. The crest of head (between the two articular facets) is attached to intervertebral disc. The heads of the typical ribs are related anteriorly to the sympathetic chain.
ii. The neck is long and lies in front of the transverse process of the corresponding vertebra.
iii. The tubercle lies on the outer surface at the junction of the neck and shaft. The articular part of the tubercle articulates with facet on the transverse process of the numerically corresponding vertebra.

Features of Shaft

The shaft is long and flat. It is curved like a letter “C”.

i. A short distance lateral to (or in front of) the tubercle, the rib is twisted and is marked by a rough line. This point is the angle of the rib, where the rib is weakest and hence liable to fracture. The fractured rib may injure the pleura and the lungs. Injury to pleura might result in pneumothorax or hemothorax or both.

ii. The shaft presents outer and inner surfaces. The lower part of inner surface is marked by costal groove. This groove houses three important structures, posterior intercostal vein, posterior intercostal artery and posterior intercostal nerve (from above downwards). Rib notching is a radiological sign in coarctation of aorta. The enlarged and tortuous posterior intercostal arteries of third to eleventh intercostal arteries erode the costal grooves.

Anterior End

The anterior end of a typical rib is wider and bears a depression for articulation with its own costal cartilage.

First Rib (Fig. 23.4)

It is obliquely placed so that its posterior end is at a higher level compared to its anterior end. Its anterior end is very broad. The inner margins of the right and left ribs bound the thoracic inlet on either side.

Unique Features

i. Its head has single articular facet.

ii. It is the shortest, broadest and the most curved.

iii. Its neck is rounded.

iv. It presents upper and lower surfaces and inner and outer margins.

v. Its anterior end articulates by costal cartilage to manubrium by synchondrosis (primary cartilaginous joint).

Special Features

i. The head of first rib articulates with body of first thoracic vertebra to form costotransverse joint by a single facet.

ii. The anterior relations of the neck are the sympathetic chain, highest intercostal vein, superior intercostal artery and T1 ventral ramus (SVAN from medial to lateral).

(Note: The neck and its anterior relations form the posterior relations of the apex of the lung. The cancer of lung apex may spread to these structures producing Horner’s syndrome and weakness of small muscles of hand with sensory changes along the inner margin of forearm and hand).

iii. The inner border of the shaft is marked by scalene tubercle, which provides insertion to scalenus anterior. The inner border gives attachment to Sibson’s fascia.

iv. The lower surface is smooth (as it is covered with costal pleura) and has no costal groove.

v. The relations of superior surface are noteworthy. The vascular groove in front of the scalene tubercle is for subclavian vein and the one behind it is for subclavian artery and the lower trunk of brachial plexus. Behind the arterial groove, the scalenus medius muscle is inserted.

Second Rib

This rib is longer and narrower than the first rib. It articulates with the sternal angle. Hence, its identification in a patient helps in counting subsequent ribs.

Tenth Rib

This rib has a single facet on its head, which articulates with the upper border of tenth thoracic vertebra near its pedicle.

Eleventh and Twelfth Ribs

These floating ribs have pointed anterior ends, which are tipped with cartilage. The twelfth rib is related to the

Fig. 23.4: Attachments and relations of superior surface of first rib
[Note the anterior relations of neck (1) Sympathetic chain; (2) Highest intercostal vein; (3) First posterior intercostal artery; (4) T1 ventral ramus]
costodiaphragmatic recess of pleura. It is related to posterior surface of kidney in lumbar region. So, in operations on kidney by lumbar route the last two ribs are important landmarks.

Injury to the lower ribs may injure the abdominal organs. The fracture of the left tenth rib may injure the spleen.

**Costal Cartilages**

The costal cartilages are of hyaline variety. They represent the unossified anterior ends of the ribs. During inspiration, they are twisted upwards. This movement of the costal cartilages stores energy, which is released during expiration. The costal cartilages provide external elastic recoil during normal quiet expiration so that the muscular effort is spared. The calcification of costal cartilages usually occurs in old age. This results in loss of elasticity of the rib cage, which in turn results in diaphragmatic or abdominal inspiration.

**Abnormal Ribs**

The costal elements of the seventh cervical and first lumbar vertebrae may grow to form a rudimentary or complete rib.

The persons born with cervical ribs come to the doctors due to neurovascular symptoms. The cervical ribs are the elongated costal elements of the seventh cervical vertebra. They may be unilateral or bilateral. They may be fully-developed ribs or just fibrous strand reaching the first rib beyond the scalene tubercle. It may be symptomless condition but sometimes it gives rise to pressure on the structures in relation to the upper surface of first rib causing neurovascular disturbances (Fig. 24.2).

**Thoracic Vertebrae**

There are twelve thoracic vertebrae. They are of two types.

1. **Typical (second to eighth)**  
   All thoracic vertebrae are characterized by presence of costal facets on the body.

2. **Atypical (ninth to twelfth)**  
   The body of the vertebra is heart-shaped and vertebral foramen is circular. The spinous processes are pointed and directed downward. There are costal facets on the body and transverse process. The costal facets are for articulation with the ribs. The pedicle is attached nearer to the upper margin so that lower vertebral notch is deeper than the upper.

**Costal Facets**

i. On each side of the body, there are two demifacets. The superior demifacets are smaller and are placed on the upper margin of body near the pedicle. The lower demifacets are placed on the lower border.

ii. The upper demifacet articulates with the lower facet on the head of the numerically corresponding rib.

iii. The lower demifacet articulates with the upper facet on the head succeeding rib.

iv. The anterior surface of transverse process near its tip bears a facet for articulation with the tubercle of corresponding rib.

**Atypical Thoracic Vertebrae**

i. In the first thoracic vertebra, the superior costal facet on the body is complete. It articulates with first rib. The inferior demifacet is for articulating with second rib.

ii. In the tenth thoracic vertebra, the body has a single complete costal facet.

iii. In the eleventh thoracic vertebra, body has complete costal facet but the transverse process has no facet.

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**Figs 23.5A and B:** Features of typical thoracic vertebra (A) Superior view; (B) Lateral view
iv. In the twelfth thoracic vertebra, the complete costal facet is located more on the pedicle. There is no facet on transverse process. The transverse process has superior, inferior lateral tubercles. The shape of the vertebra resembles that of lumbar vertebra.

### Clinical insight ...

| i. | Chostochondritis is the inflammation of the chondrosternal joints. It is very painful. |
| ii. | Flail chest is produced when there are multiple rib fractures at costochondral junctions and near the rib angles. As a result of this type of fracture, a part of rib cage remains isolated without bony support. The isolated part undergoes paradoxical movements of chest wall (moves in during inspiration and moves out during expiration). |
| iii. | Stove in chest condition develops from localized crushing injury with multiple rib fractures. The affected area is depressed and becomes relatively immobile. |
| iv. | In the fracture of ribs, pleura and lung are in danger of injury. In fracture of lower ribs, upper abdominal organs like spleen or liver are likely to be injured. |
| v. | The subperiosteal resection of ribs is performed to gain access to the thoracic cavity. In this procedure the rib segment is removed by incising the periosteum, which is left inside the body. In this way the lost rib regenerates in due course from the osteogenic layer of the periosteum. |
The thorax is the upper part of the trunk located between the neck and the abdomen. It consists of thoracic wall and thoracic cavity. In the lateral part of thoracic cavity on each side, the lung is enclosed in a serous sac called pleural cavity. The central part of the thoracic cavity between the two pleural cavities is called the mediastinum. The heart within the pericardial cavity is located inside the middle mediastinum.

**THORACIC INLET**

**Boundaries of Thoracic Inlet (Fig. 24.1)**

i. Posteriorly, body of first thoracic vertebra

ii. Laterally, inner margins of the first ribs and their costal cartilages

iii. Anteriorly, upper margin of manubrium sterni

(Note: The first rib slopes downwards and forwards, hence the first thoracic vertebral level is higher than that of the upper margin of the manubrium. Because of the inclination of the thoracic inlet, the apex of the lung with the overlying pleura appears to project into the base of the neck)

**Details of Thoracic Inlet**

The structures passing through the inlet are grouped into midline structures and those passing on either side.

i. In the midline, there are two strap muscles of the neck (sternothyroid and sternohyoid), inferior thyroid veins, trachea and the esophagus.

ii. Laterally on each side, the apex of the lung and the cervical pleura project upwards. The Sibson’s fascia passes from the inner margin of the first rib to the transverse process of seventh cervical vertebra.

The following close relations of the apex of the lung pass through the thoracic inlet.

i. Posterior to lung apex (anterior to the neck of first rib) are seen the sympathetic chain, superior intercostal artery and ventral ramus of the first thoracic nerve.

ii. The internal thoracic artery, vagus nerve and phrenic nerve descend in relation to the medial aspect of lung apex.

iii. The subclavian vessels pass in front of the lung apex in lateral direction. The scalenus anterior and medius muscles descend to gain insertion into the first rib.

iv. Additional structures present on the right of the midline are brachiocephalic artery and the right brachiocephalic vein.

v. Additional structures present on the left of the midline are left common carotid artery, left brachiocephalic vein, left recurrent laryngeal nerve and the thoracic duct.
Scalene Triangle

The scalene triangle is a narrow triangular space bounded anteriorly by the scalenus anterior, posteriorly by scalenus medius and inferiorly by upper surface of the first rib. Its contents are the lower trunk of the brachial plexus and the subclavian artery.

Clinical insight ...

Cervical Rib Syndrome (Fig. 24.2)

In the presence of a cervical rib or a congenitally hypertrophied scalenus anterior muscle, the scalene triangle is unduly narrowed resulting in compression of subclavian artery and the lower trunk of the brachial plexus. This cervical rib syndrome or scalenus anterior syndrome.

Effects of Compression of Subclavian Artery

i. Pallor and coldness of the upper limb.

ii. Reduction in the force or obliteration of the radial pulse on affected side, which is confirmed by Adson’s test done as follows. The patient sits on the stool and is asked to take deep breath in and to turn the face to the affected side. There is reduction in radial pulse in the presence of cervical rib.

Effects of Compression of Lower Trunk of Brachial Plexus

i. Numbness, tingling and pain along the medial side of the hand and little finger.

ii. Weakness and wasting of interossei and lumbricals

iii. Advanced cases show flattening of hypothenar eminence and guttering of the interosseous spaces on the dorsum of the hand.

Surgical Treatment

To relieve the symptoms, the cervical rib is surgically removed. The periosteum of the rib is removed in order to prevent regeneration of the cervical rib.

THORACIC WALL

The thoracic wall or the chest wall consists of eleven intercostal spaces bounded by ribs and costal cartilages and composed of muscles, nerves and vessels.

Surface Landmarks

i. The concave center of upper margin of manubrium is called suprasternal notch. It is at the level of T2 vertebra. The trachea is felt through the notch.

ii. The sternal angle or angle of Louis is a palpable landmark. It lies at the level of the disc between fourth thoracic and fifth thoracic vertebrae. The second rib articulates with the costal notch at this level and hence sternal angle is a reference point to count the ribs and intercostal spaces downwards in a patient.

iii. The xiphisternal joint is at the level of disc between thoracic eighth and ninth vertebrae.

Fig. 24.2: Effects of cervical rib on neurovascular structures related to superior surface of first rib (Note the dilatation of right subclavian artery distal to the site of its compression by cervical rib)
iv. The lowest part of costal margin corresponding to tenth rib in midaxillary line is at the level of third lumbar vertebra.

v. On the posterior aspect of the chest wall, the spines of the thoracic vertebrae are palpable in the midline (Fig. 24.3B).

vi. The scapula is located in the upper part of the back of thorax. Its superior angle lies opposite to second thoracic vertebra.

vii. The spine of the scapula is subcutaneous and its root is at the level of third thoracic vertebra.

viii. The inferior angle of scapula corresponds to seventh thoracic vertebra and seventh rib.

Orientation Lines (Figs 24.3A and B)

i. The midsternal line passes through the midline of sternum.

ii. The midclavicular line passes through the midpoint of the clavicle.

iii. The anterior axillary line corresponds to the anterior axillary fold.

iv. The midaxillary line passes through the midpoint of the base of the axilla.

v. The posterior axillary line corresponds to posterior axillary fold.

vi. The scapular line passes through the inferior angle of the scapula.

**Clinical insight…**

**Thoracic Wall in Clinical Examination**

The pectoral region forms the front of the anterior chest wall and the scapular region forms part of the posterior chest wall. Deeper to these regions are the intercostal spaces, deeper to which are the organs of the thoracic cavity.

**Intercostal Spaces**

The space between two adjacent ribs and their costal cartilages is called the intercostal space.
There are eleven intercostal spaces bounded by twelve ribs on each side. The upper nine spaces are close anteriorly but the short tenth and eleventh spaces have open anterior ends, which reach the level of mid-axillary line.

### Contents of Intercostal Space (Fig. 24.4)

1. Intercostal muscles
2. Intercostal nerve
3. Intercostal vessels

### Intercostal Muscles (superficial to deep)

1. External intercostal muscle
2. Internal intercostal muscle
3. Innermost intercostal muscle

#### External Intercostal Muscle
It takes origin from the lower margin of the rib above. It is inserted into the upper margin of the rib below.

- **Parts**
  1. Fleshy interosseous part (between the ribs)
  2. Membranous interchondral part (called anterior intercostal membrane) is located between the adjacent costal cartilages. The direction of the muscle fibers is downwards, forwards and medial.

#### Internal Intercostal Muscle
It takes origin from the costal groove of the rib above. It is inserted into the upper margin of the rib below.

- **Parts**
  1. The long and fleshy part extends from anterior end of intercostal space to the angle of the rib posteriorly. It is subdivided in to intercartilaginous and interosseous parts.
  2. The short membranous part (called posterior intercostal membrane) is located beyond the angle of the rib. The direction of the muscle fibers is downward, backward and lateral.

#### Innermost Intercostal Muscle
It is a discontinuous muscle layer, which is separated from costal pleura by endothoracic fascia. It is divided into sternocostalis, intercostalis intimus and subcostalis from before backwards.

- **Parts**
  1. The sternocostalis (transversus thoracis) lies behind sternum and costal cartilages (Fig 24.8). It takes origin from the posterior aspects of lower part of body of sternum, xiphoid process and also from adjacent fourth to seventh costal cartilages. From this wide origin, the fibers pass upward and laterally to reach an equally wide insertion in to the posterior aspect of costal cartilages of second to sixth ribs. It is related anteriorly to the internal thoracic artery.
  2. The intercostalis intimus originates from the ridge above the costal groove of the upper rib and is inserted on the upper margin of the lower rib.
  3. The subcostalis muscles are present in the posterior part of lower intercostal spaces only. The muscle arises from the inner surface of the rib above near its...
angle and is inserted in inner surface of the lower ribs after crossing one or two spaces.

**Nerve Supply**
The intercostal muscles receive nerve supply from the corresponding intercostal nerves.

**Actions**
1. The external intercostal muscles elevate the ribs to increase the anteroposterior and transverse diameters of the thorax during inspiration.
2. The internal intercostal muscles have dual actions.
   i. The intercartilaginous fleshy parts act synergistically with external intercostal muscles and hence assist in inspiration.
   ii. The interosseous fleshy parts depress the ribs during forced expiration.
3. The sternocostalis muscles assist in pulling the second to sixth ribs inferiorly.
4. Collectively the intercostal muscles keep the intercostal spaces rigid. This action prevents indrawing of the spaces during inspiration and bulging out of the spaces during expiration.

**Intercostal Nerves**
The intercostal nerves are the anterior primary rami of thoracic spinal nerves. They are eleven in number on each side, being equal to the number of intercostal spaces (anterior primary ramus of twelfth thoracic spinal nerve, since it lies below the twelfth rib, is called subcostal nerve).

**Unique Feature**
The intercostal nerves retain their segmental character, unlike the anterior primary rami from the other regions of the spinal cord (which form nerve plexuses like cervical, brachial, lumbar and sacral).

**Classification of Intercostal Nerves**
1. Typical intercostal nerves are the ones that are confined to their own intercostal spaces in the thoracic wall. The third, fourth, fifth and sixth intercostal nerves are typical.
2. Atypical intercostal nerves extend beyond the thoracic wall for distribution partly or entirely. The first, second, seventh to eleventh intercostal nerves are atypical.
   i. The ventral ramus of first thoracic spinal nerve contributes to the lower trunk of the brachial plexus (through which it supplies the upper limb). Hence, the first intercostal nerve is very small.
   ii. The lateral cutaneous branch of the second intercostal nerve (intercostobrachial nerve) supplies the skin of the floor of axilla and of medial side of adjacent arm.

iii. The seventh to eleventh intercostal nerves (thoracoabdominal nerves) leave the thoracic all at the costal margin to enter and supply the anterior abdominal wall.

**Communications (Fig. 24.5A)**
Each intercostal nerve communicates with sympathetic ganglion by two communicating twigs.

i. The White Ramus Communicans (WRC) carries preganglionic fibers from the intercostal nerve to the sympathetic ganglion.

ii. The Gray Ramus Communicans (GRC) carries postganglionic fibers back to the intercostal nerve from the sympathetic ganglion (Fig. 12.3).

The postganglionic sympathetic fibers supply pilomotor fibers to the arrector pilorum muscles, sudomotor fibers to the sweat glands and vasomotor for the smooth muscle of the blood vessels in the skin of the area of sensory supply of the intercostal nerve.

**Functional Components**
The intercostal nerve is composed of four functionally different types of nerve fibers.

i. The General Somatic Efferent (GSE) fibers supply the striated muscles derived from somites developmentally.

ii. The General Somatic Afferent (GSA) fibers bring cutaneous sensations to the spinal cord.

iii. The General Visceral Efferent (GVE) fibers are the sympathetic fibers for the supply of the smooth muscle of the skin (arrector pilorum), sweat glands and the blood vessels of the skin.

iv. The general visceral afferent (GVA) fibers bring visceral sensations to the spinal cord.

**Typical Intercostal Nerve (Fig. 24.5B)**
The typical intercostal nerve enters the intercostal space at its vertebral end.

**Course**

i. At first the nerve turns laterally behind the sympathetic trunk. Then it travels towards the intercostal space between the parietal pleura and the posterior intercostal membrane.

**Course in Intercostal Space (Fig. 24.4)**
The nerve enters the costal groove of the corresponding rib to course laterally and forward in the neurovascular plane, lying below the intercostal vessels (VAN). At the sternal end of the intercostal space, the intercostal nerve crosses in front of the internal thoracic artery and pierces the interchondral part of internal intercostal muscle, anterior intercostal membrane and sternocostal origin of
pectorals major muscle. It terminates as anterior cutaneous nerve.

Branches

i. The collateral branch arises from the posterior part of the intercostal nerve before it reaches the angle of the rib. This branch follows the inferior margin of the space in the neurovascular plane (Figs 24.5A and B) and may rejoin the main trunk. The collateral nerve and the main trunk supply muscular branches to the intercostal muscles and the serratus posterior superior muscle in the back.

ii. The lateral cutaneous branch arises from the nerve along with the collateral branch and runs with the main trunk for a small distance and divides into anterior and posterior branches. The posterior branches supply the skin of back overlying the scapula and latisimus dorsi muscle and anterior branches supply the skin overlying the pectoralis major muscle.

iii. The sensory branches are given to the parietal pleura and the periosteum of the ribs.

iv. The anterior cutaneous nerve supplies the skin of the pectoral region and sternum.

**Clinical insight ...**

i. The intercostal nerve block is given to produce local anesthesia in one or more intercostal spaces by injecting the anesthetic solution around the intercostal nerve near its origin, just lateral to the vertebra.

ii. The diseases of the thoracic vertebrae may irritate the intercostal nerves and thereby cause radiating pain in the area of cutaneous distribution of the affected nerves.

*Contd...*
Atypical Intercostal Nerves (Fig. 24.6)

1. The first intercostal nerve differs from the typical nerve in the following respects.
   i. It is the smallest intercostal nerve because of its large contribution to the brachial plexus.
   ii. It gives no collateral or cutaneous branches.
   iii. It courses along the lower surface of the first rib.
   iv. The neurovascular structures are arranged as Nerve, Artery and Vein (NAV) from above downward (reverse of VAN arrangement).
   v. Due to absence of its cutaneous branches, the T1 dermatome is absent on chest wall. Hence T2 dermatome is placed adjacent to C4 dermatome at the level of sternal angle.

2. The second intercostal nerve differs from the typical nerve in the following respects. Its lateral cutaneous branch enters the axilla as intercostobrachial nerve to join the medial cutaneous nerve of arm. It supplies the skin of the floor of axilla and upper medial aspect of arm.

3. The thoracoabdominal nerves are described in chapter 79 (anterior abdominal wall). During their thoracic course, they supply the intercostal muscles of the respective spaces and also give sensory branches to the parietal (costal) pleura. Irritation of these nerves in pleurisy (inflammation of parietal pleura) may cause reflex spasm of anterior abdominal muscles and referred pain to the anterior abdominal wall. Therefore, when a patient comes with the complaint of pain in the abdominal wall radiograph of the chest must be taken to rule out pathology in the pleura.

Anterior and Posterior Intercostal Arteries

i. The upper nine intercostal spaces contain three arteries, one posterior intercostal and two anterior intercostal arteries, per space.

ii. The tenth and eleventh spaces (being too short and with open anterior ends), contain a single posterior intercostal artery in each space.

Posterior Intercostal Arteries

i. In the upper two intercostal spaces the posterior intercostal arteries are the branches of superior intercostal artery (which is a branch of the costocervical trunk of the subclavian artery).

ii. It the lower nine spaces, the posterior intercostal arteries arise from the descending thoracic aorta (Figs 24.7 and 32.1). The right posterior intercostal arteries are longer than the left arteries, because the descending aorta lies along the left of the vertebral column. The posterior intercostal arteries of tenth and eleventh spaces enter the anterior abdominal wall.

Course of Posterior Intercostal Arteries

Each posterior intercostal artery enters the vertebral end of the intercostal space and travels forward in it lying above the nerve and below the vein (VAN) in the neurovascular plane. Near the angle of the rib it gives off a collateral branch. Towards the anterior end of the space, the main arterial trunk anastomoses with the upper anterior intercostal artery, while its collateral branch anastomoses with the lower anterior intercostal artery.

Anterior Intercostal Arteries

There are two anterior intercostal arteries (upper and lower) per space in upper nine spaces.
i. In the first to six spaces, the anterior intercostal arteries are the branches of internal thoracic artery on each side (Fig. 24.8).

ii. In the seventh to ninth spaces, the anterior intercostal arteries are the branches of musculophrenic artery on each side.

(Note: The tenth and eleventh spaces do not have anterior intercostal arteries).

Course of Anterior Intercostal Arteries

i. The upper and lower anterior intercostal arteries in each of the upper nine spaces pass laterally and backwards along the upper and lower margins of the respective spaces.

ii. At the junction of anterior one-third and posterior two-thirds of each space the main trunk of the posterior intercostal artery anastomoses with the upper anterior intercostal branch while the collateral artery anastomoses with the lower anterior intercostal branch.

iii. The free anastomoses between anterior and posterior intercostal arteries connect the first part of subclavian artery and the descending thoracic aorta.

iv. In a condition of narrowing of the arch of aorta (coarctation) distal to the origin of left subclavian artery, the blood is filled in the descending aorta via these intercostal anastomoses.

Internal Thoracic Artery

The internal thoracic (mammary) artery (Fig. 24.8) is a branch of the first part of the subclavian artery in the root of the neck. It descends behind the medial end of the clavicle and the upper six costal cartilages about one centimeter from the margin of the sternum. Up to the level of third cartilage, the artery is closely related to the costal pleura but below this the sternocostalis muscle intervenes between it and the pleura. The artery is crossed anteriorly by the upper six intercostal nerves and is separated from the skin by internal intercostal muscle, external intercostal membrane and pectoralis major muscle. It ends in the sixth intercostal space by dividing into superior epigastric and musculophrenic arteries. The venae comitantes accompany the internal mammary artery up to the level of third costal cartilage. Above this level, the venae comitantes unite to form a single vein, which opens into the brachiocephalic vein of the corresponding side. The internal mammary artery in female supplies the breast. It may be necessary to locate the artery for safe ligation in the third or the second intercostal space during mastectomy.

Branches

i. Pericardiophrenic
ii. Pericardial
iii. Thymic
iv. Mediastinal
v. Sternal
vi. Perforating
vii. A pair of anterior intercostal arteries per space in the upper six spaces
viii. The superior epigastric and musculophrenic arteries are its terminal branches.
Intercostal Veins (Fig. 24.10)

i. The anterior intercostal veins of the upper six spaces drain into the internal thoracic vein.

ii. The anterior intercostal veins of seventh, eighth and ninth spaces drain into the musculophrenic vein.

iii. The posterior intercostal veins reach the vertebral end of the intercostal spaces and receive intervertebral veins from the internal vertebral venous plexus. Their mode of termination on the two sides is different with the exception of highest intercostal vein.

iv. The first or highest posterior intercostal vein on the right side opens into right brachiocephalic vein and on the left side it opens into the left brachiocephalic vein.

v. The veins of second and third spaces unite to form left superior intercostal vein, which opens into left brachiocephalic vein. The right superior intercostal vein is formed by the union of second, third and fourth posterior intercostal veins and it opens into the arch of azygos vein.

vi. The veins of the remaining spaces open into the vertical part of azygos vein on the right side. However, on the left side the veins of the fourth to seventh spaces open into superior hemiazygos vein (accessory hemiazygos vein) and those from the eighth to eleventh spaces open into inferior hemiazygos vein (hemiazygos vein).

Lymphatic Drainage of Intercostal Spaces

The intercostal and parasternal (internal mammary nodes) are the two groups of lymph nodes that drain the soft and hard tissues of the intercostal spaces. The intercostal nodes are located in the posterior part of the intercostal spaces near the heads of the ribs. The parasternal nodes form longitudinal chains along the course of internal mammary (thoracic) artery.
MEDIASTINUM

The thoracic cavity contains pleural cavities surrounding the lungs on either side of a midline partition called mediastinum.

The mediastinum is a midline, narrow and elongated space (containing many structures including heart and great vessels) between the right and left pleural cavities.

Boundaries of Mediastinum
The mediastinum is bounded by sternum anteriorly. It is bounded posteriorly by thoracic vertebrae and on either side by mediastinal pleura (Fig. 25.1).

Extent
The mediastinum extends from the inlet of thorax to the diaphragm (Fig. 25.2).
It is connected to the lung on each side by the root of the lung.

**Subdivisions (Fig. 25.2)**

The mediastinum is broadly divided into superior and inferior parts by means of an imaginary line passing through the manubriosternal joint and the disc between fourth and fifth thoracic vertebrae.

The inferior mediastinum is further subdivided into anterior, middle and posterior parts.

**Boundaries of Superior Mediastinum**

It is bounded anteriorly by manubrium sterni, posteriorly by upper four thoracic vertebrae, superiorly by thoracic inlet, inferiorly by the plane passing through the disc between the fourth and fifth thoracic vertebrae and laterally by the mediastinal pleura.

**Contents (Fig. 25.3)**

i. The sternohyoid and sternothyroid muscles originate from the back of manubrium and the longus colli muscle is present on the front of upper thoracic vertebrae.

ii. The arch of aorta and its branches (left subclavian, left common carotid and brachiocephalic).

iii. The veins are the superior vena cava, right and left brachiocephalic veins and the terminal part of azygos vein. The left superior intercostal vein courses upwards to open in to the left brachiocephalic vein.

iv. The remnant of the thymus is usually present.

v. The nerves on the right side are the right vagus and right phrenic nerves.

vi. The nerves on the left side are the left vagus, left phrenic and left recurrent laryngeal nerves.

vii. The esophagus and trachea enter from the neck into the mediastinum and the thoracic duct enters the neck from the mediastinum.

viii. Lymph nodes.

**Boundaries of Anterior Mediastinum**

The anterior mediastinum is a narrow space. Anteriorly—Body of sternum Posteriorly—Fibrous pericardium Superiorly—An imaginary plane passing through sternal angle Inferiorly—Diaphragm
Contents
i. Sternopericardial ligaments
ii. Remains of thymus
iii. Lymph nodes
iv. Areolar tissue.

Boundaries of Middle Mediastinum
It is bounded anteriorly by anterior mediastinum, posteriorly by posterior mediastinum, superiorly by superior mediastinum, inferiorly by diaphragm and laterally by mediastinal pleura.

Contents
i. Fibrous pericardium
ii. Heart enveloped in serous pericardium inside the fibrous pericardium
iii. Pulmonary vessels
iv. Tracheal bifurcation and terminal bronchi
v. Deep cardiac plexus
vi. Phrenic nerves

Boundaries of Posterior Mediastinum
It is bounded anteriorly by tracheal bifurcation, pulmonary vessels, and fibrous pericardium, posteriorly by lower eight thoracic vertebrae, inferiorly by diaphragm, superiorly by superior mediastinum and laterally by mediastinal pleura.

Contents
i. Esophagus
ii. Descending thoracic aorta
iii. Azygos and hemiazygos veins
iv. Thoracic duct
v. Vagus nerves
vi. Lymph nodes
vii. Splanchnic nerves, branches of sympathetic chain. (Note that sympathetic chain lies outside the mediastinum behind the costal pleura)

Clinical insight ...

i. The mediastinal contents may be compressed due to space-occupying lesion producing diverse signs and symptoms (mediastinal syndrome). For example, an enlarged lymph node in superior mediastinum may compress on the trachea, esophagus and left recurrent laryngeal nerve producing symptoms like difficulty in breathing, difficulty in swallowing and hoarseness of voice respectively.

ii. The mediastinal shift is an indication of lung pathology. The mediastinum shifts to the affected side (Fig. 25.18) due to appreciable reduction in lung volume and decrease in intrapleural pressure as occurs in collapse of lung. Mediastinal shift is detected by palpating the trachea in the suprasternal fossa.

Embryologic insight ...

Development of Trachea, Lungs and Pleural Cavities
The development of lungs is intimately associated with the development of the pleural cavities. The intraembryonic coelom divides to form the pleural, pericardial, and peritoneal cavities. It is a horseshoe-shaped space enclosed in splanchnopleuric and somatopleuric layers. Its median part is the future pericardial cavity and the two tubular parts are the forerunners of the peritoneal cavity. The narrow connections between the above two parts are called the pericarlo-peritoneal canals (future pleural cavities).

Partition between Pericardial and Pleural Cavities
The lung bud invaginates the pericarlo-peritoneal canal of its side and expands in all directions forming a double-layered pleural cavity. The splanchnopleuric layer forms the visceral pleura and the somatopleuric layer forms the parietal pleura. The right and left pleuro-pericardial membranes develop from the body wall mesoderm. The membranes elongate with the expansion of the lung buds and finally fuse with each other. This results in complete partitioning of the pericardial cavity from the right and left pleural cavities. The membranes give rise to the fibrous pericardium except its base, which develops from the septum transversum.

Partition between Pleural and Peritoneal Cavities
The communication between the pleural and peritoneal cavities is closed by the development of right and left pleuro-peritoneal folds from the body wall mesoderm. These folds extend medially and fuse with the septum transversum and the dorsal mesentery of the esophagus. In this way peritoneal cavity is separated from the pleural cavities.

Laryngotracheal Tube (Fig. 25.4)
A laryngotracheal groove appears in the floor of the cranial end of foregut. As this groove deepens and elongates in caudal direction, it is separated from the cranial end of the foregut by formation of a tracheoesophageal septum. Thus, the laryngotracheal tube is formed from the
Endoderm of foregut. The cranial end of the tube forms the larynx, the succeeding part develops into trachea and the caudal end bifurcates to develop into bronchi and lungs. The endoderm of laryngotracheal tube form the epithelium of larynx, trachea, bronchi, bronchioles and alveoli of the lungs. The splanchnopleuric mesoderm forms the connective tissue, smooth muscle and cartilage of the respiratory passages.

Development of Bronchial Tree and Lungs

Each lung bud invaginates the medial wall of the pericardioperitoneal canal (Fig. 25.4) of the respective side and undergoes repeated divisions. The development of the lung and intrapulmonary bronchial tree takes place in three stages.

i. The glandular phase (Fig. 25.5) lasting up to sixteen weeks is characterized by development of solid tubular outgrowths (like ducts) from the lung buds.

ii. The canalicular phase lasting from sixteen weeks to twenty-six weeks is characterized by canalization of solid ducts. The blood vessels proliferate and establish contacts with the canalized ducts.

iii. The alveolar phase extends from twenty-six weeks until birth and continues postnatally. From the seventh month of intrauterine life, the alveoli start differentiating by establishing close contacts with capillary endothelium. The alveolar cells become squamous type but a few retain their cuboidal shape and acquire secretory properties, an indication of surfactant production. The developing lungs are now ready to perform normal function. Before birth, the alveoli are filled with amniotic fluid containing a small quantity of mucin and surfactant due to which the lungs sink in water. With first breath after birth, the fluid inside the alveoli is absorbed or expelled from respiratory passages and the lungs are filled with air. Hence, after the first breath the lungs float in water. The alveoli are prevented from collapse by the surfactant.

Congenital Anomalies

1. Tracheo Esophageal Fistula (TEF) is a common anomaly, in which there is communication between trachea and esophagus (Figs 25.6A to C). This is due to incomplete or defective tracheoesophageal septation accompanied by esophageal atresia. In about 90 percent of TEF, the lower segment of esophagus opens into the trachea closer to its termination. A newborn baby with this type of TEF will present with excessive frothing and choking with the first feed.

2. The absence of or inadequate secretion of the surfactant is the cause of collapse of alveoli after birth. This is one of the causes of death in neonatal period (respiratory distress syndrome).

3. The apex of right lung may be divided by the pleural fold carrying the azygos vein in its bottom. The medial part of the divided apex is called lobe of the azygos vein. This may cast a shadow in the lung apex in a radiograph, which may be mistaken for disease.

TRACHEA

The trachea or windpipe is a tube that conducts air from the larynx to the principal bronchi.

Length

In the adult, the trachea is about 12 cm long.

Location

It is situated partly in the neck and partly in the superior mediastinum (Fig. 25.7). The trachea lies in the midline in its cervical course but is deviated slightly to the right in its thoracic course.

Extent

It extends from the lower border of the cricoid cartilage (level with C6) to the upper border of the fifth thoracic
vertebra, where it divides into right and left principal bronchi.

**Mobility**

Its upper end moves with larynx and the lower end moves with respiration. During deep inspiration, the tracheal bifurcation may descend to the level of the sixth thoracic vertebra.

**Tracheal Patency**

The walls of trachea are kept patent by 15 to 20 C-shaped cartilaginous rings. The posterior ends of the cartilaginous rings are held together by smooth muscle called trachealis, which flattens the posterior wall of the trachea. The soft posterior wall of the trachea allows for the expansion of the esophagus during swallowing.

**Importance of Carina**

At tracheal bifurcation, the lower margin of the lowest cartilaginous ring is called the carina, which is a hook-shaped or keel-shaped process curving downwards and backwards between the bronchi. The carina is visible as a sharp ridge at the tracheal bifurcation during bronchoscopy. Hence, it is a useful landmark. It is located about 25 cm from the incisor teeth and 30 cm from the external nares. The mucosa of trachea is most sensitive at carina. If the tracheobronchial lymph nodes in the angle between the principal bronchi enlarge (due to spread from bronchogenic cancer) the carina becomes distorted and flattened. Therefore, morphological changes in the carina are looked for during bronchoscopy (Fig. 25.8).

**Comparative Features of Adult and Infant Trachea**

i. The average diameter of adult tracheal lumen is 12 mm. In childhood, the diameter in millimeters corresponds to the age in years. A four-year old child will have tracheal diameter of 4 mm.
ii. The trachea is more deeply placed in child compared to the adult. Hence, tracheostomy is more difficult in child.

iii. The left brachiocephalic vein may cross in front of the trachea in the suprasternal notch in children. Similarly, the brachiocephalic artery may be related to the trachea anteriorly just above the manubrium.

iv. In children up to the age of two years the thymus is large, hence it is in contact with the lower part of cervical trachea.

Anterior Relations of Cervical Part of Trachea
(Figs 25.9 and 25.10A)
The identification of anterior relations is essential in the operation of tracheostomy.

i. The following layers are seen from superficial to deep aspect, skin, superficial fascia with platysma, investing layer of deep cervical fascia.

ii. The sternohyoid and sternothyroid muscles overlap the trachea.

iii. The isthmus of the thyroid gland and the arterial anastomosis along its upper margin, cross the second to fourth or second to third tracheal rings.

iv. The inferior thyroid veins descend from the isthmus into the superior mediastinum. The thyroidea ima artery, when present is related below the isthmus.

v. The jugular venous arch crosses the trachea in the suprasternal space.

vi. The brachiocephalic artery is very closely related on the right side at the thoracic inlet.

vii. The pretracheal lymph nodes are scattered on the anterior aspect.

Posterior Relations
Posteriorly, the trachea lies on the esophagus with recurrent laryngeal nerve in the groove between trachea and esophagus.

Lateral Relations
The trachea is related laterally to the lobes of the thyroid gland, inferior thyroid arteries and common carotid artery in the carotid sheath.

Anterior Relations of Thoracic Part of Trachea

i. The arch of aorta and its two branches, brachiocephalic and left common carotid arteries are in close relation (Fig. 25.10B).

ii. The left brachiocephalic vein crosses the trachea from left to right and receives the inferior thyroid veins, which descend in front of the trachea.

iii. Remains of thymus are in contact with anterior surface.

iv. At the tracheal bifurcation, the deep cardiac plexus and tracheobronchial lymph nodes are seen.

Posterior Relation
The trachea is in contact with the esophagus.
Left Lateral Relations
The trachea is related to the arch of aorta, left common carotid artery and left subclavian artery. It is also related to the left recurrent laryngeal nerve.

Right Lateral Relations
The trachea is in contact with the mediastinal surface of right lung and pleura. Its vascular relations on the right side are venous (right brachiocephalic vein, SVC andazygos arch). It is also related to the right vagus nerve.

Vascular relations of trachea are shown in Figure 25.11.

Surface Marking
The trachea is represented on the surface by a two centimeter wide midline band from the level of cricoid cartilage to the sternal angle with a slight inclination to the right at the lower end.

Blood Supply (Fig. 25.12)

i. The cervical part is mainly supplied by inferior thyroid arteries.

ii. The thoracic part of the trachea is additionally supplied by the bronchial arteries.
ii. The interior of the trachea is examined in a patient through a bronchoscope. The biopsies from tracheobronchial lymph nodes at the tracheal bifurcation are taken through a bronchoscope.

iii. In plain radiographs, the trachea appears as a translucent and dark tubular area in the neck because of the presence of air column in it.

iv. The insertion of endotracheal tube (endotracheal intubation) is necessary for giving general anesthesia. After positioning the head of the patient appropriately, an endotracheal tube is passed through the oral cavity or the nasal cavity and then guided through the laryngeal cavity with the help of a laryngoscope and pushed down till its tip reaches well above carina. The tube is guided keeping in mind the distance of the carina from the external nares or incisor teeth.

v. Tracheostomy (Fig. 25.13) is making an artificial opening in the trachea if there is airway obstruction at laryngeal level. The site for the opening is in the cervical part of the trachea. The steps of the procedure are described along with structures in the midline of the neck in chapter 40.

vi. Enlargement of structures in relation to trachea causes tracheal compression in the neck. Thyroid swellings are the commonest cause of tracheal compression in the neck. The thoracic trachea may be compressed by enlarged lymph nodes or by aneurysm of arch of aorta in the superior mediastinum. Tracheal compression causes difficulty in breathing.

Embryologic insight ...
The trachea develops from the endodermal laryngotracheal groove. The groove forms the tube, which is separated from the developing esophagus by the tracheoesophageal septum. If this process of separation is incomplete or if there is esophageal atresia, a communication is formed between the trachea and esophagus. This is known as Tracheoesophageal fistula (TEF) (Fig. 25.6). In the common variety of TEF, the upper segment of esophagus ends blindly but the lower segment is connected to the trachea at its bifurcation. It is a serious condition. The water or milk ingested by the infant gets accumulated in upper blind segment of esophagus, from which it may be aspirated into the trachea and the lungs. The gastric contents or bile may be regurgitated into the trachea through fistulous connection and then into the lungs. Thus, fluids can reach the lungs by two routes. This is likely to cause aspiration or chemical pneumonia. The characteristic feature of this type of TEF is that, the stomach of the infant is filled with air.

Clinical insight ...
The pleura is a smooth shining serous membrane that covers the lungs. It is divisible into two parts, visceral and parietal. The visceral pleura covers the lung surface and gives it a glistening appearance. The pleura that lines the internal surfaces of the thoracic walls, is called the parietal pleura. The visceral and the parietal layers of the pleura are continuous with each other along the root of the lung and at the pulmonary ligament, which extends downwards from the hilum as a double-layered pleural fold. The pleural cavity is a potential space enclosed between the visceral and parietal pleura and contains a small amount of serous fluid.

Visceral Pleura (Figs 25.14 and 25.15)

i. The visceral pleura is inseparable from the lung.
ii. It dips into the fissures of the lungs.
iii. It shares the blood supply and nerve supply (autonomic nerves) with that of the lung.
iv. It is insensitive to pain.
v. It develops from splanchnopleuric mesoderm.

Parietal Pleura

i. The parietal pleura is more extensive than the visceral pleura.
ii. It lines the walls of thoracic cavity internally and is supported on its external surface by a thick layer of endothoracic fascia.
iii. It develops from somatopleuric mesoderm, hence is supplied by somatic nerves.
iv. It is pain sensitive.

Subdivisions of Parietal Pleura

It is subdivided into four parts depending on the location, costal (costovertebral) pleura, mediastinal pleura, diaphragmatic pleura and cervical pleura or dome of pleura. These different parts are continuous with each other along the lines of pleural reflection.

Costal Pleura

The costal pleura lines the inner aspect of the thoracic wall including ribs, intercostal spaces, sternum and sides of thoracic vertebral bodies.

Anterior Relations

The internal thoracic vessels directly rest on the pleura in the first intercostal space. Its other relations are the sternum, costal cartilages, ribs and intercostal muscles.

Posterior Relations

The costal pleura is related to the sympathetic chain and its branches. At the posterior end of the intercostal space, the intercostal nerve lies between the costal pleura and the posterior intercostal membrane.

 Mediastinal Pleura

The mediastinal pleura is in contact with the structures in the corresponding side of the mediastinum, since it covers the anterior part of the medial surface of the lung. It encloses the structures inside the lung root and becomes continuous with the visceral pleura at the hilum of lung. It extends below the lung hilum as pulmonary ligament. This ligament is a connecting bond between the mediastinum and the medial surface of the lung below the hilum.

Diaphragmatic Pleura

The diaphragmatic pleura covers the superior surface of the diaphragm. Superiorly, it is related to the base of the

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**Fig. 25.14:** Pleural cavity and costomediastinal recess in cross section

**Fig. 25.15:** Pleural cavity and costodiaphragmatic recesses (Note the continuity of visceral and mediastinal pleura at hilum of lung)
lung (costomediastinal recess of pleural cavity intervening between the two).

Cervical Pleura
The cervical pleura is the continuation of costal pleura above the level of inner margin of first rib (above the thoracic inlet). Here, it covers the apex of the lung. The cervical pleura extends posteriorly up to the neck of first rib, which is at a higher level. The suprapleural membrane or Sibson's fascia (Fig. 25.22) protects the cervical fascia. The Sibson's fascia extends from the tip of transverse process of seventh cervical vertebra to the inner margin of first rib.

Relations of Cervical Pleura
Anteriorly, subclavian vessels and scalenus anterior muscle are related. Posteriorly, sympathetic chain, superior intercostal artery and ventral ramus of first thoracic spinal nerve (Fig. 23.1) are related (same relations as those of the apex of the lung).

Lines of Pleural Reflections
i. Anteriorly, the costal pleura is continuous with the mediastinal pleura at the back of the sternum along the costomediastinal line of pleural reflection (Fig. 25.16).
ii. Inferiorly, the costal pleura is continuous with the diaphragmatic pleura along the costodiaphragmatic line of pleural reflection.
iii. Posteriorly, the costal pleura is continuous with the mediastinal pleura by the side of the vertebral column along the costovertebral line of pleural reflection (Fig. 25.17).

Surface Marking
The surface marking of the lines of pleural reflection is important because any puncture or incision at or inside these lines is likely to result in pneumothorax (air in pleural cavity) or hemothorax (blood in pleural cavity).

Costomediastinal Line
On both sides, the costomediastinal lines begin behind the sternoclavicular joints and descend in medial direction to come closer to each other at the midpoint of sternal angle. Further course of the lines is different. On the right side it runs vertically downward up to the midpoint of xiphisternal joint. On the left side it descends vertically up to the level of fourth costal cartilage and then deviates laterally to the margin of the sternum and descends close to the sternum up to the left sixth costal cartilage.

Costodiaphragmatic Line
On the right side, the costodiaphragmatic line begins at the midpoint of xiphisternal joint and turns laterally along the seventh costal cartilage to reach the eighth rib in the midclavicular line, tenth rib in the midaxillary line, and twelfth rib in the scapular line to finally end at the level of 11th and 12th ribs.

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Fig. 25.16: Lines of pleural reflection in relation to thoracic cage as seen from anterior aspect.
(Note that pleura crosses right costoxiphoid angle but not the left.)

Fig. 25.17: Lines of pleural reflection in relation to thoracic cage as seen from posterior aspect.
of spine of twelfth thoracic vertebra about two centimeter from the midline. On the left side, the line begins at the left sixth costosternal joint, beyond which it follows the course similar to that of right side. The noteworthy feature about this line of reflection is that it extends below the costoxiphoid angle on the right side only (not on the left side).

**Costovertebral Line**
This line extends from a point two centimeter lateral to the seventh cervical spine to a point two centimeters lateral to the twelfth thoracic spine.

**Cervical Pleura**
On the anterior aspect, the cervical pleura is represented by a curved line starting from the sternoclavicular joint and reaching a point 2.5 cm above the sternal end of clavicle. From here the line curves down to meet a point at the junction of medial and middle-third of clavicle.

**Pleural Recesses**
The pleural recesses are the extensions of the pleural cavities along the lines of pleural reflections. These spaces are unoccupied by lung during quiet breathing. The recesses are present because the pleural cavities are larger than the lung volumes. They are present at two locations.

i. The costomediastinal recesses (Fig. 25.14) are present along the costomediastinal lines of pleural reflection. Along this line the anterior margin of the lung does not coincide with the acute anterior margin of the pleural cavity. Thus, this recess is bounded by junctional parts of the costal and mediastinal pleurae. The right recess is very narrow and of uniform size. The left recess is wide at the level of fourth to sixth costal cartilages. The deviation of the anterior margin of the lung (due to the presence of cardiac notch) is much more compared to that of the pleural line, at this site. The left costomediastinal recess is responsible for the presence of the area of superficial cardiac dullness. Except for the wider part of the left recess the rest of the costomediastinal recesses are filled with lung during deep inspiration.

ii. The costodiaphragmatic recesses (Figs 25.16 and 25.17) are present along the costodiaphragmatic lines of pleural reflection. Along this line the lower margin of the pleura is two-rib distance below the lower margin of the lung. This recess is bounded by the costal and diaphragmatic pleurae and is unoccupied by the lung in quiet breathing. In deep inspiration, the recesses of both sides are partially filled. The right recess is related to the liver and posterior surface of right kidney and the left recess to the fundus of stomach, spleen and posterior surface of left kidney.

**Nerve Supply of Pleura**

i. The visceral pleura receives innervation from autonomic nerves, hence it is pain insensitive.

ii. The parietal pleura is supplied by somatic nerves, hence it is sensitive to painful stimuli. The pain is referred to the thoracic and abdominal walls or to the neck and shoulder. The costal pleura receives twigs from intercostal nerves.

iii. The peripheral part of diaphragmatic pleura receives branches from the intercostal nerves whereas its central part from the phrenic nerves. The mediastinal pleura is supplied by the phrenic nerve.

**Arterial Supply of Pleura**
The visceral pleura is supplied by the bronchial arteries and the parietal pleura by the intercostal and internal mammary arteries.

**Functional Importance of Pleural Cavity**
When the lungs expand and contract during normal breathing, they slide back-and-forth within the pleural cavity. To facilitate this, the mesothelial cells of the serous membrane (pleura) secrete a small quantity of interstitial fluid continuously into the pleural space. The total amount of fluid is kept at the minimal level by a unique mechanism of continuous turnover of the fluid which is responsible for maintaining the cavity as a potential space and for maintaining the negative pressure in the pleural cavity, which is necessary to retain the visceral pleura in contact with the parietal pleura. If there is positive pressure in the pleural cavity (for example, pneumothorax) the inherent elastic recoil of the lung tissue pulls the visceral pleura away from the parietal pleura causing collapse of the lung.
LUNGS

Lungs are the seats of oxygenation of blood. Each lung lies free in its own pleural cavity, attached to the mediastinum only by its root and the pulmonary ligament. The lungs of the children are pink in color unlike in the adult, where deposition of carbon particles (inhaled from atmospheric air) imparts grayish black color to the lungs. During life the lungs are soft, elastic and spongy. Being air-filled, they float on water. The lungs of the newborn before the first breath sink in water.

Gross Features

The shape of each lung is conical with a rounded apex and a broad base (Fig. 25.20).

Surfaces

There are three surfaces, a large costal surface in contact with ribs and intercostal spaces, a base or diaphragmatic surface in contact with diaphragm and a medial surface facing mediastinum and vertebral column.

The medial surface is subdivided into anterior larger mediastinal surface and posterior smaller vertebral surface. The mediastinal surface bears the hilum of the lung.

Borders (Margins)

i. The sharp anterior border separates the mediastinal and costal surfaces.
ii. The rounded posterior border separates the vertebral and costal surfaces.
iii. The inferior border intervenes between the base (diaphragmatic surface) and other two surfaces.

**Fissures**

i. There are two fissures (oblique and horizontal) in right lung, which divide the right lung into three lobes (upper, middle and lower).
ii. There is one fissure (oblique) in left lung, which divides the left lung into two lobes (upper and lower).

**External Features of Right and Left Lungs**

i. The average weight in adult of right lung is 600 gm and that of left lung is 550 gm.
ii. The right lung is broader and shorter than the left lung because the massive liver pushes the right dome of the diaphragm upwards.
iii. The anterior margin of the right lung is sharp and straight. The anterior margin of left lung is sharp but not straight as it presents a cardiac notch and a projecting lingula below it.
iv. The relations of the structures at the hilum on the two lungs are different (Fig. 25.21). The structures from above downwards in the right lung are, eparterial bronchus, pulmonary artery, hyparterial bronchus and inferior pulmonary vein and in the left lung, pulmonary artery, principal bronchus and inferior pulmonary vein. However, none of these differences is reliable in assigning side to an isolated lung. For identification of the side of the lung, it is held in anatomical position (as if it belongs to the holder's own body). The apex points upwards, base downwards, sharp margin anteriorly and surface bearing the hilum medially.

**Surface Markings of Fissures (Fig. 25.22)**

i. The oblique fissure is marked by a line passing downward and forward from a point on the posterior chest wall about two centimeter lateral to the spine of third thoracic vertebra. The line crosses the fifth rib in the mid-axillary line and reaches the sixth costal cartilage seven to eight cms lateral to the mid-line (or at the sixth costochondral junction). Roughly the oblique fissure corresponds to the medial border of the scapula in the fully abducted position of the arm.
ii. The horizontal fissure runs along the level of the right fourth costal cartilage and rib to meet the oblique fissure in the mid-axillary line (fifth rib).

**Surface Marking of Lung**

i. The summit of the apex of the lung is about 2.5 cm above the medial end of the clavicle. It is 3 to 4 cm above the sternal end of the first rib.
ii. The anterior margin of right lung coincides with the costomediastinal line of pleural reflection. The anterior margin of left lung coincides with the costomediastinal line of pleural reflection up to the level of fourth costal cartilage. Below this level it deviates from the mid-line for a distance of 3.5 cms between the fourth and sixth costal cartilages (due to the presence of cardiac notch on the anterior margin of lung).

iii. The inferior margin of lung is indicated by a line starting at the level of sixth costal cartilage on the left side and midpoint of the xiphisternum on the right side. Traced further it cuts the sixth rib in the mid-clavicular line, eighth rib in the mid-axillary line and tenth rib in the scapular line.

iv. The posterior margin of lung extends vertically upwards from the transverse process of the tenth thoracic vertebra to a point lateral to the spine of the seventh cervical vertebra.

Clinical insight ...

Auscultation Sites
In order to find out the disease or normalcy of the pleura or lung the clinician hears the breath sounds with the help of a stethoscope (auscultation). The knowledge of the surface marking of the lung is of use in delineating lung lobes on the surface of the chest wall.

i. The apex of the lung is auscultated above the medial-third of the clavicle anteriorly and in the upper part of suprascapular region posteriorly.

ii. The upper lobe of the right lung is heard anteriorly in the area extending from the clavicle to the level of fourth costal cartilage.

iii. The upper lobe of left lung is heard anteriorly in the area extending from the clavicle to the level of sixth costal cartilage.

iv. The middle lobe of right lung is heard anteriorly between the right fourth and sixth ribs in front of the midaxillary line.

v. The apical or superior segment of the lower lobe (on both sides) is heard posteriorly in the interval between the medial border of the scapula and the vertebral spines. The basal segments of the lower lobe (on both sides) are heard posteriorly in the infraspinacular region up to the level of tenth rib.

Relations of Apex
The relations of the apex of the lung (Fig. 25.23) are very important.

The apex is covered with the dome of the cervical pleura. The supra-pleural membrane or Sibson’s fascia protects the apex and the covering pleura in the root of the neck (this fascia is derived partly from endothoracic fascia and partly from scalenus minimus or pleuralis muscle).

Clinical insight ...

Malignancy of Lung Apex
The malignancy of the apex of the lung may present as symptoms and signs produced due to spread of cancer to neighboring structures.

i. Spread of cancer in subclavian or brachiocephalic vein produces venous engorgement and edema in the arm or neck and face.

ii. Pressure on the subclavian artery results in diminished pulse in the arm (brachial or radial, etc) on the affected side.

iii. Infiltration in the phrenic nerve results in paralysis of hemidiaphragm.

Pancoast Syndrome
When the structures in posterior relation of lung apex are involved due to cancer of lung apex, it produces symptoms and signs, which are collectively called pancoast syndrome.

i. Pain in ulnar distribution and wasting of small muscles of hand (due to injury to ventral ramus of T1 or lower trunk of brachial plexus)

ii. Horner’s syndrome (due to injury to sympathetic chain)

iii. Erosion of first or first and second ribs

Clinical insight ...

Medial Surface
The medial surface of the lung has a larger mediastinal surface, which is characterized by hilum of the lung and pulmonary ligament. This surface presents markings and grooves produced by the structures in the mediastinum. The smaller and convex vertebral surface is devoid of markings.
Impressions on Mediastinal Surface of Right Lung (Fig. 25.24)

i. A little below the apex, the right subclavian artery produces a notch on the anterior margin of the lung. The right first rib produces a notch on the anterior margin below that of right subclavian artery.

ii. There is a large cardiac impression in front of and below the hilum. The right atrium and the right ventricle (mainly in the anterior part) are related here.

iii. Superiorly, cardiac impression is continuous with groove for superior vena cava, which is located in front
of the hilum and is prolonged upwards as the groove for right brachiocephalic vein.

iv. A deep groove for the arch of azygos vein begins from the posterior margin of the groove for SVC and arches backwards over the hilum of the lung.

v. Above the hilum, trachea and right vagus nerve are related posterior to the groove for SVC.

vi. The right phrenic nerve descends in front of the hilum and crosses the groove for SVC, cardiac impression and the groove for IVC.

vii. The esophagus makes a wide shallow groove behind the trachea, the hilum and the pulmonary ligament. This groove stops short of the lower margin of the lung.

viii. The inferior vena cava is related to the lung posteroinferior to the cardiac impression.

Vertebral Surface of Right Lung

This surface is in contact with the right aspect of thoracic vertebrae and intervertebral discs, posterior intercostal vessels and splanchnic nerves (branches of thoracic sympathetic chain).

Impressions on Mediastinal Surface of Left Lung (Fig. 25.25)

i. There is a large cardiac impression in front of and below the hilum. The left ventricle is mainly related to this area. The anterior part however, is related to the infundibulum of right ventricle.

ii. The pulmonary trunk lies in front of the hilum in continuation of the area for infundibulum.

iii. The arch of aorta produces a deep and wide groove immediately above the hilum.

iv. In continuation of groove for arch of aorta there is a groove for descending thoracic aorta behind the hilum and pulmonary ligament. It reaches up to the lower margin of the lung.

v. The grooves for left subclavian artery and for left common carotid artery course upwards from the groove for arch of aorta. The left common carotid artery produces an anteriorly located short groove. The groove for left subclavian artery begins posterior to that of common carotid artery and runs upwards to cut the anterior margin just below the apex.

vi. The first rib comes in contact with this surface below that of left subclavian artery.

vii. The thoracic duct and esophagus are related behind the groove for left subclavian artery.

viii. The left brachiocephalic vein lies in a faint linear depression in front of the left subclavian artery.

ix. The left phrenic nerve descends in front of the hilum and crosses the cardiac impression.

x. The lower esophageal impression lies in front of the groove for descending aorta and behind and below the lower end of the pulmonary ligament.

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**Fig. 25.25:** Relations of medial (mediastinal and vertebral) surface of left lung
Vertebral Surface of Left Lung
This surface is related to the left aspects of thoracic vertebrae and intervening discs, posterior intercostal vessels and splanchnic nerves (branches of thoracic sympathetic chain).

Root of Lung (Fig. 25.26)
The root of lung connects the mediastinum to the lung. All the structures, which enter and leave the hilum of the lung, are enclosed in a tubular sheath of mediastinal pleura. This tubular sheath with its enclosed contents is called the root of the lung.

Vertebral Level
The lung root lies opposite T5 to T7 vertebrae.

Contents
i. Single bronchus (principal bronchus on the left side) and two bronchi (eparterial and hyparterial) on the right side
ii. Pulmonary veins
iii. Pulmonary artery
iv. Bronchial vessels
v. Lymph vessels and hilar or bronchopulmonary lymph nodes
vi. Pulmonary nerve plexuses.

Pulmonary Ligament
It is a double fold of mediastinal pleura below the level of pulmonary hilum. It connects the mediastinal surface below the lung root to the side of posterior mediastinum. The layers of the pulmonary ligament are continuous medially with mediastinal pleura, laterally with the visceral pleura and superiorly with the pleura covering the lung root. Its lower border is free. There is a potential space between the two layers of the pulmonary ligament, which provides a dead space for expansion of inferior pulmonary veins during increased venous return and for the descent of lung root during inspiration.

Bronchial Tree (Fig. 25.27)
The principal bronchus passes inferolateral from the bifurcation of the trachea to the hilum of each lung. The bronchi divide in a tree-like fashion within the lung. Each principal bronchus divides into secondary or lobar bronchi, which in turn divide into segmental or tertiary bronchi.

Right Main Bronchus
This is wider, shorter (length 2.5 cm) and more vertical than the left bronchus. Therefore, an aspirated foreign body is more likely to enter the right lung. The right main bronchus gives its first branch, the eparterial bronchus and then enters the hilum of the lung as the hyparterial bronchus.

i. The eparterial bronchus continues as the right superior lobar bronchus inside the lung and divides into three segmental bronchi namely, apical, anterior, and posterior.

ii. The hyparterial bronchus divides into middle and right inferior lobar bronchi inside the lung. The middle lobar bronchus divides into two segmental bronchi called medial and lateral. The right inferior lobar bronchus divides into five segmental bronchi for the inferior lobe. The first branch to arise is the superior or apical
segmental bronchus, which is given off from the posterior aspect and goes directly backwards to the superior segment of the inferior lobe. In the supine position of the body, this segmental bronchus projects directly posteriorly and since it is the first branch to arise, foreign body is inhaled into it. The superior bronchopulmonary segment of lower lobe is most dependent and hence secretions tend to collect in it (Fig. 25.28). Next branch to arise is called the medial basal bronchus to serve a small area below the hilum. The remaining bronchus divides into three segmental bronchi called anterior basal, posterior basal and lateral basal.

**Left Main Bronchus**

This bronchus is narrower, less vertical and longer (length 5cm) than the right. Passing to the left from its origin, it lies inferior to the aortic arch and crosses the esophagus anteriorly (producing esophageal constriction). It enters the hilum of the lung and divides into superior and inferior lobar bronchi.

i. The left superior lobar bronchus takes origin from the anterior aspect of the principal bronchus and curves laterally to divide into superior and inferior divisions. The superior division gives off an anterior segmental bronchus and is then called apico-posterior segmental bronchus, which soon divides into apical and posterior segmental bronchi. The inferior division descends towards the lingula and divides into superior and inferior lingular segmental bronchi.

ii. The left inferior lobar bronchus gives off its first branch called the superior (apical) segmental bronchus for the upper part of the inferior lobe. Similar to the right side, this bronchus projects directly posteriorly and in the supine position tends to collect secretions. After a further course of 1 to 2 cm, the inferior lobar bronchus divides into anteromedial and posterolateral stems. The anteromedial stem divides into medial basal and anterior basal segmental bronchi while the posterolateral stem divides into lateral and posterior basal segmental bronchi.
Intrapulmonary Airways

Within each lung there are conducting airways (from lobar bronchi to terminal bronchioles) and respiratory areas (respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli). As segmental bronchi branch until they progressively become smaller and narrower. Air passages less than one mm in diameter are termed bronchioles. They are devoid of cartilage and hence their wall consists of smooth muscle only. The bronchioles divide till they reach the stage of terminal bronchioles, which enter the lung lobule. The terminal bronchioles divide to give rise to respiratory bronchioles. A few alveoli sprout from the respiratory bronchioles, which divide to give rise to alveolar ducts. Each alveolar duct expands to form atrium, which sprouts a number of alveolar sacs, which in turn are studded with alveoli. The alveoli are thin-walled pouches, which provide the respiratory surface for gaseous exchange. The alveoli are surrounded by pulmonary capillary bed. The alveolar epithelium is of simple squamous type. The type II cells are slightly larger and secrete surfactant. The blood-air barrier consists of Type I alveolar cells (simple squamous), capillary endothelium and the basement membranes of the two in between.

Bronchopulmonary Segments

The bronchopulmonary segment is defined as a structural and functional unit of the lung parenchyma ventilated or aerated by a segmental or a tertiary bronchus (Table 25.1).

Characteristic Features (Fig. 25.29)

i. The shape of the bronchopulmonary segment is pyramidal with apex pointing towards the hilum and the base towards the lung surface.

ii. Each segment has a covering of loose connective tissue.

iii. Each segment contains segmental bronchus and its further subdivisions, segmental branches of pulmonary artery and of bronchial artery. Air and impure blood pass in the center of each segment.

iv. The tributaries of pulmonary veins supported in loose connective tissue are located in the intersegmental planes. Thus, the pure blood passes along the periphery of each segment.

v. Each segment can be delineated radiologically (bronchography).

vi. Segmental resection is surgical removal of a diseased bronchopulmonary segment. During surgery, the segmental bronchus of the diseased segment is located by dissection and it is clamped along with the blood vessels. This enables to delineate the segment, as the surface of that segment will darken due to loss of blood supply and air.

Blood Supply of Lungs

1. The pulmonary arteries carry deoxygenated blood to the lung from the right ventricle. After entering the hilum, the pulmonary arteries follow the divisions of the segmental bronchi. The arterioles accompanying
the terminal and respiratory bronchioles are thin-walled (without muscle fibers). These end up forming capillaries, which are in close proximity to the alveoli. The venous ends of the capillary beds join to form veins, which travel in the intersegmental planes. The intersegmental veins finally unite to form two pulmonary veins in each lung.

2. The pulmonary veins carry oxygenated blood from the lungs to the left atrium.
3. The bronchial arteries provide nutrition to the bronchial tree up to the level of terminal bronchioles (to the non-respiratory portions of the lungs).
4. The respiratory portions of the lungs are nourished from pulmonary capillary beds and directly from atmospheric air contained inside the alveoli.

**Bronchial Arteries (Fig. 32.10)**

The bronchial arteries supply the intrapulmonary bronchial tree and the connective tissue of lung parenchyma.

i. The single right bronchial artery takes origin from either the left bronchial artery or the third right posterior intercostal artery or the descending aorta.

ii. On the left side there are two bronchial arteries, upper and lower. Both are the direct branches of descending thoracic aorta at the level of tracheal bifurcation.

**Bronchial Veins**

i. The right bronchial vein opens into the azygos vein.

ii. The left bronchial vein opens into either the left superior intercostal vein or the accessory hemiazygos vein.

**Lymphatic Drainage (Fig. 25.30)**

The lymphatic drainage of the lung is important because lung cancer spreads by lymphatic path.

i. Two sets of lymphatic plexuses, superficial and deep, drain the lungs.

ii. The superficial plexus is sub-pleural in location and the deep plexus is seen along the bronchi and blood vessels.

iii. These two sets communicate with each other at the hilum and drain into the bronchopulmonary lymph nodes, which are also called hilar lymph nodes. These nodes are black in color due to the carbon particles drained into them from lungs.

iv. The efferent lymph vessels from the hilar nodes pass through tracheobronchial and paratracheal nodes.

v. The tracheobronchial nodes communicate with the nodes in the base of the neck. These lymph nodes enlarge in pulmonary tuberculosis also.

vi. The enlarged nodes may sometimes obstruct a lobar bronchus causing collapse (atelectasis) of the entire lobe.

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**Fig. 25.29:** Bronchopulmonary segment showing its blood vessels, ramifications of segmental bronchus and lung parenchyma.
**Nerve Supply**

The lungs receive both sympathetic and parasympathetic nerves from the pulmonary plexuses.

i. The afferent fibers from the lung originate in endings sensitive to stretch, which are involved in reflex control of respiration and coughing.

ii. The parasympathetic fibers are cholinergic. The parasympathetic stimulation causes bronchoconstriction and increased secretion of the bronchial glands. The attack of bronchial asthma is produced due to spasm of smooth muscles in the wall of bronchioles. This may be precipitated by excessive vagal stimulation (due to exposure to pollen dust, cold air, ordinary dust, smoke, etc.).

iii. The sympathetic fibers are adrenergic. The sympathetic stimulation causes bronchodilatation, vasoconstriction and decreased secretion.

iv. To counteract the spasm of the muscles in an attack of asthma, either sympathomimetic or anticholinergic drugs are given. Sympathomimetic drugs like adrenaline mimic the action of sympathetic stimulation (bronchodilatation). Anticholinergic drugs like atropine nullify the bronchoconstriction action of cholinergic fibers, which results in dilatation of bronchi.

**Radiological Anatomy**

i. In a plain radiograph, first the soft tissue shadows are examined. The trachea is identified in the midline in the superior mediastinum as a translucent air column. The lung fields are translucent, but the bronchovascular markings are seen as branching opacities throughout the lungs. The hilum is recognized as an opaque area because it contains large blood vessels and lymph nodes. The costodiaphragmatic recesses are visible and always examined for presence of fluid.

ii. The CT scans and MRI of the thorax are also useful to study internal anatomy.

iii. Bronchography is done to visualize the bronchial tree by introducing contrast medium through nose or mouth into the respiratory tract. After this the radiographs are taken. Nowadays bronchography is replaced by CT scan.

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**Clinical insight ...**

i. In bronchoscopy (Fig. 25.8), the interior of trachea and the bronchi is inspected using a bronchoscope. Carina at tracheal bifurcation is an important landmark visible through the bronchoscope. A flexible fiberoptic bronchoscope can be introduced under local anesthesia as a bedside procedure. Transbronchial biopsies can be obtained through this instrument.

ii. Mendelson’s syndrome is the aspiration pneumonia in the superior (apical) segment of the lower lobe. The anatomical reason for this is that in the supine position of the body the superior segmental bronchus is the most dependent. Hence, it tends to collect the secretions, which may obstruct the bronchus leading to collapse of the superior segment of the lower lobe (atelectasis) and pneumonia. This can be easily verified by percussive dullness in interscapular area and absence or diminished breath sounds in the same area.

iii. The bronchiectasis is the condition in which bronchi and bronchioles are dilated. The segmental bronchi to the basal segments of the lower lobe are prone to this condition in which the smaller divisions of the bronchi become permanently dilated and filled with pus. Postural drainage is performed to remove pus by giving appropriate position to the patient.

iv. The bronchogenic carcinoma originates from the epithelium of the bronchi. Cigarette smoke and automobile smoke increase the risk of this cancer. The presence of circular shadow (coin lesion) or an irregular...
Fig. 25.31: Radiograph chest showing dense shadow (due to cancer indicated by arrow) in left lung

Contd...

shadow in a plain X-ray of chest may be the only finding in an otherwise asymptomatic patient. Carcinoma of left lung is detectable in plain radiograph of chest (Fig. 25.31).

v. Figure 25.18 shows another pathological condition of lung in which there is mycetoma (fungal colony) in a pre-existing tuberculous cavity in the left lung.
DIAPHRAGM

The diaphragm is a movable partition between the thoracic and abdominal cavities. It is partly muscular and partly tendinous. It is the chief muscle of inspiration. The diaphragm descends during inspiration and ascends during expiration. During quiet breathing it descends for a distance of 1.5 cm. The movements of the diaphragm can be observed in the living beings by the fluoroscopic examination. The position of the diaphragm varies with position of body. In supine position, the diaphragm is highest and shows maximum movements but reverse is the case in sitting position.

Parts and Relations

i. The superior surface of the diaphragm projects as two domes or cupola into the thoracic cavity. The domes are covered with diaphragmatic pleura. The base of each lung fits into the corresponding dome.

ii. The central tendon is a depressed area between the two domes of diaphragm. The central tendon is fused with the base of the fibrous pericardium.

iii. The deeply concave inferior surface of the diaphragm forms the roof of the abdominal cavity. It is covered with parietal peritoneum. The right side of this surface is related to the right lobe of the liver, right kidney and right suprarenal gland. The left side of this surface is related to the left lobe of the liver, fundus of stomach, spleen, left kidney and left suprarenal gland.

Surface Marking

i. Anteriorly, the right dome reaches a point as far as the upper border of the right fifth rib in the midclavicular line and the left dome reaches as far as the lower border of the left fifth rib.

ii. Posteriorly, the right dome is level with a point 1.25 cm below the inferior angle of scapula and the left dome is level with a point 2.5 cm below the inferior angle of scapula. Thus, the right dome is at a higher level due to the presence of a large right lobe of the liver under it.

iii. The central tendon is at the level of a line joining the xiphisternal joint to the spine of eighth thoracic vertebra.

Attachments

The diaphragm is attached circumferentially to the margins of thoracic outlet (Fig. 26.1).

Origin

According to the site of origin, the diaphragm is subdivided into three parts.

i. Sternal part arises as two muscular slips from the back of the xiphoid process.

ii. Costal part arises as six muscular slips from the inner surfaces of the costal cartilages and adjacent parts of the lower six ribs.

iii. Vertebral part arises as right and left crura and by arcuate ligaments on each side.

The right crus is attached to the front of the bodies of the upper three lumbar vertebrae and the intervening intervertebral discs. The right crus is larger in size because...
of the presence of heavy liver on the right side. A few fibers of the right crus deviate to the left of the midline to encircle the lower end of the esophagus. Some fibers of the right crus are attached to the duodenojejunal flexure as suspensory ligament of duodenum (muscle of Treitz).

The left crus is attached to the corresponding part of upper two lumbar vertebrae and the intervening disc.

The median arcuate ligament is a poorly defined tendinous arch joining the two crura across the lower border of the twelfth thoracic vertebra.

The medial and lateral arcuate ligaments or lumbo-costal arches give origin to the diaphragmatic muscle.

The medial arcuate ligament is the thickening of fascia covering psoas major muscle stretching from the side of the body of the first lumbar vertebra to the middle of the front of the transverse process of the same vertebra. The lateral arcuate ligament is the thickening of upper margin of the anterior layer of thoracolumbar fascia in front of the quadratus lumborum muscle. It stretches from the transverse process of first lumbar vertebra to the twelfth rib on each side.

**Insertion**

From this circumferential origin, the fibers of muscular diaphragm converge towards the central tendon for insertion. The central tendon has no bony attachments. It is trifoliate in shape and is inseparably fused with the base of the fibrous pericardium.

**Apertures in Diaphragm (Fig. 26.2)**

There are three major apertures and a number of minor apertures in the diaphragm for the passage of structures between thorax and abdomen.

**Fig. 26.1:** Sternal, costal and vertebral origin of diaphragm from abdominal aspect (Numbers 7 to 12 indicate ribs)

**Fig. 26.2:** Structures passing through diaphragm NV bundle—intercostal neurovascular bundle (Number 7 to 12 indicates ribs)
Major Apertures

i. The quadrilateral vena caval aperture lies at the level of eighth thoracic vertebra. It is located in the central tendon to the right of the midline. The wall of the inferior vena cava is fused with the margins of the opening. The contraction of the diaphragm enlarges the caval opening thereby dilating the vein and promoting the venous return. The branches of the right phrenic nerve pass through this opening along with IVC.

ii. The elliptical esophageal hiatus is located in the muscular part of the diaphragm just posterior to the central tendon and to the left of the midline. The fibers of the right crus encircle it. It is at the level of the tenth thoracic vertebra. The contraction of the diaphragm has a sphincteric effect on the hiatus (pinchcock effect). The vagal trunks and the esophageal branches of left gastric vessels pass through the hiatus along with esophagus.

iii. The rounded aortic opening lies posterior to the median arcuate ligament at the level of twelfth thoracic vertebra. The contraction of the diaphragm has no effect on this opening. The thoracic duct and vena azygos pass through the opening along with the aorta.

Minor Apertures

i. Superior epigastric vessels pass through a gap (space of Larry) between sternal origin and costal origin from seventh costal cartilage.

ii. Musculophrenic vessels pass through the interval between slips of origin of diaphragm from the seventh and eighth ribs. The seventh intercostal nerve and vessels also pass through this interval.

iii. The eighth to eleventh intercostal nerves and vessels pass through intervals between the adjacent costal origins from subsequent ribs.

iv. Subcostal nerves and vessels pass behind the lateral arcuate ligament.

v. Sympathetic chains pass behind the medial arcuate ligaments.

vi. Greater, lesser and least splanchnic nerves pierce the crus of the corresponding side.

vii. Hemiazygos vein pierces the left crus.

viii. Right phrenic nerve passes usually through the IVC opening and the left phrenic nerve through the muscular part in front of the central tendon.

Sensory Nerve Supply

i. The central part of diaphragm and related pleura and peritoneum are supplied by sensory fibers of phrenic nerves. Irritation of the pleura or the peritoneum of the central part of diaphragm gives rise to referred pain in front of and at the tip of the shoulder, which is the area of cutaneous supply of supraclavicular nerves (C3, C4).

ii. The peripheral part of diaphragm is supplied by lower intercostal nerves.

Arterial Supply

i. Superior phrenic arteries (also called phrenic arteries), which are the last branches of thoracic aorta, are distributed to posterior part of the superior surface of the diaphragm.

ii. The musculophrenic and pericardiacophrenic branches of the internal thoracic artery supply anterior part of the superior surface of diaphragm.

iii. Inferior phrenic arteries, which are the first branches of abdominal aorta, supply the inferior surface of the diaphragm.

Lymphatic Drainage

1. The thoracic surface drains as follows:

   i. Its anterior part drains into the anterior diaphragmatic nodes and parasternal nodes.

   ii. The middle part drains into right and left lateral diaphragmatic nodes, parasternal nodes and posterior mediastinal nodes.

   iii. The posterior part drains into posterior diaphragmatic nodes and posterior mediastinal nodes.

2. The abdominal surface drains as follows:

   i. The right half of diaphragm drains into lymph nodes lying along inferior phrenic artery and in the right para-aortic lymph nodes.

   ii. The left half drains in preaortic nodes and in nodes around lower end of esophagus.

Actions

i. The diaphragm is a muscle of inspiration. When the diaphragm contracts, the domes of the diaphragm along with the central tendon descend; thereby increasing the vertical diameter of the thoracic cavity. Once the limit of the descent is reached the central tendon becomes a fixed point around which the muscular diaphragm contracts. This contraction
Diaphragm and Phrenic Nerves

elevates the lower ribs thereby pushing forwards the sternum and the upper ribs, which increases the transverse and anteroposterior diameters of the thoracic cavity.

ii. The contraction of the diaphragm raises the intra-abdominal pressure, which is useful in all expulsive activities like micturition, defecation and parturition. It also helps in weightlifting when the raised intra-abdominal pressure is kept sustained by closure of the glottis after taking a deep breath. This maintains the vertebral column in extended position, thus helping the trunk muscles in lifting heavy weights.

iii. The contraction of the diaphragm facilitates venous and lymph return. The rise in the intra-abdominal pressure and decrease in the intrathoracic pressure compress the blood in the inferior vena cava and lymph in the cisterna chyli. This results in upward movement of the blood towards the right atrium and of the lymph towards the thoracic duct.

Embryologic insight (Fig. 26.3)...

The diaphragm is entirely mesodermal. It develops in the neck of the embryo from four different sources as follows:

i. Septum transversum
ii. Right and left pleuroperitoneal membranes
iii. Dorsal mesentery of the esophagus
iv. Body wall mesoderm
v. The muscle of the diaphragm develops from the third, fourth and fifth cervical myotomes and hence, its motor innervation is from the phrenic nerve. When the diaphragm descends from the neck to its definitive position, its nerve supply is also dragged down. This explains the long course of the phrenic nerves.

Congenital Diaphragmatic Hernia

i. The retrosternal hernia occurs through foramen of Morgagni, which is an enlarged space of Lary.

ii. The posterolateral hernia occurs through the vertebrocostal triangle (also called foramen of Bochdalek). It is a gap between the costal and vertebral origins of the diaphragm. This gap results due to failure of closure of the pleuroperitoneal canals on account of non-development of pleuroperitoneal membrane. This occurs more commonly on the left side. The abdominal viscera may herniate through this defect into the thorax producing hypoplastic lung (Fig. 26.4) and respiratory distress soon after birth. Figure 26.5 shows a child with congenital diaphragmatic hernia (CDH) with typical scaphoid or sunken abdomen. The radiograph of chest shows herniated intestines and hypoplastic lung and shift of mediastinum to the right (Fig. 26.6). The surgical repair of hernia and closure of foramen of Bochdalek is shown in Figure 26.7.
Clinical insight ...

**Hiatal or Hiatus Hernia**

The acquired diaphragmatic hernia (hiatus hernia) occurs through the esophageal opening (hiatus). It is of two types.

i. In the sliding hernia the cardio-esophageal junction and the cardiac end of the stomach pass through the esophageal opening to enter the posterior mediastinum (Fig. 26.8A). This is caused due to weakness of the diaphragmatic muscle surrounding the esophageal opening and increased intra-abdominal pressure due to any cause. There is regurgitation or reflux of acid contents of the stomach into the esophagus causing peptic esophagitis (heartburn is the main symptom).

ii. In the rolling hiatus hernia, a part of the stomach passes through the esophageal opening into the posterior mediastinum. There is no reflux of gastric contents into the esophagus as the cardio-esophageal junction is in normal position (Fig. 26.8B).

**Diaphragmatic Paralysis**

i. Unilateral diaphragmatic paralysis is caused by damage to the phrenic nerve. The condition is diagnosed when an elevated hemidiaphragm as seen on fluoroscopy moves paradoxically.

ii. The bilateral diaphragmatic paralysis is a near fatal condition as it leads to respiratory failure.

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**Fig. 26.6**: Multiple air-filled areas depicted by arrows indicating herniated intestine in thorax

**Fig. 26.7**: Surgical repair of defect in diaphragm using synthetic mesh

**Fig. 26.8A**: Sliding type of hiatus hernia (Note that there is upward shift of stomach (arrow) fundus and abdominal esophagus in posterior mediastinum)

**Fig. 26.8B**: Para-esophageal/rolling type of hiatus hernia (Arrow indicates the upward shift of stomach (not fundus))
Mechanism of Respiration
The respiration rate in a healthy adult is 18 to 20 per minute. Each respiratory cycle consists of an inspiratory and an expiratory phase. Inspiration increases the thoracic volume with a simultaneous decrease in the intrapulmonary pressure. This ensures the inflow of air into the lungs until the pressures equalize. The expiration decreases thoracic volume with a simultaneous increase in the intrapulmonary pressure. This causes the air to flow out of the lungs until the pressures equalize.

Quiet Inspiration
1. The movements of the ribs take place at costovertebral and costotransverse joints, which are the joints between the posterior ends of the ribs and the thoracic vertebrae.
   i. In the pump-handle movement, the upper ribs (2–6) rotate around an axis, which passes through costo-vertebral and costo-transverse joints. This rotation results in upward and forward movements of the anterior ends of the ribs along with the sternum. The lower ribs (7–10) are elevated as a unit, thereby lifting the lower end of the sternum upward and forward. The final effect is the increase in the anteroposterior diameter of the thoracic cavity.
   ii. In bucket-handle movement, the ribs are rotated along an axis, which passes through the tubercle of the rib and the middle of the sternum. The effect of this rotation is the elevation of the middle parts of the ribs in lateral direction so as to increase the transverse diameter of the thoracic cavity.
2. The diaphragm forms a mobile floor of the thoracic cavity. Its contraction results in the descent of the diaphragm by about 1 to 1.5 cm in quiet inspiration. The contraction of the diaphragm is accompanied by the reciprocal relaxation of the anterior abdominal muscles. The descent of the diaphragm results in increase in the vertical dimension of the thoracic cavity. The diaphragm can also act on the lower ribs at the end of its vertical descent. Keeping the central tendon as a fixed point, the diaphragmatic contraction elevates the lower ribs thereby increasing the anteroposterior and transverse diameters of the thorax.

Muscles of Inspiration
i. The most important muscle of inspiration is the diaphragm.
ii. The contraction of the external intercostal muscles and the interchondral portion of the internal intercostal muscles, results in elevation of the ribs.
iii. During movements of the ribs, the first rib is fixed by the contraction of the scalenus anterior and scalenus medius muscles.

Forced Inspiration
Additional, muscles are brought into play to increase the volume of the thoracic cavity.

i. The first two ribs are elevated along with the manubrium sterni by active contraction of scalene and sternomastoid muscles.
ii. The pectoral, levatores costarum and serratus anterior and posterior muscles elevate the ribs.
iii. The power of the diaphragmatic contraction is increased by fixing the twelfth rib with the help of active contraction of quadratus lumborum.

Quiet Expiration
Quiet expiration is largely a passive process. The elastic recoil of the lungs (intrinsic elastic recoil) and of the chest wall (extrinsic elastic recoil) accompanied by the relaxation of the diaphragm and external intercostal muscles is responsible for it. The relaxation of the diaphragm is accompanied by the reciprocal increase in the tone of anterior abdominal muscles. The extrinsic elastic recoil diminishes with age because the costal cartilages undergo calcification. Elderly people tend to breathe diaphragmatically. The diseases that reduce the intrinsic elastic recoil of the lungs, such as emphysema, affect the expiratory process and make it stressful.

Forced Expiration
Forced expiration is an active process.

i. Active and forceful contraction of muscles of anterior abdominal wall pushes the diaphragm upwards.
ii. In addition, the quadratus lumborum contracts to pull the twelfth rib down.
iii. The interosseous parts of the internal intercostal muscles contract to pull the ribs down.
iv. The serratus posterior inferior and latissimus dorsi muscles may also play a minor role.

PHRENIC NERVES
The right and left phrenic nerves are the only motor supply to the muscle of the corresponding half of the diaphragm. They are mixed nerves with 2:1 proportion of motor and sensory fibers. The sensory fibers supply the diaphragmatic and mediastinal pleura, fibrous and parietal pericardium and diaphragmatic peritoneum of its side.

Origin
The phrenic nerve arises in the neck from cervical plexus. It mainly carries fibers of ventral ramus of the fourth cervical nerve but receives contribution from the third and fifth cervical nerves as well. Hence, the root value of phrenic nerve is C3, C4, C5 (Fig. 26.9). Accessory phrenic nerve is occasionally present. It arises from nerve to subclavius, carries C5 fibers and joins the phrenic nerve in the thorax (Fig. 26.10).
Course and Relations

The phrenic nerve has a long course, which can be divided into cervical and thoracic parts.

Cervical Course of Phrenic Nerves

The phrenic nerve begins from the cervical plexus and descends on the anterior surface of the scalenus anterior muscle. The prevertebral layer of the deep cervical fascia plasters down the phrenic nerve to this muscle. During its further descent the nerve crosses the scalenus anterior muscle lateromedially. Anteriorly, the phrenic nerve is overlapped by internal jugular vein and sternomastoid muscle. It is crossed by intermediate tendon of omohyoid, transverse cervical and suprascapular arteries, (and thoracic duct on left side). Its posterior relation is scalenus anterior muscle (Fig. 26.9). On the right side, the phrenic nerve lies anterior to scalenus anterior throughout its cervical course. However, on the left side its posterior relations are the scalenus anterior muscle and the first part of left subclavian artery. This is due to the fact that the left phrenic nerve leaves the scalenus anterior muscle from its medial margin near the root of the neck, unlike the right phrenic nerve, which retains its anterior relation to the muscle till the lower end of the muscle.

Thoracic Course of Phrenic Nerves

The right and left phrenic nerves enter the superior mediastinum through the thoracic inlet. The left phrenic nerve enters between the left subclavian vein in front and the first part of the left subclavian artery behind. The right phrenic nerve enters by passing between the right subclavian vein in front and the right scalenus anterior muscle behind. Both the phrenic nerves cross the internal thoracic artery from lateral to medial side on its anterior aspect (Fig. 26.9). The left phrenic nerve is longer than the right and the right phrenic nerve is shorter and more vertical in the thoracic course. Both the nerves at first pass through the superior mediastinum and then in front of the hilum of the respective lung to enter the middle mediastinum. Both descend in close relation to the respective lateral surfaces of fibrous pericardium. The pericardiacophrenic vessels accompany the phrenic nerves in their thoracic course (Fig. 26.9).

Course of Right Phrenic Nerve

The right phrenic nerve passes down along the right side of right brachiocephalic vein, superior vena cava, right atrium covered by right side of fibrous pericardium and lastly the thoracic part of inferior vena cava. In the middle mediastinum the nerve lies between the mediastinal pleura laterally and the fibrous pericardium medially. It leaves the
thorax by passing through the vena caval opening or by piercing the central tendon in the vicinity of the opening.

Course of Left Phrenic Nerve
The left phrenic nerve passes between the left common carotid and left subclavian arteries. Initially, it is laterally related to the left vagus nerve. Next, it crosses the left vagus nerve superficially and comes to lie medial to it. Then, the phrenic nerve crosses the arch of aorta on its left and anterior aspect. After this, the left phrenic nerve descends in front of the root of the left lung and in front of the fibrous pericardium covering the left ventricle. In the middle mediastinum, the nerve lies between the mediastinal pleura laterally and fibrous pericardium medially. It leaves the thorax by piercing the muscular part of diaphragm to the left of the anterior folium of the central tendon.

Distribution
The phrenic nerves divide into branches, which ramify in the substance of the diaphragm or on its inferior surface and supply motor branches to anterior and posterior parts of muscle of the diaphragm. The sensory branches are given to the peritoneum lining the inferior surface of diaphragm, diaphragmatic pleura, mediastinal pleura and to the parietal and fibrous pericardium. In the inflammation of peritoneum or the pleura, the pain is referred to the shoulder, which is the area of C4 dermatome.

Clinical insight ...

Injury to Phrenic Nerve
i. The phrenic nerve may be injured either in the neck or in the thorax. This results in paralysis of hemidiaphragm, which can be detected by X-ray screening. The paralyzed half of the diaphragm moves paradoxically during respiration and is pushed up in the thorax.
ii. The avulsion of phrenic nerve is sometimes necessary in treating certain diseases of lung. The phrenic nerve is approached via the base of the posterior triangle of the neck. It is freed from the prevertebral fascia in front of the scalenus anterior muscle and raised on a hook and then divided. The distal end of the nerve is grasped and twisted around the forceps and pulled upwards to tear out as much of the nerve as possible. If the accessory phrenic nerve is present, it is also avulsed.
The heart is the first organ to start function in the human embryo. During the third week of intrauterine life, the angiogenic cells in the cardiogenic area at the cranial end of the embryonic disc form right and left endothelial cardiac tubes. Around twenty second day of development, a single straight cardiac tube is formed by their fusion. Thus, the cardiac tube is mesodermal in origin. It is located in the splanchnopleuric mesoderm in the floor of the pericardial coelom. With the formation of the head fold of the embryonic disc, the pericardial coelom undergoes 180 degree rotation. As a result of this the cardiac tube and the splanchnopleuric mesoderm come to lie on the dorsal aspect of the pericardial coelom. As the heart tube invaginates the splanchnopleuric mesoderm, it is encircled by it. The splanchnopleuric mesoderm forms the myoepicardial mantle around the cardiac tube.

**Subdivisions of Cardiac Tube**

The cardiac tube is divisible into five chambers (Fig. 27.1) in craniocaudal order as follows:

i. **Truncus arteriosus**

ii. **Bulbus cordis**

iii. **Common ventricle**

iv. **Common atrium**

v. **Sinus venosus**

The truncus arteriosus is the cranial or arterial end of cardiac tube. It projects out as ventral aortic sac, which is connected by the arch arteries to the dorsal aorta on each side.

The sinus venosus is the caudal or venous end of cardiac tube. It receives three pairs of veins on each side. Its two sides are drawn out as two horns The sinus venosus joins the atrial chamber by a midline sinu-atrial orifice.

A narrow atrioventricular canal intervenes between the common ventricular and atrial chambers.

By the end of 25 to 27 days the embryonic heart begins rhythmic beating.
Further Development of Cardiac Tube

The folding of the cardiac tube changes the tubular heart to a U-shaped bulbo-ventricular loop. Subsequently, the sinus venosus moves upwards along with atrial chamber to lie behind and above the ventricle. The shape of the heart now changes to S-configuration (Fig. 27.2). At this stage, the bulbus cordis and the ventricular chamber are separated by a deep bulbo-ventricular sulcus externally and a corresponding ridge internally. However, this sulcus becomes gradually shallower so that the bulbus cordis and the ventricle form a common chamber in continuation with truncus arteriosus. Due to positional changes of the various parts of cardiac tube, the contour of the embryonic heart resembles that of the adult heart.

Fate of Sinus Venosus (Figs 27.3A to C)

The sinus venosus is in communication with the atrial chamber by a mid-line sinuatrial orifice guarded by right and left venous valves. The left horn starts shrinking in size because of the diversion of blood from the left to the right side via transverse venous channels. The left horn is reduced to a tributary of the
right horn, which grows proportionately very large in size. The position of the sinuatrial orifice is shifted to the right and its orientation becomes vertical. The cranial ends of the right and left venous valves fuse to form the septum spurium (Figs 27.4A to C). The right horn of sinus venosus is absorbed into the right half of the primitive atrial chamber to form the smooth sinus venarum of the right atrium. The left horn of the sinus venosus along with part of left common cardinal vein develops into coronary sinus. The venous valves guarding the sinuatrial opening also undergo modifications. The superior and inferior limbic bands divide the right venous valve into crista terminalis, valve of IVC opening and valve of coronary sinus opening. The sinus septum is a fold of inferior limbic band between the vena caval and coronary sinus openings. The sinus septum extends to gain attachment to the lower dorsal end of septum secundum. The left venous valve along with septum spurium fuses with the interatrial septum.

**Septation of Embryonic Heart**

During four to eight weeks of embryonic life, septation simultaneously takes place in atrioventricular canal, atrium, ventricle, bulbus cordis and truncus arteriosus. The partition of a single heart tube in a four chambered pump, which contains four valves and gives rise to two blood vessels, is achieved by formation of seven septa, the septum intermedium, septum primum, septum secundum, aortico-pulmonary septum, proximal bulbar septum, distal bulbar septum and interventricular septum.

1. **Septum intermedium** divides the atrioventricular canal into right and left halves. The dorsal and ventral walls of the atrioventricular canal develop endocardial cushions, which fuse with each other to form the septum.

2. **Interatrial septum** is a valvular septum between the developing right and left atria. This septum develops in stages because of its unique function during fetal life.
   i. At first, a thin septum primum, grows down gradually (towards the septum intermedium) from the roof of the common atrium near the midline. The steadily narrowing gap between the septum primum and septum intermedium is called foramen primum or ostium primum (Figs 27.5A to C).
ii. Before the fusion of septum primum with septum intermedium (and consequent closure of the foramen primum), the upper part of the septum primum breaks down to form foramen secundum or ostium secundum.

iii. A thick septum secundum (to the right of the septum primum) grows from the roof of the atrial chamber, in the downward direction until it covers the foramen secundum on its right side.

iv. The lower margin of septum secundum is free and concave (it is called crista dividens). The oblique gap between the lower margin of septum secundum and the upper margin of septum primum is called foramen ovale. This foramen short-circuits the inferior vena caval blood to the left atrium. The flow of blood is unidirectional from the right atrium to the left only. The septum primum acts as a flap valve since the pressure is greater in the right atrium than in the left in fetal life.

v. The foramen ovale closes after birth. This is accomplished as follows. The rise in the left atrial pressure soon after establishment of pulmonary circulation keeps the septum primum pressed against the septum secundum until they fuse. The septum primum becomes the floor of fossa ovalis and the lower margin of the septum secundum forms the limbus fossa ovalis.

vi. The functional closure of the foramen ovale occurs immediately after birth while the anatomical closure occurs 6 to 12 months after birth. In 15 to 20 percent of persons probe patency remains (this is symptom free).

Contd...

In ASD there is increased load on the right side of the heart leading to progressive enlargement of right atrium, right ventricle and the pulmonary trunk. The disease manifests as effort intolerance (fatigue and breathlessness on exertion) in the third or fourth decade of life and thereafter. The atrial septal defects can be corrected by surgery.

Development of Pulmonary Veins (Figs 27.5A to C)

A single primary or common pulmonary vein develops from the dorsal wall of the left half of the common atrial chamber. This vein is believed to originate in the angiogenic cells in early dorsal mesocardium. These cells soon establish continuity with the endothelial cells of the cardiac tube. The single pulmonary vein divides into right and left pulmonary veins, which again divide and enter the lung bud. The common trunk of the original pulmonary vein with its right and left divisions until the bifurcation is absorbed inside the common atrium on the left side. The result of this absorption is that four separate pulmonary veins establish communication with the left half of common atrium.

Developmental Sources of Atria

1. The right atrium develops from three sources.
   i. The rough part develops from the right half of common atrium.
   ii. The smooth part or sinus venarum develops from the right horn of sinus venosus.
   iii. The vestibule of the atrioventricular orifice develops from the right half of AV canal.

2. The left atrium develops from three sources.
The rough part develops from the left half of common atrium.

The smooth part develops from the absorbed divisions and stem of pulmonary vein.

The vestibule of the atrioventricular orifice develops from the left half of the AV canal.

Atrioventricular Valves

The AV valves are formed from the endocardial cushions in the right and left atrioventricular canals. The ventricular surface of the cushions is excavated to form the valves, which are attached to ventricular walls by trabecular cords modified later into chordae tendinae and papillary muscles. In this way, three leaflets are formed on the right side (tricuspid valve) and two leaflets on the left side (mitral valve).

Septation in Truncus Arteriosus, Bulbus Cordis and Common Ventricle (Fig. 27.7)

The process of septation in the truncus arteriosus, bulbus cordis and primitive ventricle is interdependent.

Development of Ascending Aorta and Pulmonary Trunk

The truncus arteriosus is subdivided by a spiral septum (aortico pulmonary septum) into ascending aorta and pulmonary trunk.

Development of Semilunar Valves

At the trunco conal junction a distal bulbar septum is formed by the fusion of right and left endocardial cushions.

The spiral septum fuses with the distal bulbar septum and divides it into anterior and posterior parts. The anterior part forms the pulmonary valve at the origin of pulmonary trunk. The posterior part forms the aortic valve at the origin of ascending aorta. In each part one more cushion develops, as a result of which each part comes to have three endocardial cushions.

Pulmonary Cushions

i. Anterior
ii. Right posterior
iii. Left posterior.

Aortic Cushions

i. Posterior
ii. Right anterior
iii. Left anterior

The positions of these cushions change due to levorotation of heart.

In the definitive stage the pulmonary cusps are, one posterior, right anterior and left anterior.

The aortic cusps are, one anterior, right posterior and left posterior (corresponding to aortic sinuses at the root of ascending aorta).

Development of Outflow Tracts of Ventricles

The bulbus cordis is divided into infundibulum and aortic vestibule (outflow tract of right and left ventricle respectively) by proximal bulbar septum. This septum is formed by fusion of right and left bulbar ridges.
**Interventricular Septum (Fig. 27.8)**

The interventricular septum is of composite origin because its muscular and membranous parts develop from separate sources.

i. The muscular part is the first to develop from the floor of the bulboventricular cavity. It divides the lower dilated part of the cavity into right and left halves. A large gap between the upper margin of the muscular septum and the bulboventricular ridge is called the interventricular foramen.

ii. The interventricular foramen is closed to a certain extent by the right and left bulbar ridges of proximal bulbar septum, from above. The narrowed gap is completely filled by proliferation from the right end of endocardial cushion tissue of septum intermedium.

iii. Thus, the membranous part of septum develops from right bulbar ridge, left bulbar ridge and proliferation from endocardial cushion. The attachment of the septal cusp of the tricuspid valve divides the membranous septum into an anterior interventricular part and a posterior atrioventricular part.

**Developmental Sources of Ventricles**

1. The right ventricle develops from two sources.
   i. The inflow part develops from the right half of common ventricle.
   ii. The outflow part (infundibulum) develops from bulbus cordis.

2. The left ventricle develops from two sources.
   i. The inflow part develops from the left half of the common ventricle.
   ii. The outflow part (aortic vestibule) develops from the bulbus cordis.

**Development of Conducting Tissue**

The nodal tissue develops from the sinus venosus close to the opening of the common cardinal vein. The right nodal tissue becomes the SA node around third month and is located near the opening of the superior vena cava in the upper part of the right atrium. The AV node develops from the left nodal tissue in the sinus venosus as well as in the endocardial cushions in the AV canal around six week stage of the embryo.

**Clinical insight ...**

**Congenital Anomalies**

i. In dextrocardia, the heart rotates to the right so that its apex is located in the right fifth intercostal space.

ii. In ectopia cordis, the heart is exposed on the chest wall due to defective formation of anterior thoracic wall with cleft sternum.

iii. The ventricular septal defect (VSD) is a commonly occurring congenital anomaly. The defects in the membranous part of the septum are very common. VSD may occur singly or in combination with other cardiac defects. Large VSD may lead to pulmonary hypertension and congestive cardiac failure in infancy.

iv. Tetralogy of Fallot (TOF) is a combination of four defects (Fig. 27.9), which includes VSD, over-riding of aorta (ascending aorta-having connection to both ventricles), pulmonary stenosis (and narrowing of pulmonary trunk, and right ventricular hypertrophy. The aorta carries mixed blood, which results in cyanosis. The child may have cyanotic spells especially during crying. There is shortness of breath or dyspnea on exertion, which is relieved by assuming squatting position for a few minutes. The reason for this is that squatting blocks the venous return and increases the peripheral resistance of the arteries so that more blood reaches the lungs.
PHARYNGEAL ARCH ARTERIES

The basic arterial pattern of the embryo at the end of fourth week of development is like that of fishes as follows.

i. A pair of dorsal aortae is seen on the dorsal body wall of the embryo. The dorsal aortae fuse below the level of the seventh intersegmental arteries to form a single dorsal aorta.

ii. On the ventral body wall there is an aortic sac, which is the dilated part of the truncus arteriosus.

iii. The aortic sac is drawn out cranially as right and left horns (limbs). These horns are equivalent to the ventral aortae of fishes. They are connected to dorsal aortae through a series of six aortic arch arteries that pass through the pharyngeal arches (equivalent to gills). The cranial arch arteries degenerate as the caudal ones make their appearance. Therefore, at any given time all of the six arch arteries are never present in human being. The fifth arch artery is rudimentary. The third, fourth and sixth arch arteries along with the aortic sac and dorsal aortae give rise to the definitive arteries of the thorax and neck.

Transformation of Arch Arteries (Fig. 28.1)

The symmetrical pattern of arch arteries and dorsal aortae undergoes following changes during sixth to eighth weeks.

i. The duc tus caroticus, which is a segment of dorsal aorta between the third and fourth arch arteries involutes on both sides. This creates a break in the dorsal aorta of each side.

ii. The sixth arch arteries are divided into dorsal and ventral segments due to the appearance of a connection to the lung bud.

iii. The dorsal segment of the sixth arch artery on the right side involutes.

iv. The right dorsal aorta disintegrates between the origin of right seventh intersegmental artery and the point of its fusion with left dorsal aorta. This breaks the connection between right and left dorsal aortae.

Derivatives of Arch Arteries

i. The right pulmonary artery develops from ventral segment of right sixth arch artery.

ii. The left pulmonary artery develops from ventral segment of left sixth arch artery.

iii. The ductus arteriosus develops from the dorsal segment of left sixth arch artery.

iv. The arch of aorta develops from four sources namely aortic sac, left horn of aortic sac, left fourth arch artery and part of left dorsal aorta.

v. The brachiocephalic artery develops from right horn of aortic sac between sixth and fourth arch arteries.

vi. The common carotid artery develops from the right horn of aortic sac between fourth and third arch
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arteries plus a small contribution from the proximal part of third arch artery of its side.

vii. The internal carotid artery develops from the distal part of third arch artery and the dorsal aorta above ductus caroticus.

viii. The external carotid artery is a new sprout from the proximal part of third arch artery.

ix. The left subclavian artery develops from the left seventh intersegmental artery.

x. The right subclavian artery develops from three sources, right fourth arch artery, part of right dorsal aorta and right seventh intersegmental artery.

xi. The descending thoracic aorta and abdominal aorta are derived from the fused dorsal aortae.

Relation to Recurrent Laryngeal Nerves

The recurrent laryngeal nerves are related to the dorsal segments of the sixth arch arteries. When the heart and the arch arteries descend from the neck to the thorax, the nerves are pulled down. Since the recurrent laryngeal nerves supply the larynx, they retrace their course upwards. In this process, the nerves hook round the sixth arch arteries on both sides.

i. On the right side, the dorsal segment of the sixth arch artery involutes and the fifth arch artery is rudimentary. Therefore, the right recurrent laryngeal nerve recurs around the lowest persisting arch artery on the right side (which later on becomes the right subclavian artery).

ii. On the left side, the dorsal segment of the sixth arch artery becomes the ductus arteriosus, which in postnatal life modifies into the ligamentum arteriosum. Therefore, the left recurrent laryngeal nerve hooks round the lowest persisting arch artery on the left side, namely, ligamentum arteriosum.

Clinical insight ...

Coarctation of Aorta

Coarctation of aorta means narrowing of the lumen of the arch of aorta. There are two types of coarctation (Figs 28.2A and B). In preductal type, the narrowing is proximal to the attachment of ductus arteriosus while in postductal type, it is distal to the attachment of the ductus. In preductal type, the ductus is invariably patent while in the postductal type, it is obliterated. The method of filling of the descending aorta distal to the narrowing is different in the two types. In the preductal type, the aorta receives deoxygenated blood through the patent ductus arteriosus. In the postductal type, the aorta is filled with blood through collateral circulation (Fig. 28.3). The postductal coarctation is more common. Its characteristic...
The circulation of blood in the prenatal life is different from that of postnatal life, primarily because the lungs of the fetus are not functional.

**Aberrant Right Subclavian Artery (Figs 28.5A and B)**

In this anomaly, the right subclavian artery takes origin from the arch of the aorta beyond the left subclavian artery. It crosses behind the esophagus to reach the right side. The cause of this anomaly is the involution of the right fourth arch artery and the persistence of the normally disintegrating segment of right dorsal aorta. The anomaly can be confirmed radiologically since the aberrant artery indents the barium-filled esophagus at the level of the fourth thoracic vertebra. Often, dysphagia is the main complaint. The aberrant right subclavian artery is responsible for the occurrence of nonrecurrent right recurrent laryngeal nerve. This nerve fails to recur since the right subclavian artery does not develop from the right fourth arch artery. The right recurrent laryngeal nerve arises from the vertical part of the right vagus in the neck (Fig. 28.6).

**FETAL CIRCULATION (FIG. 28.7)**

The circulation of blood in the prenatal life is different from that of postnatal life, primarily because the lungs of the fetus are not functional.
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Fig. 28.6: Aberrant right subclavian artery (Note that this anomaly is associated with nonrecurrence of right recurrent laryngeal nerve)

Unique Features of Fetal Circulation

i. There are three shunts or bypass channels (ductus venosus, foramen ovale and ductus arteriosus).

ii. There are three blood vessels connected to placenta (left umbilical vein and left and right umbilical arteries).

iii. The placenta acts as fetal lungs.

Blood Circulation

The left umbilical vein supplies oxygenated blood. It originates in the placenta. It enters the fetus through the umbilical cord and umbilicus and reaches the liver, where it joins the left branch of portal vein.

First Shunt in Liver

The blood is diverted from the left branch of portal vein to the inferior vena cava by the ductus venosus (bypassing liver).

The inferior vena cava (IVC) brings this oxygenated blood to the right atrium.

Second Shunt in Heart

From the right atrium, the oxygenated blood is directed through the foramen ovale to the left atrium without passing through the pulmonary vessels and lungs. From the left atrium, the blood enters the left ventricle and then into the ascending aorta.

Third Shunt to Bypass Lung

The venous blood from right ventricle reaches arch of aorta (instead of reaching lungs) via shunt called ductus arteriosus, which connects the aorta and the left pulmonary artery (at its beginning from pulmonary trunk) Thus, the upper part of the body receives more oxygenated blood compared to the lower part because of mixing of venous blood in the aorta distal to the connection with the ductus arteriosus.
The right and left umbilical arteries carry the deoxygenated blood from the lower end of abdominal aorta for purification to the placenta.

**Postnatal Changes in Fetal Circulation**
The physiological closure of the three shunts and three blood vessels mentioned above occurs immediately after birth. In the case of ductus arteriosus, the physiological closure is facilitated by release of bradykinin in lungs after first breath. The bradykinin stimulates the smooth muscle in the wall of ductus to contract.

**Time of Anatomical Closure**

i. Umbilical vessels and ductus venosus—Two to three months after birth.

ii. Ductus arteriosus—One to three months after birth

iii. Foramen ovale—Six months after birth.

**Fate of Fetal Shunts and Umbilical Blood Vessels**

i. The left umbilical vein becomes the ligamentum teres of liver.

ii. The ductus venosus becomes the ligamentum venosum.

iii. The foramen ovale is indicated by fossa ovalis and limbus fossa ovalis in the interatrial septum.

iv. The ductus arteriosus becomes the ligamentum arteriosum.

v. The umbilical arteries undergo changes as follows. Their proximal patent parts form the superior vesical arteries and distal obliterated parts become the lateral umbilical ligaments.

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**Patent Ductus Arteriosus**
The patent ductus arteriosus (PDA) is commonly seen in the rubella syndrome, which occurs in children whose mothers had German measles during the first two months of pregnancy. PDA may occur singly or in combination with other cardiac defects. In PDA, the ductus arteriosus fails to obliterate postnatally. So a communication exists between the arch of aorta and left pulmonary artery even after birth (Fig. 28.8). Since the pulmonary arterial pressure is lower than that in the aorta, there is a continuous flow of blood from the aorta to the pulmonary artery. This is the reason for the presence of characteristic continuous murmur (called machinery murmur or rail in tunnel murmur). There is overloading of pulmonary circulation. The symptoms of overload of pulmonary circulation are recurrent respiratory infections, shortness of breath on exertion and palpitation. Surgical correction is feasible in three to six months after birth.
PERICARDIUM

The pericardium is a fibroserous sac that covers the heart and the roots of great vessels in the middle mediastinum (Fig. 29.1). It is located behind the body of the sternum and the second to sixth costal cartilages and in front of the fifth to eighth thoracic vertebrae.

Subdivisions

i. Outer fibrous pericardium

ii. Inner serous pericardium consisting of inner visceral pericardium (epicardium) and outer parietal pericardium.

Pericardial Cavity

It is a potential space enclosed between the parietal and visceral layers of serous pericardium. It contains a small quantity of serous fluid. This facilitates the sliding of the two serous layers over each other during cardiac movements.

Embryologic insight ...

i. The pericardial cavity develops from cranial part of the intraembryonic coelom. The cardiac tube invaginates the pericardial sac from the dorsal side and is suspended by dorsal mesocardium.

ii. Visceral pericardium (epicardium) develops from myoepicardial mantle (splanchnopleuric mesoderm) that envelops the endothelial heart tube.

iii. The parietal pericardium develops from somatopleuric mesoderm of pericardial cavity.

iv. The fibrous pericardium develops from fusion of right and left pericardiopleural membranes and septum transversum.

Development of Transverse Sinus

The transverse sinus develops as result of degeneration of dorsal mesocardium. After the folding of the cardiac tube its venous and arterial ends come close to each other and the space enclosed between them (space at the site of dorsal mesocardium) becomes the transverse sinus. This is the embryological explanation of relations of transverse sinus (pulmonary trunk and ascending aorta representing the arterial end of cardiac tube form the anterior boundary and the atria representing the venous end form the posterior boundary of the transverse sinus).
Fibrous Pericardium (Fig. 26.9)

It is a tough fibrous sac, which is shaped like a cone with an apex directed superiorly and a wide base inferiorly.

i. The apex is continuous with the adventitia of great vessels at the level of sternal angle.

ii. The base blends with the central tendon of diaphragm. Inferior vena cava pierces the base posteriorly on the right side.

iii. Anteriorly, the fibrous pericardium is related to the structures in the anterior mediastinum. It is connected to body of sternum by upper and lower sternopericardial ligaments. The anterior margins of lungs and pleurae overlap this surface except over the bare area of the pericardium (opposite fourth and fifth costal cartilages on the left side), where the anterior margins of left lung and pleura deviate and the pericardium comes in direct contact with the thoracic wall. Thymus located in anterior mediastinum is related to the upper part of pericardium in childhood.

iv. Posteriorly, the fibrous pericardium is related to the principal bronchi, the descending thoracic aorta and esophagus. This aspect is pierced by four pulmonary veins.

v. Laterally, it is related to the mediastinal pleura and through it to the mediastinal surface of respective lung. Phrenic nerve and pericardiacophrenic vessels descend on the left and right lateral surfaces of the fibrous pericardium. Incisions in the pericardium are always vertically placed to avoid injury to the phrenic nerves.

Functions

The fibrous pericardium retains the heart in the middle mediastinum and prevents its overdistention. In the lifesaving procedure like external cardiac massage, the heart is squeezed inside the firm fibrous pericardium between the fixed vertebral column and somewhat resilient sternum and costal cartilages by applying rhythmic pressure to the lower sternum.

Blood Supply

The pericardial branches of the internal thoracic artery and of descending thoracic aorta provide arterial blood.
pericardial reflection from IVC and right pulmonary veins. On the left, it is limited by the pericardial reflection from left, pulmonary veins. Superiorly, there is pericardial reflection along the superior margins of the left atrium. The sinus is open inferiorly. The oblique sinus intervenes between the left atrium anteriorly and the esophagus posteriorly. It is believed to act as a bursa for the left atrium to expand during filling.

Blood Supply and Nerve Supply of Serous Pericardium

The parietal layer shares its blood supply and nerve supply with the fibrous pericardium. The visceral layer shares its blood supply and nerve supply with the myocardium.

**Clinical insight ...**

i. Inflammation of serous pericardium is called pericarditis, which may be due to bacterial or viral infections. Pain of pericarditis is felt in the precordium (front of chest) or epigastrum. Pericardial friction rub is heard on auscultation over left sternal border and upper ribs.

ii. Accumulation of fluid in pericardial cavity is known as pericardial effusion. The heart sounds are faintly audible on auscultation. X-ray chest shows globular heart shadow.

iii. Excess fluid in pericardial effusion is removed by one of the two routes. In parasternal route, the needle is inserted in the left fourth or fifth intercostal space close to the sternum avoiding injury to the internal thoracic vessels. Since the line of pleural reflection deviates in 4th and 5th intercostal spaces the needle does not pierce the pleura. This route is also preferred for giving intracardiac injections. In the subcostal (costophrenic) route (Fig. 29.4), the needle is inserted at the left costophrenic angle in an upward and backward direction through the rectus sheath and the central tendon of diaphragm. In this approach, the pleura is saved because the pleural line of reflection does not extend below the costal margin on the left side (Fig. 25.16).

iv. Cardiac tamponade is a condition in which there is rapid accumulation of fluid (blood or serous fluid) in the pericardial cavity. This interferes with the atrial filling during diastole and causes decrease in cardiac output, increase in heart rate and increase in venous pressure. Immediate aspiration of fluid is necessary to restore normal cardiac output.

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**HEART**

The heart is a four-chambered muscular pump. It is covered with double-layered serous membrane (pericardium enclosing a potential pericardial cavity. The muscle of the heart is known as myocardium, which contracts nonstop throughout life. The right side of the heart consisting of right atrium and ventricle receives venous blood, which is pumped to the lungs for oxygenation by the pulmonary trunk and pulmonary arteries. The left side of the heart consisting of left atrium and ventricle receives oxygenated blood, which is pumped to the entire body by the aorta and its branches. The interatrial septum and the interventricular septum are the partitions between atria and ventricles, respectively. There are four cardiac orifices, two atrioventricular orifices (mitral and tricuspid) and two semilunar orifices (pulmonary and aortic).

**Orientation of Heart in Thorax**

The heart is placed obliquely in the middle mediastinum. Approximately two-thirds of the heart lies to the left and one-third to the right of the midline (Fig. 29.5). The heart
makes an angle of 45° with the sagittal plane. Therefore, the terms right and left used in reference to relationship of cardiac chambers to each other are not strictly true. The correct perspective regarding the position and relations of the cardiac chambers is depicted in Figures 29.6A and B, in which one can observe that the right part of the heart is in anterior location in respect to its left part due to the left-rotation of heart (rotation of the heart to the left). The right atrium is anterior, inferior and to the right of the left atrium. The interatrial septum is inclined in a plane that is midway between the coronal and sagittal planes. The major part of right ventricle is anterior to the left ventricle. Hence, if a knife is pushed in to the chest by the side of the sternum in the left-fifth or sixth intercostal space, it will enter the right ventricle. However, the lower end of the right ventricle is to the right of the apical part of left ventricle. The pulmonary orifice of right ventricle is actually to the left, superior and anterior to the aortic orifice of the left ventricle. The left atrium forms the most posterior part of the heart. Therefore, it is very close to the esophagus located in the posterior mediastinum. The left ventricle is prominent inferiorly as it forms the left margin and the apex of the heart.

**External Features**
The average size of the heart is of that of a clenched fist of the person. The average weight of the adult heart is 280 g.

**Atrioventricular Sulcus**
The atria are separated from the ventricles by an almost circular atrioventricular or coronary sulcus. This sulcus has an anterior part on the sternocostal surface (Fig. 29.7) and the posterior part between the base of the heart and the diaphragmatic surface (Fig. 29.9).

i. The anterior part of the sulcus contains right coronary artery on right side and the circumflex artery in its extreme left end.

ii. The posterior part of the sulcus contains the coronary sinus, right coronary artery, circumflex artery and small cardiac vein.

**Interventricular Sulci**
These are located on the anterior and inferior surfaces respectively, indicating the line of attachment of the interventricular septum.
**Interatrial Sulcus**

It is visible on the posterior aspect of the base of the heart.

**Crux of Heart**

The point of junction of the atrioventricular, interatrial and posterior interventricular sulci is termed the crux of the heart.

**Borders (Margins) and Surfaces**

The heart has a pointed apex directed inferiorly and a broad base directed posterosuperiorly. There are four margins limiting four surfaces. The margins are, superior, inferior (acute), right and left (obtuse).

The surfaces are, anterior or sternocostal, inferior or diaphragmatic, left and right.

**Apex of Heart**

The apex is the most mobile part of the heart. It is directed downward, forward and to the left. It is formed by left ventricle only. The apex is located at the junction of inferior and left borders of the heart. It is separated from the anterior thoracic wall by left lung and pleura. The apex beat is the impulse produced by the apex when it impinges on the chest wall during systole. It may be visible in thin individuals or is felt in the left fifth intercostal space nine centimeters away from the midline.

**Margins of Heart**

i. The right margin is entirely formed by the right atrium and is almost vertical.

ii. The inferior or acute margin is formed by right ventricle mainly with a very small contribution by the left ventricle. The right marginal branch of right coronary artery and the accompanying vein course along this margin (anterior and posterior interventricular grooves cut this margin a little to the right of cardiac apex at a point called apical incisure or notch, where anterior and posterior interventricular arteries meet).

iii. The left or obtuse margin is formed by left ventricle mainly with a small contribution by left auricle superiorly. The left end of coronary sulcus and its contents namely, circumflex artery and great cardiac vein cross the left margin. The marginal branch of circumflex artery runs along the left margin.

iv. The superior margin is formed by the upper margins of the atria and is hidden from the sternocostal surface by the ascending aorta and pulmonary trunk. The bifurcation of the pulmonary trunk coincides with this margin.

**Surfaces of Heart**

The heart presents sternocostal, diaphragmatic, posterior, right and left surfaces.

**Sternocostal Surface (Figs 29.7 and 29.8)**

The sternocostal surface faces upwards, forwards and to the left. The chambers contributing to this surface are right ventricle, right atrium, right auricle, a small strip of left ventricle and left auricle.

i. The atrioventricular (coronary) sulcus is present to the right of roots of the great vessels between the right ventricle and right atrium. It extends up to the junction of the right and inferior margins. The sulcus contains right coronary artery embedded in the fat. The anterior cardiac veins cross over the sulcus to reach the right atrium.

ii. The ventricular part of the sternocostal surface lies to the left of the coronary sulcus. The anterior interventricular groove (sulcus) demarcates the two ventricles on this surface. It contains anterior interventricular branch of left coronary artery and the great cardiac vein embedded in fat.

iii. Superiorly and to the left, the right ventricle is prolonged as the infundibulum, which continues as the pulmonary trunk.

iv. Inferiorly and to the left, the left ventricle forms the apex of the heart.

v. A finger-shaped left auricle projects on the sternocostal surface to overlap the left aspect of the pulmonary trunk.

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**Clinical insight ...**

**Shift of Apex**

In hypertrophy of left ventricle, the apex shifts in downward and lateral direction. A few causes of downward and lateral shift of the apex are systemic hypertension, mitral regurgitation and aortic regurgitation. In right ventricular hypertrophy as occurs in pulmonary stenosis, the apex shifts in lateral direction only.
Anteriorly, the sternocostal surface is related (from within outwards) to the pericardium, anterior mediastinum, anterior margins of the lungs and pleura (including the left costomediastinal recess), the body of sternum and the third to sixth costal cartilages. The Figure 29.8 depicts appearance of sternocostal surface of heart in a patient undergoing bypass surgery.

**Diaphragmatic Surface (Fig. 29.9)**

The diaphragmatic surface is flat and rests on the central tendon of diaphragm. The left ventricle (left two-thirds) and the right ventricle (right one-third) contribute to this surface. The demarcating line between the two ventricles is the posterior interventricular groove, which contains posterior interventricular branch of right coronary artery and middle cardiac vein.

**Posterior Surface (Base)**

This surface is quadrilateral in outline and faces backwards and to the right. It lies at the level of fifth to eighth thoracic vertebrae in supine position. In standing position, it descends by one vertebra.

i. The left atrium forms the left two-thirds of the base and the right atrium forms the right one-third.

ii. A faint interatrial groove marks the demarcation between the two atria.

iii. Six large veins open into the base (four pulmonary veins (one pair on each side) open into left atrium and two great veins (SVC and IVC) open into the right atrium.

iv. The base is related anteriorly to the transverse sinus of pericardium and the roots of the great vessels. Posteriorly, it is separated by the oblique sinus from posterior part of fibrous pericardium. The esophagus is an immediate posterior relation of fibrous pericardium. It is to be noted that the thickness of tissue between the base of heart and esophagus is only 0.5 cm.

v. The left surface or left pulmonary surface is in contact with mediastinal pleura and mediastinal surface of left lung. This surface is widest above, where it is crossed by the left part of the atroventricular sulcus, which contains the circumflex artery, the great cardiac vein and the beginning of coronary sinus.

vi. The rounded right surface or the right pulmonary surface is in contact with mediastinal pleura and mediastinal surface of right lung.
Surface Marking (Fig. 29.16)

i. The apex of the heart is marked by a point nine centimeter away from the midline in the left fifth intercostal space.

ii. The right margin is represented by a line joining a point on the lower part of the second right intercostal space (close to the sternum) to a point on the right sixth costal cartilage 1 to 2 cm from the sternal margin.

iii. The inferior margin is represented by a line joining a point on the right sixth costal cartilage 1 to 2 cm from the margin of the sternum to a point coinciding with the apex.

iv. The left margin is represented by a line joining the point of the apex to a point on the second left intercostal space 1 to 2 cm from the sternal margin.

v. The superior margin is indicated by a line from a point on the upper part on the left second intercostal space 1 to 2 cm lateral to the sternal margin to a point close to the margin of the sternum in the lower part of right second intercostal space.

vi. The anterior part of the atrioventricular sulcus is indicated by an oblique line extending from the sternal end of the left-third costal cartilage to the sternal end of right sixth costal cartilage.

Chambers of Heart
The heart has four chambers, right atrium, left atrium, right ventricle and left ventricle.

Right Atrium
The right atrium receives the venous blood from the entire body. The right atrium has the thinnest wall. The right atrium forms part of the sternocostal surface of the heart. The right auricle projects from it to overlap the right side of the base of the pulmonary trunk. The sulcus terminalis is a visible groove that extends from the right side of the SVC opening to the right side of the IVC opening.

Interior of Right Atrium (Fig. 29.10)
The cavity of the right atrium is divisible into three parts.

i. The sinus venarum or smooth part is located posteriorly.

ii. Right atrium proper along with right auricle forms the rough part.

iii. The vestibule of tricuspid valve forms the floor or anteroinferior part.

Sinus Venarum
This part shows following features.

i. The opening of the superior vena cava is located at the roof of the right atrium. An intervenous tubercle located below this opening, directs the superior vena caval blood to the tricuspid orifice in fetal life.

ii. The opening of inferior vena cava is guarded by a small eustachian valve. It is located at the lowest and posterior part of the atrium near the interatrial septum.

iii. The opening of coronary sinus draining the myocardium is guarded by a thin Thebesian valve. It is located between the opening of IVC and the tricuspid orifice.

iv. There are multiple small openings of venae cordis minimae (smallest cardiac veins, also called Thebesian veins). These veins begin in myocardial capillary bed and open in all chambers of heart.

Right Atrium Proper and Auricle
i. The crista terminalis demarcates the rough and smooth parts of right atrium. It corresponds to the sulcus terminalis on the external surface of atrium. It is a C-shaped muscular ridge. It starts at the upper end of the interatrial septum, passes in front of the SVC opening and then turns along its lateral margin downward to reach the opening of the IVC.

ii. The musculi pectinati (so called because of their resemblance to comb) are the parallel muscular ridges extending from the crista into the right auricle. The dense trabeculations of musculi pectinati inside the right auricle makes it a potential site for thrombi formation. The thrombi dislodged from the right atrium enter the pulmonary circulation and may produce pulmonary embolism.

iii. The SA node is located in the right atrial wall in subepicardial position at the upper end of sulcus terminalis close to the opening of the superior vena cava.

iv. The anterior cardiac veins open into the rough part of the atrium.
Vestibule of Tricuspid Valve
This is the anteroinferior part (floor) of the right atrium. It leads into the tricuspid orifice.

i. Koch’s triangle is an identifiable landmark in the right atrium during surgery. It has three boundaries namely the valve of coronary sinus (posteriorly), tendon of Todaro (superiorly), and the attached margin of the septal cusp of tricuspid valve (anteriorly). The AV node lies at the apex of Koch’s triangle, which is a feature of the floor of the right atrium near the lower end of the interatrial septum.

The above description is according to “Cardiac anatomy by Anderson and Backer”, which is based on dissection and histological study of human hearts. However, according to majority of descriptions its location is in the lower part of interatrial septum).

ii. The atrioventricular membranous septum is located anterosuperior to the tendon of Todaro. It intervenes between the right atrium and the left ventricle.

iii. The torus aorticus is the bulge in the atrial wall above the atrioventricular membranous septum, produced due to the adjacent noncoronary aortic sinus at the base of ascending aorta.

Interatrial Septum (Fig. 29.10)
The interatrial septum forms the septal or posteromedial wall of the right atrium. The septal wall shows fossa ovalis, which is an ovoid, membranous and depressed portion. A curved ridge called the limbus fossa ovalis forms the superior, right and left margins of the fossa ovalis. The floor of the fossa ovalis represents the septum primum and the limbus fossa ovalis is the remnant of the lower margin of the septum secundum of the fetal heart (Fig. 27.5). So, the fossa ovalis with its limbus indicates the site of the valvular foramen ovale of fetal circulation. This foramen is normally completely obliterated after birth. A small slit (probe patency) may be found along the upper margin of the fossa ovalis in one-third of normal heart.

(For developmental sources of right atrium refer to chapter 27).

Right Ventricle
The right ventricle receives blood from the right atrium through the tricuspid orifice and pumps it through the pulmonary orifice into the pulmonary trunk. The right ventricle takes large share in the formation of sternocostal surface of the heart and a small share in the diaphragmatic surface. The thickness of the ventricular wall is proportionate to its workload. In fetal stage, the right ventricle short-circuits blood into the aorta through the ductus arteriosus. Hence, its wall is thicker than that of left ventricle. In postnatal stage, the right ventricle pumps blood into pulmonary circulation, where systolic arterial pressure is 25 to 35 mm Hg. Hence, the thickness of its walls is much less compared to that of left ventricle. The shape of the cavity of the right ventricle is crescentic.

Interior of Right Ventricle (Fig. 29.11)
The cavity of the right ventricle is divisible into three parts.

i. The inlet (inflow) part contains the tricuspid valve.

ii. The trabecular body (ventricle proper) is the rough part.

iii. The outlet (outflow) part (infundibulum or conus arteriosus) is the smooth part that leads to the pulmonary orifice.

The inflow and outflow parts are present in the roof of the ventricle. The supraventricular crest, which is the largest muscular ridge in the right ventricle, separates the outflow and inflow parts. This crest is an arched structure consisting of a parietal limb and a septal limb. The parietal limb is part of the anterior wall of the ventricle and provides attachment to the anterior cusp of the tricuspid valve. The septal limb meets the interventricular septum, where it merges with the septomarginal trabecula.

Inlet of Right Ventricle
The inlet shows the tricuspid valve. The orifice of the tricuspid valve accommodates the tips of three fingers. The annulus of this valve is a ring of collagenous tissue, which gives attachment to the cusps of the valve. The three cusps
of the valve are termed anterior, posterior and septal. The anterior cusp is attached to the supraventricular crest, the posterior to the posterior wall and the septal to the membranous interventricular septum. Each cusp has two surfaces (atrial and ventricular). The chordae tendineae arising from the anterior papillary muscle are attached to the anterior and posterior cusps; those from posterior papillary muscle to the posterior and septal cusps; and those from the septal muscles or directly from the septum to the anterior and septal cusps. During ventricular diastole (when the intraventricular pressure is low), the papillary muscles are relaxed and the chordae tendineae are slack. At this stage, valves open and the apices of the cusps project into the ventricle. The blood flows freely from the right atrium to the right ventricle. During ventricular systole (when the intraventricular pressure is high), the cusps are driven upward. The papillary muscles contract and tighten the chordae tendineae. This action is responsible for the closure of the valve by apposition of the atrial or smooth surfaces of the cusps.

**Right Ventricle Proper**

The cavity of right ventricle proper (trabecular body) is characterized by the presence of muscular projections, which are collectively called the trabeculae carneae. There are three types of trabeculae in the right ventricle, namely, ridges, bridges and papillary muscles.

i. The ridges are found all over the cavity in large numbers.

ii. The bridges are the elevations, which are fixed at the two ends but remain free in between. The septomarginal trabecula (moderator band) is the best example of this type. This trabecula passes from the interventricular septum to the base of the anterior papillary muscle. The important feature of this trabecula is that it carries the right branch of atroventricular bundle (RBB) in its substance. This ensures early contraction of papillary muscles, so that chordae tendineae are already taut before the ventricular contraction begins.

iii. The papillary muscles are conical muscular projections. Depending on their attachment to the ventricular wall, the papillary muscles are described as anterior, posterior and septal. The large anterior papillary muscle is attached to the right anterolateral wall, where it blends with the right end of the septomarginal trabecula. The posterior papillary muscle is attached to the inferior wall. The septal papillary muscles, when present are several small muscles attached to the septal limb of the septomarginal trabecula.

**Infundibulum (Outflow part)**

It is funnel-shaped. It supports the pulmonary orifice. Unlike the rest of ventricular cavity the infundibulum is smooth. The supraventricular crest constitutes its posterior and right lateral walls and the membranous septum separates it from the aortic vestibule of the left ventricle.

**Pulmonary Valve**

The pulmonary valve is the most superior and anterior valve. In normal individuals, it lies anterior by about half its diameter, and to the left of the aortic valve. It has three semilunar cusps, right anterior, left anterior and posterior. A localized thickening of fibrous tissue (called the nodule of Arantius) is present in the midpoint of the free margins of the cusps. The thin margin on either side of the nodule is called the lunule. The pulmonary sinuses are the dilatations in the wall of the pulmonary trunk just above the cusps. At the end of systole, when the intraventricular pressure falls, there is a tendency for blood to return to the ventricle. This blood fills the pulmonary sinuses, thereby approximating the cusps to each other. At the beginning of ventricular systole, the rise in pressure forces the cusps to open and project into the pulmonary trunk.

(For developmental sources of right ventricle refer to chapter 27).

**Left Atrium**

The left atrium is cubical in shape. It is positioned behind and to the left of the right atrium. The pulmonary trunk and the ascending aorta conceal its anterior surface. The left atrium forms the left two-thirds of the base of the heart. The left auricle projects anterosuperiorly from it to overlap the left aspect of the pulmonary trunk. This chamber receives the oxygenated blood from two pairs of pulmonary veins and sends the same to the left ventricle through mitral orifice (For relations of the left atrium refer to base of the heart).

**Interior of Left Atrium**

The interior of left atrium is divided into three parts.

i. The smooth part presents the openings of the pulmonary veins, two on either side on its posterior wall.

ii. The rough part is confined to the left auricle, which has musculi pectinati. The left auricle is a potential site of formation of thrombi, which if dislodged, can result in embolism in the systemic arteries (renal, internal carotid, common iliac, femoral, brachial, etc.).

iii. The vestibule of the mitral valve is a narrow passage just preceding the mitral orifice.

Figure 29.12 is a radiograph of chest showing dilatation of left atrium due to mitral stenosis. (For developmental sources of left atrium refer to chapter 27)
Thorax

Left Ventricle

The left ventricle is a powerful pump, which propels blood into the systemic circulation against the peripheral vascular resistance of 80/120 mm Hg. In keeping with this workload, the wall of the left ventricle is three times thicker than that of the right ventricle. The left ventricle forms the cardiac apex, one-third of the sternocostal surface, two-thirds of the inferior surface and part of the left surface of the heart. The left ventricle receives the blood from the left atrium and pumps the same into the ascending aorta via the aortic orifice.

Interior of Left Ventricle

The cavity of the left ventricle is circular on cross section. The left ventricle is divisible into three parts.

i. The inflow or inlet part containing the mitral valve

ii. The trabeculated body or ventricle proper

iii. The outflow part or aortic vestibule

Inflow Part

It contains mitral valve, which lies superior, posterior and to the left of the tricuspid valve and posteroinferior and slightly to the left of the aortic valve. The mitral orifice can admit the tips of two fingers. Its shape is like a horseshoe. The valve has two cusps, hence the name bicuspid valve. The mitral cusps resemble in shape of the Bishop’s miter (crown). The anterior cusp is attached to upper and right part of the margin of the orifice and is considerably longer. The posterior or mural cusp is attached to the lower and left part of the margin. The anterior cusp forms the only partition between left ventricular inflow and outflow orifices. The chordae tendineae are attached to the free margin of anterior cusp but to the free margin and ventricular surface of the posterior cusp. At the onset of diastole the mitral valve opens passively due to the lower pressure in the left ventricle. With the onset of atrial systole there is active opening of valve cusps and maximum filling takes place. During ventricular systole, papillary muscles contract. This increases the tension in the chordae tendineae causing the effective valve closure.

Left Ventricle Proper

The ventricle proper has rough walls with muscular projections called trabeculae carneae, which form a fine meshwork. The trabeculae are especially rich at the apex and on the inferior wall. The septum and the upper part of the anterior wall are relatively smooth. There are two papillary muscles. The anterior papillary muscle originates from the anterior wall and its chordae tendineae are attached to both the cusps of the mitral valve. The posterior papillary muscle originates from the inferior wall and its chordae tendineae are attached to both the cusps of the mitral valve.

Aortic Vestibule (Outflow part)

This is the smooth part of the left ventricle. It is situated a little in front and to the right of the mitral valve. The anterior cusp of the mitral valve and the adjacent part of fibrous skeleton of the heart (subaortic curtain) form its posterior wall. The membranous part of the interventricular septum forms its anterior and right walls and separates it from right ventricle and right atrium.

Figure 29.13 depicts the appearance of left ventricle after left ventricular angiography.

(For developmental sources of left ventricle refer to chapter 27).

Aortic Valve

The aortic valve presents three cusps or leaflets and is stronger in structure than the pulmonary valve. The free margins of the cusps project into the ascending aorta. Like the pulmonary valve, the free margins of the cusps present nodules in the center and lunules on either side. The cusps are present within three aortic sinuses of Valsalva. According to the position of the cusps, the sinuses are described as anterior, right posterior and left posterior. The anterior aortic sinus gives origin to right coronary artery and left posterior aortic sinus gives origin to left coronary artery. The right posterior aortic sinus is called the noncoronary sinus, which projects in the right atrium to produce torus aorticus. During diastole, the closed aortic valve supports an aortic column of blood. The three nodules are apposed and the valve is tightly closed. As the ventricular systole, begins the pressure in the ventricle exceeds that of the aorta and the valve opens passively. The free margins of the cusps become almost straight lines making the figure 29.12: Dilatation of left atrium in mitral stenosis (Arrow is pointing to left atrium)
orifice triangular when fully open. During ejection, a small amount of blood enters the sinuses, which helps to maintain the position of the valves during systole and initiate their approximation at the end of systole.

**Interventricular Septum (Fig. 29.14)**

The interventricular septum is a partition between the two ventricles. The septum is oriented in three different planes. Its attachment to the anterior wall is indicated by the anterior interventricular groove on the sternocostal surface and to the inferior surface by the posterior interventricular groove. The right surface of the septum faces forwards and bulges into the right ventricle, while the left surface looks backwards and is concave towards the left ventricle.

**Parts of Interventricular Septum**

It has two parts, muscular and membranous.

i. The muscular part of the septum is very large and very thick.

ii. The membranous part is located posterosuperior to the muscular part. It appears as a small oval transparent area, which is in continuity with the central fibrous body (part of fibrous skeleton of heart). The attachment of the septal cusp of the tricuspid valve divides the membranous part into anterior interventricular part and a posterior atrioventricular part.

(Fig. 29.14). The interventricular part separates the aortic vestibule of the left ventricle from the infundibulum of the right ventricle. The atrioventricular part separates the aortic vestibule from the floor of the right atrium.

**Conducting Tissue in Interventricular Septum**

i. The membranous septum is pierced by the left branch of the atrioventricular bundle near its junction with the muscular part.

ii. The left surface of the muscular septum carries the left branch of atrioventricular bundle in the sub-endocardial position. The right branch of the atrioventricular bundle passes along the right surface of the septum in the subendocardial position. The septomarginal trabecula attached to this surface of the septum carries the right bundle to the anterior papillary muscle.

**Arterial Supply of Interventricular Septum (Fig. 29.15)**

i. Septal branches of anterior interventricular artery (a branch of left coronary artery).

ii. Small posterior septal branches of the anterior interventricular and short septal branches of posterior interventricular artery (a branch of right coronary artery) supply the posterior one-third of the septum. So, the left coronary artery takes a larger share in the arterial supply of the interventricular septum in the “right dominance”. But in the case of the “left dominance” the entire supply is derived from the left coronary artery.
The thrombosis of the septal branches results in septal infarction and heart block.

**Surface Markings of Cardiac Valves (Fig. 29.16)**

i. The pulmonary orifice is indicated by a 2.5 cm long transverse line partly behind the left third costal cartilage and partly behind the adjacent left half of sternum.

ii. The aortic orifice is denoted by an oblique line 2.5 cm long, behind the left half of the body of sternum at the level of third left intercostal space.

iii. A three centimeter long oblique line behind the left half of the sternum, opposite to the fourth left costal cartilage marks the mitral orifice.

iv. A four centimeter long line placed vertically behind the right half of the sternum, opposite to the fourth intercostal space.

**Surface Markings of Cardiac Auscultation Areas (Fig. 29.16)**

i. Pulmonary valve—Second intercostal space to the left of sternum.

ii. Aortic valve—Second intercostal space to the right of sternum.

iii. Tricuspid valve—Fifth intercostal space over the center of the body of sternum.

iv. Mitral valve—Near the cardiac apex.

**Radiological Anatomy of Heart (Fig. 29.17)**

i. In the posteroanterior (PA) X-ray of chest, the transverse diameter of the cardiac shadow of normal sized heart is equal to half the diameter of the chest. When it exceeds this ratio (1:2), it is suggestive of cardiac enlargement.

ii. The margins of the cardiac shadow are identifiable in the PA, RAO (Right Anterior Oblique) and LAO (Left Anterior Oblique) views of chest X-rays.

iii. The right margin of the cardiac shadow is formed by the SVC, right atrium and IVC from above downward.

iv. The left margin is formed by the aortic knuckle (prominence due to arch of aorta), pulmonary bay containing pulmonary trunk, left auricle and left ventricle from above downward.

v. The inferior margin of the cardiac shadow merges with the shadow of the diaphragm and the liver.

vi. In the Right Anterior Oblique (RAO) view of chest X-ray, the heart shadow shows all the four chambers. This view is used to assess the size of the left atrium in mitral stenosis with the help of Barium swallow.

vii. In the Left Oblique Anterior (LAO) view of the chest X-ray, the heart shadow is largely made up of right ventricle anteriorly and left ventricle posteriorly.

viii. The serial CT scans of the thorax is the best way to study the anatomical relations of the heart and the surrounding structures to each other.

ix. In cardiac catheterization and angiography, the cardiac chambers are delineated with the help of the contrast medium. A special cardiac catheter is passed through the femoral vein to reach the right side of heart. The left side of the heart is approached through the brachial or femoral artery (Fig. 29.13).

x. Echocardiography (ECHO) is a modified ultrasound imaging of the heart. It is a simple and noninvasive
procedure, which gives the details of internal anatomical features of the heart. The usual approach of this procedure is transthoracic. One drawback of this route is that it is not possible to properly see the structures at the base of the heart. This drawback is overcome by the transesophageal echography, which improves the imaging of the base considerably because the esophagus is separated from the base of the heart by at most 0.5 cm of tissue.

**Diseases of the valves of the heart are very common. Usually, there is history of rheumatic fever in the childhood in such cases. Depending on the extent of the damage to the valve components, the orifice may be narrowed causing stenosis or the valves may become incompetent causing regurgitation. These defects produce structural as well as functional effects.**

**Disorders of Mitral Valve**

i. The mitral stenosis (narrowing of mitral orifice) is most common in young age. There is obstruction to the left atrial blood during ventricular filling. This leads to rise in left atrial pressure followed by pulmonary venous hypertension, which is the cause of respiratory symptoms like, shortness of breath (dyspnoea), cough and hemoptysis (blood in sputum). There is enlargement of left atrium (radiograph), which may press on the esophagus causing dysphagia and on left recurrent laryngeal nerve causing hoarseness of voice (Ortner's syndrome). The stasis of blood in left auricle encourages clot formation. The detached clots form emboli, which enter the left ventricle, ascending aorta and the systemic circulation. The complications like gangrene of lower limb (due to occlusion of femoral artery), myocardial infarction (due to occlusion of coronary artery), stroke (due to occlusion of cerebral artery) or renal infarct (due to occlusion of segmental branch of renal artery) may occur once the emboli enter the systemic arterial tree. There are various options available for treating mitral stenosis. Mitral valvotomy means dilatation of the stenosed mitral orifice. In balloon valvotomy, a special balloon is introduced inside the left atrium through the arterial route. In the surgical treatment, the mitral valve is dilated by closed mitral valvotomy or open mitral valvotomy. In some cases, the diseased mitral valve is replaced by artificial (prosthetic) valve.

ii. In mitral regurgitation, the incompetent mitral valve fails to close during systole. The blood from left ventricle regurgitates in to the left atrium during systole. So, during diastole there is overfilling of the left ventricle. In this process a part of blood shuttles between left atrium and left ventricle. This increases the workload of the left ventricle. Eventually gross dilatation and hypertrophy of left ventricle may culminate in left ventricular failure.

**Disorders of Aortic Valve**

i. In aortic stenosis, the blood accumulates inside the left ventricle causing its hypertrophy and dilatation. There is low cardiac output, which may manifest as angina pectoris and syncope (fainting) on exertion. The disease may culminate in left ventricular failure.

ii. In aortic regurgitation, incompetent aortic valve fails to close the aortic orifice completely during diastole. There is overfilling of left ventricle during diastole because it receives blood from left atrium as well as ascending aorta. The left ventricle undergoes dilatation and hypertrophy. Gradually this leads to left ventricular failure.

**Disorders of Tricuspid Valve**

i. In tricuspid stenosis, the tricuspid orifice is narrowed. The blood flow from right atrium to right ventricle is reduced, which results in reduction of blood in the pulmonary circulation. The net result is decreased cardiac output and elevation of right atrial pressure leading to systemic venous congestion and right heart failure.

ii. In tricuspid regurgitation, the tricuspid orifice undergoes stretching as a result of right ventricular dilatation or infarction. The pressure in the right atrium increases due to regurgitation of blood into it during systole. Ultimately the right side of the heart dilates and gives rise to systemic venous congestion and right heart failure.

**Pulmonary Stenosis**

The pulmonary stenosis is almost always congenital, either isolated or as part of Fallot’s tetralogy. The stenosis of the pulmonary orifice results in hypertrophy of the right ventricle and reduction in the cardiac output.
The myocardium beats nonstop throughout life and is capable of working harder during times of increased physical activities. Therefore, the oxygen demand of the myocardium is very high. The right and left coronary arteries supply blood to the heart. The stems of the two arteries and their major anastomosing branches (located in the sub-pericardial fat) encircle the heart like an obliquely inverted crown.

Unique Features of Coronary Arteries

i. The coronary arteries are the biggest vasa vesora (pleural of vasa vasorum) in the body because the heart is considered to be a modified blood vessel.

ii. The coronary arteries are functionally end arteries but anatomically they are not. The branches of the two coronary arteries anastomose at arteriolar level, but the caliber of the anastomosing arteries is not sufficient to maintain normal circulation, if one of the arteries is suddenly blocked.

iii. Unlike other arteries of the body the coronary arteries fill during diastole of the ventricles. Duration of the systole in a cardiac cycle is constant irrespective of the rate of heart. Therefore in response to increase in the heart rate (tachycardia) diastole will be shortened, thus reducing the coronary filling. So in patients with coronary artery disease increase in heart rate due to any cause may precipitate ischemia (reduction in arterial supply to heart).

iv. The coronary arteries are more prone to atherosclerosis (subendothelial deposition of lipids) compared to other arteries hence ischemic heart diseases are very common.

Origin of Right Coronary Artery (Fig. 30.1)
The right coronary artery takes origin from the anterior aortic sinus at the root of the ascending aorta.

Course (Figs 30.2A and B)
Its course is divided into three segments.

i. The first segment of the artery extends from the aortic root to the coronary sulcus on the sternocostal surface. It courses between the pulmonary trunk and the right auricle in anterior direction to appear on the sternocostal surface.

ii. The second segment lies in the coronary sulcus, where it runs almost vertically downward to reach the lower end of the right margin of heart. This segment is covered by sub-pericardial fat and is crossed by anterior cardiac veins.
The third segment of the artery occupies the right portion of coronary sulcus on the posterior aspect (Fig. 30.3) and runs upwards and to the left from the lower end of the right margin along with small cardiac vein.

**Termination**

The right coronary artery terminates by different modes in the posterior part of the coronary sulcus. In 60 percent of subjects it ends a little to the left of the crux by anastomosing with circumflex branch of the left coronary artery. In 10% of subjects it terminates at the lower end of the right margin while in another 10% it terminates between the right border and the crux. In the remaining 20% it reaches the left border by coursing the entire coronary sulcus, thus replacing a part of circumflex artery.

**Branches of Right Coronary Artery**

i. The first segment of the artery gives origin to right conus artery, which supplies the base of the pulmonary trunk. If the conus artery arises independently from the anterior aortic sinus, it is called the third coronary artery.

ii. The second segment of the artery gives off the right anterior atrial branch (supplying the anterior part of the right atrium and the SA node through a nodal branch), right anterior ventricular branches (supplying the anterior part of the right ventricle) and the right marginal artery, which travels along the inferior margin of the heart, supplying both the ventricles on its way.

iii. The third segment of the artery gives off the right posterior ventricular branches (supplying the diaphragmatic surface of right ventricle), right posterior atrial branches and AV nodal branches. Lastly, it gives off a large posterior interventricular artery (termed as posterior descending artery), which travels in the posterior interventricular groove along with middle cardiac vein and supplies the diaphragmatic surface of both ventricles and the posterior one-third of the interventricular septum.
Area of Supply
The right coronary artery supplies right atrium, right ventricle, posterior one-third of interventricular septum and nodal tissue.

Origin of Left Coronary Artery (Fig. 30.1)
The left coronary artery takes origin from the left posterior aortic sinus at the root of the ascending aorta. It is larger in size and much shorter than the right coronary artery. It supplies a greater volume of myocardium.

Course
Its short stem courses anteriorly between pulmonary trunk and left auricle to emerge on the sternocostal surface, where it divides into terminal branches of equal size namely, anterior interventricular artery (termed as left anterior descending artery) and circumflex artery.

Branches of Left Coronary Artery
i. The anterior interventricular artery (also termed as left anterior descending or LAD artery) descends in the anterior interventricular groove on the sternocostal surface accompanied by great cardiac vein. It terminates by meeting the end of the posterior interventricular artery either at the apex of the heart or in the posterior interventricular groove after winding round the apex. Its branches are, right and left ventricular, left conus and anterior septal. One of the left anterior ventricular branches is especially large and is called diagonal artery. The left conus artery anastomoses (around the infundibulum) with the right conus artery (a branch of right coronary artery). The anterior septal branches supply the anterior two thirds of the interventricular septum. Thus, it is evident that the anterior interventricular (LAD) artery supplies a large area of left ventricle and of the interventricular septum. Moreover, it is very much prone to atherosclerosis and narrowing in men. Hence, its block may cause massive and fatal infarction. On account of this LAD has been popularly called the “widow maker”.

ii. The circumflex artery continues in the left part of the coronary sulcus and curves round the left margin of the heart to appear in the left portion of the coronary sulcus on the posterior aspect (Fig. 30.3). Usually, it terminates to the left of the crux by anastomosing with the right coronary artery but at times it continues as the posterior interventricular artery. The circumflex artery gives rise to left marginal artery, ventricular branches to inferior surface of left ventricle and left atrial branches.

Area of Supply
The left coronary artery supplies most of the left ventricle, a narrow strip of right ventricle, anterior two thirds of the interventricular septum and the left atrium.

Coronary Dominance
In the right dominance the posterior interventricular artery arises from the right coronary artery while in the left dominance the posterior interventricular artery is a branch of the left coronary artery. In balanced pattern both the coronary arteries give rise to these branches, which run parallel in the posterior interventricular sulcus.

Coronary Anastomosis
In normal healthy heart, the coronary arteries are the true end arteries as their anastomoses are inadequate to maintain circulation in the event of sudden occlusion of a major branch of coronary artery. However, with slow onset occlusion in coronary arteries like in atherosclerosis, there is time for newer anastomoses to develop so that the normal nutrition of the myocardium is not affected.

Clinical insight ...

i. The coronary angiography is a radiological procedure by which coronary arteries are visualized after injecting a contrast medium into them. Angiography is useful in localizing the sites of the blocks in the coronary arteries or their branches. In this procedure a special catheter is passed usually through the femoral artery up into the aorta till the base of the ascending aorta. The contrast material is injected into the coronary ostia located at this site and then the radiographs are taken. Figures 30.4 and 30.5 show normal coronary arteries after angiography.

ii. In angina pectoris due to narrowing of coronary artery or arteries, there is reduction in blood supply to the myocardium. This results in lack of sufficient oxygen to the myocardium (ischemia). As a consequence, on physical exertion the patient experiences pain in the chest. The typical anginal pain is of gripping or constricting type of retrosternal pain, which radiates to the inner side of left arm or shoulder or to the neck. The anginal pain is accompanied by weakness, dizziness and perspiration. It is relieved after rest.

iii. In myocardial infarction (MI) there is a complete block in the coronary artery or its major branch either due to thrombus or embolus formation on the atheromatous patch in the vessel. This results in complete loss of blood supply to the myocardium with consequent infarction. Massive myocardial infarction is usually fatal.

Contd...
Restoration of Arterial Supply of Ischemic Myocardium

There are two methods by which the blood supply to the myocardium can be restored if the main coronary arteries or their main branches are blocked.

i. The percutaneous transluminal coronary angioplasty (PTCA) is done for increasing the inside diameter of the narrowed coronary artery. A balloon catheter is passed into the coronary artery and the balloon is inflated at the site of the block in order to squash the atheromatous plaque against the wall of the artery. Nowadays stenting of blocked artery is a preferred method (Fig. 30.6).

ii. The coronary artery bypass graft (CABG) is a major surgical procedure (pictures from avijit collection). The patient’s own vessels are used for the graft. The commonly used vessels are the great saphenous vein, the internal mammary artery and the radial artery. Amongst these options, internal mammary artery graft is the most favored. This graft has greatest success rate because the wall of the internal mammary artery has elastic tissue in it and chances of restenosis are far less. In patients with multiple blocks (three or four) all the three blood vessels can be used. Figures 30.7 A and B shows the internal mammary artery graft for blocked LAD and saphenous vein graft for right coronary block. A segment of saphenous vein in the thigh is taken out and anastomosed with the ascending aorta on one hand and to the patent part of the affected artery beyond the block. The segment of vein is reversed during grafting so that its valves do not hamper the blood flow. Before taking the radial artery graft, the patency of the ulnar artery is always ascertained by Allen’s test (Fig.18.8). An intraoperative view of LIMA to LAD graft is depicted in Figure 30.8.

Veins of Heart (Fig. 30.9)

There are three major veins, which drain blood from the myocardium.

i. The coronary sinus is the chief vein of the heart. It collects venous blood from the myocardium and empties it into the right atrium.
ii. There are three or four anterior cardiac veins, which directly open in the anterior part of the right atrium.

iii. The venae cordis minimae (Thebesian veins) are scattered all over the myocardium and open directly into all the cardiac chambers.

**Coronary Sinus**

This is a short (2.5 cm long) and wide venous channel located in the posterior part of coronary sulcus between the left atrium and left ventricle. The myocardial fibers from the atrium often cover it superficially.

**Embryologic insight ...**

The coronary sinus develops from the left horn of the sinus venosus and part of left common cardinal vein (Fig. 27.3).

**Origin and Termination**

The coronary sinus begins as the continuation of the great cardiac vein at the left end of the coronary sulcus. From here it courses downward and to the right lying between the left atrium and ventricle and opens in the smooth part of the right atrium. The opening of the coronary sinus...
is guarded by a small valve (Thebesian) and is located between the opening of inferior vena cava (IVC) and the tricuspid orifice.

**Tributaries**

i. The great cardiac vein begins at the cardiac apex. It ascends in the anterior interventricular groove to enter the coronary sulcus and follows this to reach the left border of the heart, where it joins the left end of the coronary sinus.

ii. The middle cardiac vein begins at the cardiac apex, ascends in the posterior interventricular groove and joins the coronary sinus at its right end.

iii. The small cardiac vein has a variable course. It may follow the right coronary artery and open into the right end of the coronary sinus. It may take the place of right marginal vein so that it accompanies the right marginal artery as well as the right coronary artery in its posterior course.

iv. The posterior vein of left ventricle lies parallel to the middle cardiac vein.

v. The oblique vein of left atrium or oblique vein of Marshall opens near the left end of the coronary sinus. It is connected to the left superior intercostal vein by ligament of left vena cava (Fig. 42.3). The oblique vein and the ligament are the remnants of the left common cardinal vein.
FIBROUS SKELETON OF HEART

The fibrous skeleton (Fig. 31.1) of the heart gives support to the cardiac valves and the myocardium. It is described as a dynamically deformable tissue. The fibrous skeleton gives origin to the myocardium of atria and the ventricles and ensures electrophysiological discontinuity between the atria and ventricle except where the bundle of His penetrates the central fibrous body.

Component Parts

The atrioventricular valves and the aortic valve are located close to each other and share a common fibrous ring (annulus) while the pulmonary valve has a separate fibrous ring, being a little away from the other three valves. At the aortic orifice, the fibrous ring is the strongest. The pulmonary annulus is connected to the aortic annulus by the tendon of conus or infundibulum. The common fibrous tissue between the annulus of AV valves behind and the aortic orifice in front is divisible into:

i. Left fibrous trigone, where the aortic and mitral valves meet.
ii. Subaortic curtain between the aortic valve and the gap in the mitral valve annulus.
iii. Right fibrous trigone, where the aortic, mitral and tricuspid rings meet and which is continuous with the membranous part of the interventricular septum. The central fibrous body is the combination of right fibrous trigone and the membranous part of interventricular septum. The bundle of His penetrates this important structure. The tendon of Todaro is the collagenous connection between the central fibrous body and the valve of the inferior vena cava. The atrioventricular dehiscence is a serious condition resulting from the injury to the central fibrous body.

CONDUCTING TISSUE OF HEART

The conducting tissue (Fig. 31.2) consists of excitable tissue, which consists of modified myofibers. This specialized tissue is responsible for maintaining the heart rate at 70 to 90 per minute in the adult.

Components

The conducting tissue consists of, sinusatrial (SA) node, internodal pathways, atrioventricular (AV) node, atrioventricular bundle of His, right and left bundle branches and Purkinje fibers (conduction myofibers)

i. The SA node is situated in the wall of the right atrium at the upper end of the crista terminalis partially surrounding the opening of the superior vena cava. It is subepicardial in position. It is capable of generating electrical impulses, hence it is called the pacemaker of the heart. The SA node is a very vascular area of the heart.
It is believed that three internodal pathways exist across the atrial wall and they connect the SA node to the AV node. Similarly a path (Bachmann’s bundle) connecting right and left atria is also believed to exist. But for want of histological evidence of these paths, it is assumed that the internodal and interatrial conduction occurs through ordinary working myocardium.

The AV node is located in the triangle of Koch in the lower part of the right atrium to the left of the coronary sinus opening. It extends downwards up to the junction of interatrial septum and the central fibrous trigone. In this way, the AV node is related to both the AV valves, interatrial septum, membranous part of interventricular septum and the aortic valve. The AV node initiates the ventricular systole. The impulse is carried in the atrioventricular bundle to the ventricles. If the SA node is damaged the AV node can take over the function of the pacemaker.

The atrioventricular bundle of His is the only muscular connection between the myocardium of atria and ventricles. It passes through the central fibrous body and along the posterior margin of the membranous interventricular septum to the junction of the muscular and membranous parts of the septum. At this level, it divides in two bundle branches, one for each ventricle. The right bundle branch (RBB) passes down on the right side of the interventricular septum. A part of this bundle enters the septomarginal trabecula, which carries it to the anterior papillary muscle, and the remainder breaks up into fine fibers, which supply the, rest of the right ventricle. The left bundle branch (LBB) pierces the septum and passes down in a superficial position on the left aspect of the septum. It divides into fibers that enter the ventricular musculature. The fibers of the bundle of His are in continuity with Purkinje fibers in the ventricular wall.

**Arterial Supply of Conducting Tissue (Fig. 31.3)**

- SA node is supplied by the nodal branch of right coronary artery near its origin in 60 percent of people. In the remaining 40 percent the circumflex branch of left coronary supplies it.
- AV node is supplied by the branch of right coronary artery at the crux of heart in 90 percent of people. In 10%, the circumflex branch of left coronary artery supplies it.
- The atrioventricular bundle of His is supplied by septal branches of right coronary artery.
- The right bundle branch (moderator band) is supplied by septal branches of left coronary artery.
- The left bundle branch is supplied largely by septal branches of (from anterior interventricular branch of left coronary artery) and its posterior subdivision is supplied additionally by septal branches of posterior interventricular branch of right coronary artery.

**NERVE SUPPLY OF HEART**

Both sympathetic and parasympathetic nerves control the action of heart through the cardiac plexuses and the coronary plexuses.

**Efferent Nerve Supply**

- Parasympathetic efferent supply is via the cervical cardiac branches of vagus and cardiac branches of recurrent laryngeal nerves. The parasympathetic is cardioinhibitory in function.
ii. The sympathetic supply is via the three cervical cardiac branches and a few thoracic cardiac branches of the sympathetic chain. The sympathetic is cardioaccelerator in function.

**Afferent Nerve Supply**

The heart is insensitive to touch, cutting, cold or heat but ischemia and resultant accumulation of metabolic products stimulate pain nerve endings in the myocardium. The pain sensation is carried in the middle and inferior cervical cardiac branches and thoracic cardiac branches of the sympathetic chain to the thoracic ganglia of the sympathetic chain (Fig. 31.4). From here, the impulse passes via the white rami to the thoracic spinal nerves (T1 - T5) and to the dorsal root ganglia. The central processes of the neurons in the dorsal root ganglia carry the impulses to the posterior horns of T1 to T5 spinal segments (mostly of the left side). The afferent fibers in the vagus nerves reach the medulla oblongata and are concerned with reflexes controlling the cardiovascular activity.

**Clinical insight ...**

**Referred Pain in Angina Pectoris**

When the pain impulses from ischemic myocardium reach the spinal cord, they stimulate the somatic sensory neurons of the corresponding segments of the spinal cord, usually on the left side. Thus, pain is felt in T1 and T2 dermatomes (along the inner border of the left upper limb). The pain may also be felt in the precordium and back, which are supplied by T2 to T5 spinal nerves. It is worthy of note that individuals with transplanted heart do not experience anginal pain. This is so because transplanted heart is a denervated donor heart, in which regeneration of the nerves is not possible in the host.

*Contd...*
MAJOR BLOOD VESSELS OF THORAX

The major blood vessels of thorax are as follows:

i. Pulmonary vessels
ii. Ascending aorta
iii. Arch of aorta
iv. Descending thoracic aorta
v. Superior vena cava
vi. Azygos system of veins.

Pulmonary Vessels

The pulmonary vessels consist of pulmonary trunk and its terminal branches, the right and left pulmonary arteries, and one pair of pulmonary veins on each side. The pulmonary arteries and veins communicate with each other at the pulmonary capillary bed in the lungs. The pulmonary arteries carry deoxygenated blood from the right ventricle to the lungs and the pulmonary veins bring oxygenated blood back to the left atrium.

Pulmonary Trunk

This vessel begins as the continuation of infundibulum of the right ventricle at the pulmonary valve (Fig. 32.1). It is five centimeter long and three centimeter wide. It systolic pressure is 15 to 25 mm Hg. The pulmonary trunk bifurcates into right and left pulmonary arteries inside the fibrous pericardium. Its bifurcation is at the level of the superior margin of the atria (level with fifth thoracic vertebra).

Clinical insight ...

Surface Marking

A 2.5 cm broad horizontal line is drawn at the level of left third costal cartilage, extending partly behind the sternum.

Relations

The relation of pulmonary trunk to the ascending aorta is important. Both the vessels are covered in a common sleeve of visceral pericardium due to their common development from the truncus arteriosus. The pulmonary trunk is in front of the ascending aorta at its beginning but soon it comes to lie on the left of the ascending aorta. Both vessels form the anterior boundary of transverse sinus of pericardium hence lie in front of the left atrium. At its origin the pulmonary trunk is flanked by the corresponding coronary artery and auricle.
Course and Distribution of Pulmonary Arteries

i. The right pulmonary artery has a longer intrapericardial course than the left pulmonary artery. During its intra-pericardial course it is related anteriorly (in succession) to the ascending aorta, SVC and the upper right pulmonary vein. Posterior to it but outside the fibrous pericardium, are the esophagus and the right main bronchus. After piercing the fibrous pericardium the artery reaches the hilum of right lung, where it divides into two unequal branches. The smaller branch enters the upper lobe of the lung while the larger branch soon divides into lobar branches for the middle and the lower lobes. The lobar branches divide into segmental branches for individual broncho-pulmonary segments of a particular lobe. Thus, the arterial divisions follow the pattern of bronchial tree.

ii. The left pulmonary artery has a very short intrapericardial course. After it pierces the fibrous pericardium it is related anteriorly to left lung and pleura and posteriorly to the left main bronchus, descending aorta and left vagus nerve. Superiorly the ligamentum arteriosum connects it to arch of aorta. At the hilum of the left lung it divides into two equal branches for the two lobes of the left lung. Each lobar branch gives off segmental branches corresponding to the number of broncho-pulmonary segments. The segmental arteries repeatedly subdivide till they join the capillary bed surrounding the alveoli. The branching pattern of the left pulmonary artery shows frequent variations.

Pulmonary Veins (Fig. 32.3)
The pulmonary veins originate as small venous tributaries from the pulmonary capillaries. The veins lie in the planes separating the adjacent broncho-pulmonary segments so that they are able to pick up oxygen from more than one segment. The intersegmental veins unite to form lobar veins. A pair of pulmonary veins emerges on each side from the hilum of lung. The veins proceed transversely to pierce the fibrous pericardium and open into the posterior wall of the left atrium. The walls of the pulmonary veins contain cardiac muscle fibers instead of the smooth muscle fibers. They are valveless veins.

Clinical insight ...

i. The pulmonary edema means accumulation of serous fluid in the lung alveoli as a result of rise in the hydrostatic pressure in the capillaries. Left ventricular failure due to acute myocardial infarction, mitral stenosis, mitral regurgitation or systemic hypertension. It can also occur in pneumonia. In pulmonary edema the patient experiences intense dyspnea (breathlessness), sweating, frothy sputum and cyanosis.

ii. The pulmonary embolism means occlusion of pulmonary artery or its branches by emboli. The emboli usually originate from thrombosis in distant peripheral veins.

Contd...
Chapter

Ascending Aorta (Fig. 32.4)
The ascending aorta begins from the left ventricle at the level of aortic valve. It continues as the arch of aorta at the level of sternal angle. Its length is five centimeter and diameter is three centimeter. It is entirely intrapericardial.

Surface Marking
The aortic valve is drawn on the left half of the body of sternum at the level of third intercostal space by a line 2.5 cm broad. From the ends of this line two parallel lines are drawn in upward direction to reach the right half of sternum at the sternal angle. The upper end of the ascending aorta is represented by a line on the right half of the sternum at this level.

Sinuses of Valsalva
Just above the aortic valves the wall of the ascending aorta shows dilatations, called aortic sinuses of Valsalva. Their positions are anterior, right posterior and left posterior.

i. The anterior aortic sinus is called the right coronary sinus because it gives origin to right coronary artery.

ii. The left posterior sinus is called the left coronary sinus because it gives origin to left coronary artery.

iii. The right posterior sinus is called the non-coronary sinus.

Bulb of Ascending Aorta
It is a dilatation on the right side of the ascending aorta, which is subjected to constant thrust of the forceful blood current ejected from the left ventricle. This site is prone to aneurysm.

Relations
The ascending aorta pierces the apex of fibrous pericardium at the level of sternal angle. It is enclosed with the pulmonary trunk in a common sleeve of visceral pericardium.

Anterior Relations
i. Its lowest part is related to infundibulum of right ventricle and the auricle of right atrium.

ii. Its middle part is in relation to the pulmonary trunk.

iii. Its lowest part is related to the pericardium.

Posterior Relation
The transverse sinus of pericardium is the posterior relation and it separates the ascending aorta from the left atrium.

Right Relation
The SVC and the right atrium form close relation on the right side.

Left Relation
The pulmonary trunk is related on the left side. Note that the pulmonary trunk is at first related anteriorly and then comes on the left side.

Branches
i. Right coronary artery

ii. Left coronary artery.
Arch of Aorta (Fig. 32.5)
The arch of aorta (aortic arch) is located in the superior mediastinum. It is the continuation of ascending aorta and it continues as the descending thoracic aorta, both events take place at the level of sternal angle. The arch begins anteriorly while it ends posteriorly (very close to the left side of the fourth thoracic vertebra). The arch reaches the level of mid-manubrium, as it spans the distance between its two ends.

Course
The arch of aorta begins at the level of right second costal cartilage and turns upwards, backwards and to the left in front of the trachea. Having reached the middle of the back of manubrium, it turns backwards and downwards along the left side of the trachea up to the level of lower border of fourth thoracic vertebra, where it becomes the descending aorta. During its course it describes two convexities (first upward and second to the left).

Surface Marking (Fig. 32.6)
The arch of aorta is represented by a curved and wide (2.5 cm) band, which connects the right second costal cartilage close to the sternum to the left second costo-sternal junction. The most convex point of this band reaches the midpoint of the manubrium sterni.

Relations (Fig. 32.7)
1. Anteriorly and to the left the structures that cross the arch from anterior to posterior are as follows:
   i. Left phrenic nerve
   ii. Inferior cervical cardiac branch of left vagus nerve
   iii. Superior cervical cardiac branch of left sympathetic chain.
   iv. Left vagus nerve.
   v. Left superior intercostal vein crosses the arch between phrenic and vagus nerves.
2. Inferiorly the arch is related to the bifurcation of pulmonary trunk, left pulmonary artery and the left main bronchus. The ligamentum arteriosum connects the arch of aorta (distal to the origin of left subclavian artery) to the beginning of the left pulmonary artery. The left recurrent laryngeal nerve winds round the ligamentum arteriosum. The superficial cardiac plexus lies on its anterior aspect.
3. Posteriorly and to the right, the structures that are related from before backward are as follows:
   i. Lower end of trachea (with deep cardiac plexus in front of it)
**Chapter 32**

**Major Blood Vessels of Thorax**

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### ii. Left recurrent laryngeal nerve

### iii. Left side of esophagus

### iv. Thoracic duct

### v. Left side of fourth thoracic vertebra

4. Superiorly three branches arise from the upper convexity of the arch.
   i. Brachiocephalic artery
   ii. Left common carotid artery
   iii. Left subclavian artery

The brachiocephalic (innominate) artery arises from the summit of the arch. Beyond this the arch gives origin to left common carotid and left subclavian arteries. Occasionally a fourth branch called thyroidea ima may arise from the arch. Some variations in the branches are, the left vertebral artery or inferior thyroid artery may arise from the arch.

#### Arterial Supply

i. The vasa vasorum (small twigs from the branches of the aortic arch) enter its wall from outside. These branches supply outer part of aortic wall.

ii. The inner part of the aortic wall is nourished from the blood in the lumen of the arch.

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**Embryologic insight (Fig. 32.9)...**

The arch develops from four sources as follows.

i. Aortic sac
ii. Left horn of aortic sac
iii. Left fourth arch artery
iv. Left dorsal aorta

**Congenital Anomalies**

i. Patent ductus arteriosus (Fig. 28.8)
ii. Coarctation of aorta (Fig. 28.2 and 28.3)
iii. Aberrant right subclavian artery (Fig. 28.5)
iv. Double aortic arch.

For details of the development and anomalies of the arch of aorta refer to chapter 28 on pharyngeal arches.

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**Clinical insight ...**

**Aneurysm (Figs 28.2 and 28.4)**

The aneurysm of aortic arch is a localized dilatation of the vessel. A characteristic clinical sign of this condition is the tracheal tug, which is a tugging sensation felt in the suprasternal notch, where trachea is palpated in extended position of the neck. The aneurysm usually causes compression of neighboring structures in the superior mediastinum producing diverse.

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*Contd...*
Thorax

Radiological Appearance

i. In the P-A view of X-ray chest, the arch of aorta appears as a small projection at the upper end of the left margin of the cardiac shadow. It is called aortic knuckle.

ii. In LAO (left anterior oblique) view of X-ray chest a translucent space enclosed by the arch is identifiable. It is called aortic window in which faint shadows of pulmonary arteries may be seen.

Descending Thoracic Aorta (Fig. 32.10)

Location

The descending thoracic aorta is located in posterior mediastinum.

Extent

It extends from the left side of the lower border of fourth thoracic vertebra to the lower border of the front of the twelfth thoracic vertebra.

At its upper end it is continuous with the arch of aorta. At its lower end it passes through the aortic opening of the diaphragm to become continuous with the abdominal aorta. At its commencement the aorta is to the left of the vertebral column. During its descent it gradually inclines towards the midline till it lies directly anterior to the vertebral column at its entry point into the abdomen.

Surface Marking

A 2.5 cm broad line is drawn on the left part of the sternal angle and the adjoining part of second left costal cartilage. Another line of same breadth is drawn on the anterior abdominal wall about 2 to 2.5 cm above the transpyloric plane in the median plane. The ends of the broad lines are connected to parallel lines to mark the aorta on the surface.

Relations

i. Anteriorly, the descending aorta is related to, from above downwards, the left lung root, pericardium (with left atrium inside it), esophagus and the diaphragm.

ii. Posteriorly, it is related to the vertebral column and hemiazygos veins.

iii. The right relation in the upper part is the right side to the esophagus. The other relations on the right side are the thoracic duct and vena azygos. Its lower part comes in contact with the right lung and pleura.

iv. On the left side, the descending aorta produces a deep vertical groove on the medial surface of the left lung (posterior to the hilum and extending up to the lower end of the medial surface).

Branches of Descending Aorta

Visceral

Pericardial

Esophageal Mediastinal

Upper and lower left bronchial

Parietal

Posterior intercostal arteries of 3rd to 11th spaces

Subcostal arteries

Superior phrenic or phrenic arteries

Clinical insight...

Dissecting Aneurysm (Fig. 32.11)

The aortic dissection (dissecting aneurysm) is a condition that mostly affects the thoracic aorta. There is a tear in the intima of aorta through which blood from aortic lumen enters its wall.

Contd...
A channel of blood is created in the tunica media. This causes dilatation of the aorta. The patient usually experiences pain in the back due to compression of intercostal nerves. Occasionally the aorta may rupture into the left pleural cavity. Surgical treatment consists of transection of diseased segment followed by end-to-end anastomosis or replacement with prosthetic vascular graft.

**Major Veins of Thorax**

**Superior Vena Cava**

The superior vena cava (SVC) drains blood from the head and neck, upper limb, walls of thorax and upper abdomen into the right atrium of the heart.

**Length**

It is seven centimeter long.

**Parts**

i. Extrapericardial part in the superior mediastinum.
   ii. Intrapericardial part in the middle mediastinum.

The superior vena cava is without valves since gravity facilitates the flow of blood inside it.

**Formation**

The superior vena cava is formed by the union of the right and left brachiocephalic veins behind the lower border of right first costal cartilage close to the sternum (Fig. 32.12).

**Course**

It passes vertically downwards behind the first and second right intercostal spaces and pierces the fibrous pericardium to open into the upper posterior part of the right atrium at the level of the third costal cartilage. The arch of the azygos vein opens into it just before the superior vena cava pierces the fibrous pericardium. The intrapericardial part is closely related to the ascending aorta and the right pulmonary artery.

**Surface Marking**

This vein is represented by two parallel and vertical lines two centimeter apart starting from the lower border of the first costal cartilage to the upper border of the third costal cartilage close to the right side of sternum.

**Brachiocephalic Veins**

There are two brachiocephalic veins (right and left) (Fig. 32.12).

**Formation**

Each is formed behind the sternoclavicular joint by the union of the internal jugular and subclavian veins.
Termination

The right and left brachiocephalic veins unite to form the SVC at the lower margin of right first costal cartilage close to the sternum. Both veins are devoid of valves.

i. The right brachiocephalic vein is short (2.5 cm) and extends from the right sternoclavicular joint to the lower margin of first costal cartilage. Its tributaries are, the right vertebral vein, right internal thoracic vein, right inferior thyroid vein and the first right posterior intercostal vein.

ii. The left brachiocephalic vein is about twice the length of the right vein (6 cm). It runs obliquely across the superior mediastinum from the left sternoclavicular joint to the lower margin of first right costal cartilage, where it unites with the right vein. It is closely related to the posterior surface of the manubrium sterni. This relation should be kept in mind while performing sternal puncture. Posteriorly, it is related to the three branches of the arch of aorta and two nerves (left vagus and left phrenic). This vein receives the left vertebral vein, left internal thoracic vein, left inferior thyroid vein (sometimes both inferior thyroid veins drain into it), first left posterior intercostal vein, left superior intercostal vein, thymic veins and pericardial veins.

Azygos Vein (Fig. 24.10)

The name azygos means single or without a companion. The azygos vein is present on the right side only. It is provided with valves. It presents a tortuous appearance.

Formation in Abdomen

The azygos vein begins in the abdomen usually as a continuation of lumbar azygos vein (which arises from posterior part of IVC) or is formed by the union of right ascending lumbar and right subcostal veins (Fig. 33.2).

Exit from Abdomen

The azygos vein leaves the abdomen through the aortic opening of the diaphragm and enters the posterior mediastinum.

Course in Posterior Mediastinum

Here, it ascends vertically upwards lying in front of the vertebral column up to the level of the fourth thoracic vertebra, where it arches forwards superior to the hilum of the right lung (which it grooves) to open into the SVC just before the latter pierces the fibrous pericardium.

Tributaries

i. Right superior intercostal vein

ii. Right posterior intercostal veins from the fourth space downwards

iii. Right subcostal vein

iv. Ascending lumbar vein

v. Hemiazygos vein

vi. Accessory hemiazygos vein

vii. Right bronchial vein

viii. Esophageal veins

ix. Pericardial veins

taxi. Mediastinal veins.

Hemiazygos Vein (Inferior Hemiazygos Vein)

This vein is present on the left side. It is formed like the azygos vein in the abdomen from either the continuation of left lumbar azygos vein that arises from the posterior surface of the left renal vein or by the union of left ascending lumbar and the left subcostal veins. The hemiazygos vein pierces the left crus of the diaphragm and enters the posterior mediastinum. It passes vertically upward lying on the front of the vertebral bodies and crosses over to the right side in front of the eighth thoracic vertebra to open into the azygos vein. This vein receives, left ascending lumbar vein, left subcostal vein and the left posterior intercostal veins of the ninth to eleventh intercostal spaces.

Accessory Hemiazygos Vein (Superior Azygos Vein)

This vein begins as the continuation of usually the fifth posterior intercostal vein and descends on the left side of the vertebral column. At the level of the seventh thoracic vertebra it crosses over to the right side behind the descending aorta and the thoracic duct to open into the azygos vein. This vein receives the fifth to seventh left posterior intercostal veins and the left bronchial vein.

Posterior Intercostal Veins (Fig. 24.10)

There are eleven pairs of posterior intercostal veins. Each posterior intercostal vein drains its intercostal space.

1. The vein of the first space (the highest intercostal vein) ascends in front of the neck of the first rib and then arches over the cervical pleura in anterior direction to open into the corresponding brachiocephalic vein.

2. The right superior intercostal vein begins by the union of right posterior intercostal veins of the second, third and often the fourth spaces. It opens into the arch of the azygos vein.

3. The left superior intercostal vein begins by the union of left posterior intercostal veins of the second, third and often the fourth spaces. It descends to the level of the vertebral end of the aortic arch and then crosses the
left and anterior surfaces of the arch of aorta. It terminates in the left brachiocephalic vein. Its tributaries are the left bronchial vein, and sometimes the left pericardiophrenic vein.

4. The posterior intercostal veins of the remaining spaces (from fourth to eleventh) on the right side drain into the vertical part of azygos vein.

5. The corresponding veins on the left side drain into hemiazygos veins as mentioned above.

**Venous Communications**

The posterior intercostal veins communicate with anterior intercostal veins, which are the tributaries of internal thoracic veins. They communicate with the vertebral venous plexuses. This communication is responsible for venous spread of cancer cells in the vertebrae and skull bones from primary cancer in breast.

**Collateral Venous Circulation**

The superior vena cava may be compressed at two sites.

i. In the superior mediastinum (above the entry of azygos vein)

ii. In the middle mediastinum (below the entry of azygos vein).

Depending on the site of obstruction the different collateral pathways are developed.

1. In the obstruction above the entry of azygos vein the following two venous routes drain the blood from the upper part of the body into right atrium.
   i. The blood from the internal thoracic veins reaches the azygos vein via the anastomoses between the anterior and posterior intercostal veins. The azygos vein opens into superior vena cava, which opens into the right atrium.

2. If the obstruction is below the entry of azygos vein, venous blood from the upper part of the body reaches the right atrium via the inferior vena cava as follows:
   i. There is reversal of blood flow in the azygos vein. As a result of this the blood from azygos vein reaches the inferior vena cava via the lumbar azygos or ascending lumbar vein (formative tributaries of vena azygos, which have connections with IVC).
   ii. There are other devious routes to reach the inferior vena cava as follows:
      One route is via the communication of superior and inferior epigastric veins to the external iliac vein and finally to IVC. Another route is by communications of superficial veins of thorax and anterior abdominal wall.
      The lateral thoracic vein (a tributary of axillary vein) communicates with superficial epigastric veins of anterior abdominal wall by thoraco-epigastric veins.

**Development of Veins of Thorax**

During the fourth week of embryonic life there is a symmetrical pattern of venous channels. There are three pairs of cardinal veins (Fig. 27.1).

**Cardinal Veins**

1. Anterior cardinal veins drain the cephalic half of the embryo.
2. Posterior cardinal veins drain the caudal half of the embryo.
3. Common cardinal veins or the ducts of Cuvier (formed by the union of anterior and posterior cardinal veins) enter the respective horns of the sinus venosus.

**Loss of Symmetry of Cardinal Veins (Fig. 27.3)**

During the fifth to seventh weeks the symmetry a transverse anastomotic channel develops between right and left anterior cardinal veins. This channel diverts the venous blood from the left to the right side, consequent to which the veins on the left side shrink in size.

**Developmental Sources of Individual Veins**

1. The right brachiocephalic vein develops from the part of right anterior cardinal vein, which is cranial to the transverse anastomosis.
2. The left brachiocephalic vein develops from following two sources:
   i. Left anterior cardinal vein cranial to the transverse anastomosis.
   ii. Transverse anastomosis
3. The superior vena cava develops from two source as follows:
   i. Extrapericardial part from right anterior cardinal vein caudal to the transverse anastomosis.
   ii. Intrapericardial part from right common cardinal vein (right duct of Cuvier)
4. The left superior intercostal vein develops from two sources as follows:
   i. Left anterior cardinal
   ii. Terminal part of left posterior cardinal vein.
5. The oblique vein of Marshall is a remnant of left common cardinal vein. It is connected to the left superior intercostal vein by means of a ligament (ligament of left vena cava), which is also a remnant of left common cardinal vein.
6. The arch of azygos vein develops from the terminal part of right posterior cardinal vein.
LYMPHATIC ORGANS

The lymphatic organs in the thorax consist of thymus, thoracic lymph nodes and the thoracic duct.

Thymus

The thymus is the primary lymphoid organ. It is the only lymphoid organ that is responsible for the differentiation of T lymphocytes. The thymic secretory products are indispensable for the development and maintenance of an immunologically competent T lymphocyte pool for the entire body.

**Location** (Fig. 33.1)

The thymus mainly lies in superior mediastinum with extension in anterior mediastinum in front of the pericardium.

**Shape**

It is roughly pyramidal with the base pointed inferiorly. The thymus is often bilobed but the two lobes are joined in the midline by connective tissue.

**Age Changes**

i. At birth, the thymus is well-developed and weighs about 30 g.

ii. At puberty, it reaches maximum size and weighs about 40 g.

iii. During adulthood, there is a gradual reduction in the weight as the lymphatic tissue is replaced by fatty tissue.

iv. In old age, it is much reduced in size and turns into a fibro-fatty mass. The number of lymphocytes inside the thymus is greatly reduced. However, lymphocyte production and differentiation persist throughout life.

**Relations in Superior Mediastinum**

i. It is related anteriorly to the manubrium sterni, sternohyoid and sternothyroid muscles.

Fig. 33.1: Location and appearance of thymus in adolescence
ii. It is related posteriorly to left brachiocephalic vein, the arch of aorta and its three branches.

**Relations in Anterior Mediastinum**

i. It is related anteriorly to the body of sternum and upper four costal cartilages.
ii. It is related posteriorly to fibrous pericardium.

**Blood Supply**

The branches of internal thoracic artery and inferior thyroid artery supply the thymus. The thymic veins usually drain into the left brachiocephalic vein, though drainage into internal thoracic and inferior thyroid veins is also possible.

**Lymphatic Drainage**

The efferent lymphatic vessels drain into the brachiocephalic, tracheobronchial and parasternal lymph nodes. The thymus receives no afferent lymphatics.

**Functions**

i. Undifferentiated lymphocytes from the bone marrow enter the thymus from circulating blood. The processing of T lymphocytes takes place within the thymus.
ii. The T cells committed to the production of cell-bound or cell-mediated immunity are released into the circulation and populate the other lymphatic tissues, bone marrow and blood. They are responsible for the formation of B lymphocytes.

**Unique Features of Thymus**

i. The thymus is the primary lymphoid organ essential for development of other lymphoid tissues, like lymph nodes, spleen, etc.
ii. It is composed of only T lymphocytes.
iii. Unlike other lymphoid tissues, its stroma is provided by epithelial reticular cells.
iv. The epithelial reticular cells are endodermal and lymphocytes are mesenchymal in origin.
v. The epithelial reticular cells secrete thymic hormones (thymulin, thymosin, etc.), which are involved in differentiation of T lymphocytes.
vi. Blood-thymus barrier is present in cortex of thymus. It is composed of basement membrane of capillaries and epithelial reticular cells.

**Clinical insight ...**

i. Patients with thymic aplasia, agenesis or hypoplasia, as occurs in DiGeorge syndrome and Nezelof’s syndrome (refer to chapter 42 on pharyngeal apparatus) have lymphopenia, decreased immunity and die early from infection. DiGeorge syndrome presents with severest form of deficient T cell immunity.
ii. The causes of thymic atrophy in young age are ionizing radiation, severe malnutrition, prolonged administration of glucocorticoids and cytotoxic drugs.
iii. In hyperplasia of thymus, there are lymphatic follicles in the thymic lobules. The patient may develop myasthenia gravis. The epithelial cell tumor of thymus called thymoma may present as myasthenia gravis. When the thymoma is large in size, it may compress on trachea, esophagus and large veins in the superior mediastinum.
iv. Myasthenia gravis is a chronic autoimmune disease of adults, in which there is reduction in the power of certain voluntary muscles for repetitive contractions. The cause is the destruction of acetylcholine receptor proteins of neuromuscular junction by autoimmune antibodies produced by T lymphocytes. The muscles commonly involved are the levator palpebrae superioris (causing bilateral ptosis) and the extraocular muscles (causing diplopia).

**Lymph Nodes of Thorax**

The lymph nodes that drain the thoracic walls are superficial lymph nodes and those that drain the deeper contents of thorax belong to the deeper group.

**Superficial Lymph Nodes**

i. The parasternal lymph nodes are located along each internal thoracic artery. These nodes receive lymph vessels from mammary gland, deeper structures of supraumbilical anterior abdominal wall, superior hepatic surface and the deeper parts of anterior thoracic wall. The efferent lymphatic vessels from the parasternal nodes unite with the efferents from tracheobronchial and brachiocephalic nodes to form the bronchomediastinal trunk.
ii. The intercostal lymph nodes are placed at the posterior end of the intercostal spaces. They receive deep lymph vessels from mammary gland and the posterolateral aspect of thoracic wall. Efferents from the nodes in lower four to seven intercostal spaces on both sides
unite to form the descending thoracic lymph trunk which descends into the abdomen through aortic orifice and may join the thoracic duct. Efferents from the nodes in the upper left intercostal spaces form the upper intercostal lymph trunk, which ends in the thoracic duct, and the corresponding ones on the right side join the right lymph trunk. The posterior nodes lie on the back of the crura of the diaphragm and are connected to the lateral aortic (para-aortic) nodes in the abdomen and the posterior mediastinal nodes.

**Deeper Lymph Nodes**

i. The brachiocephalic nodes lie in the superior mediastinum anterior to the brachiocephalic veins. They receive lymph from thymus, thyroid, pericardium, heart and the lateral diaphragmatic nodes. Their efferents unite with those from tracheobronchial nodes to form right and left bronchomediastinal trunks.

ii. The posterior mediastinal nodes lie vertically in the posterior mediastinum along the descending aorta and the esophagus. They receive lymph from the contents of posterior mediastinum, diaphragm including the lateral and posterior diaphragmatic nodes. Their efferents join the thoracic duct.

iii. The tracheobronchial nodes (Fig. 25.30) consist of five subgroups. The paratracheal nodes are seen on the front and sides of the trachea. The superior tracheobronchial nodes lie in the angles between trachea and bronchi. The inferior tracheobronchial nodes are present in the angle between the primary bronchi.

iv. The bronchopulmonary or hilar lymph nodes are present in the hilum of the lung.

v. The pulmonary lymph nodes are inside the lung substance. These nodes drain lungs and bronchi, thoracic trachea, heart and receive lymph from posterior mediastinal nodes. Their efferents join the efferents of parasternal and brachiocephalic nodes to form right and left bronchomediastinal trunks. The right bronchomediastinal trunk opens independently at right jugulosubclavian junction. The left bronchomediastinal trunk opens into thoracic duct.

**Thoracic Duct**

The thoracic duct is a thin walled elongated lymph vessel about 45 cm long. It conveys the lymph from the body into the venous stream. The lymph in the thoracic duct is milky white in color because it is loaded with fat globules.

**Extent**

The thoracic duct extends from the upper end of cisterna chyli on the posterior abdominal wall to the junction of left internal jugular and left subclavian veins, at the base of the neck.

**Appearance**

The thoracic duct is beaded in appearance due to the presence of numerous valves throughout its course. A constant valve guards the opening of the duct in the jugulosubclavian junction to prevent regurgitation of blood into the duct.

**Area of Drainage**

The thoracic duct drains lymph from the entire body except the right half of thorax, right half of head and neck and the right upper limb (Fig. 4.1).

**Course and Relations (Fig. 33.2)**

Its course can be divided into three parts: abdominal, thoracic and cervical.

i. The abdominal part of the thoracic duct begins at the lower border of the twelfth thoracic vertebra as a continuation of cisterna chyli (a receptacle of lymph on the posterior abdominal wall) and enters the thorax through the aortic opening of the diaphragm. At the aortic opening, it is related anteriorly to the median arcuate ligament and posteriorly to the twelfth thoracic vertebra. The azygos vein is on its right and the aorta on its left.
ii. In the posterior mediastinum, the thoracic duct ascends to the right of the midline lying on the vertebral bodies. On reaching the level of the fifth thoracic vertebra it gradually inclines to the left and enters the superior mediastinum at the left side of the sternal angle. The esophagus is related to it anteriorly. The azygos vein is on its right and thoracic aorta is on its left.

iii. In the superior mediastinum, the thoracic duct ascends along the left margin of esophagus to the thoracic inlet. Anteriorly, it is related to the arch of aorta and the left subclavian artery above it. Posteriorly, it lies on the bodies of upper four thoracic vertebrae. On its right, it is related to the esophagus and on its left, it is related to the left lung and pleura.

iv. The cervical part of the thoracic duct (Fig. 33.3) arches laterally at the level of transverse process of the seventh cervical vertebra. The summit of the arch is three to four cm above the clavicle. Anteriorly, the arch is related to the carotid sheath and its contents. Its posterior relations are important. The ascending limb of its arch is related to left vertebral artery and vein, left stellate ganglion and left thyrocervical trunk and its three branches. The descending limb of the arch is related to the medial margin of scalenus anterior muscle, the left phrenic nerve and the first part of left subclavian artery.

**Termination**

In the usual mode of termination, the thoracic duct opens at the union of left subclavian and left internal jugular veins.

**Tributaries**

A large number of tributaries join the thoracic duct throughout its course.

i. Descending thoracic lymph trunks (from lymph nodes of lower intercostal spaces).

ii. Ascending lumbar lymph trunks (in abdomen).

iii. Upper intercostal trunk of left side.

iv. Mediastinal trunks (from mediastinum, diaphragm and diaphragmatic surface of liver).

v. Left bronchomediastinal trunk (from lungs and mediastinum).

vi. Left jugular trunk (from head and neck).

vii. Left subclavian trunk (from upper limb).

**Clinical insight ...**

i. The injury to the thoracic part of the thoracic duct may cause chyllothorax (lymph in the pleural cavity).

ii. The thoracic duct may be obstructed by microfilarial parasites in which case it produces widespread effects like, chyllothorax, chyloperitoneum and even the accumulation of lymph in the tunica vaginalis testis (hydrocele).

iii. The cervical part of thoracic duct may be injured during removal of the left supraclavicular lymph nodes. This is a serious complication, which needs prompt treatment.

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**Right Lymphovenous Portal**

On the right side there are three lymph trunks that converge at the jugulosubclavian junction. They are the right jugular trunk (draining the right half of head and neck), the right subclavian trunk (draining the right upper limb) and the right bronchomediastinal trunk from the right half of thorax. The termination of the three lymph trunks of right side is subject to variation. Usually, the lymph trunks open independently in the jugulosubclavian junction. Occasionally, the three trunks unite to form the right lymphatic duct, which has a similar course in the neck like that of thoracic duct.

### AUTONOMIC NERVES OF THORAX

The autonomic nervous system has sympathetic and parasympathetic components. The cervical and thoracic branches of vagus nerve (parasympathetic) and of the sympathetic chains form autonomic plexuses in the thorax, which supply the visceral musculature and secretory glands through postganglionic branches. The visceral afferent fibers are carried from the viscera via the plexuses to the spinal cord and brainstem.
Vagus Nerve (Parasympathetic Supply)

The vagus nerve (tenth cranial nerve) originates in the medulla oblongata and carries the preganglionic parasympathetic fibers from the dorsal nucleus of vagus. These fibers leave the vagus nerve through its cervical and thoracic branches (superior and inferior cervical cardiac branches of vagus nerve). They take part in the formation of superficial and deep cardiac plexuses. The right recurrent laryngeal nerve is given off at the root of the neck from the right vagus. This nerve gives rise to thoracic cardiac branches.

Course in Thorax

In the superior mediastinum, the right vagus nerve lies on the right side of trachea. It is posteromedial to the superior vena cava and then passes deep to azygos arch to reach the posterior aspect of the hilum of the right lung. The left vagus nerve is positioned between left common carotid and left subclavian arteries. Then it crosses the left surface of the arch of aorta to reach the posterior side of the hilum of the left lung. At the hilum of the lung, each vagus nerve divides into a number of branches, which join the sympathetic branches to form pulmonary plexuses. Below the hilum, the vagal branches on both sides come in relation to the esophagus. The right vagus nerve is located on the posterior side and the left vagus nerve on the anterior side of the esophagus. After taking part in the esophageal plexuses along with sympathetic branches, the vagus nerves leave the thorax through the esophageal opening as posterior vagal trunk (right vagus) and anterior vagal trunk (left vagus).

Branches in Thorax

i. Thoracic cardiac branches
ii. Pulmonary branches
iii. Esophageal branches
iv. Left recurrent laryngeal nerve.

As the left vagus nerve crosses in front of the left surface of the arch of aorta, it gives off the left recurrent laryngeal branch, which winds round the ligamentum arteriosum and then passes upwards and medially deep to the arch of aorta. Similar to the right recurrent laryngeal nerve, the left recurrent laryngeal nerve gives rise to thoracic cardiac branches.

Visceral Afferent Fibers

There are visceral afferent fibers in these cervical and thoracic cardiac branches, which terminate in the sensory ganglia of the vagus nerve. The central processes of these ganglia carry the impulses to the medulla oblongata. The vagus nerves carry sensations from the heart, great blood vessels and respiratory organs. The visceral afferent fibers are involved in maintaining the reflex activity of these organs.

Sympathetic Chains (Fig. 33.4)

Each sympathetic chain extends from the base of the cranium to the coccyx. It passes through the cervical, thoracic, lumbar and sacral (pelvic) regions. It bears a number of ganglia along its length, where majority of preganglionic fibers synapse. The sympathetic chain gives cervical cardiac and thoracic branches for the supply of the thoracic viscera. There are three cervical cardiac branches on each side. They are named as superior, middle and inferior cervical cardiac branches according to the ganglion from which they originate.

Fig. 33.4: Greater, lesser and least splanchnic branches of thoracic part of sympathetic chain (Numbers 2 to 12 indicate sympathetic ganglia)
**Thoracic Branches of Sympathetic Chain**

The sympathetic chain enters the thorax through the thoracic inlet. The thoracic part of the chain consists of eleven ganglia. The first thoracic ganglion is fused with inferior cervical ganglion to form cervicothoracic or stellate ganglion, which lies in front of the neck of the first rib. The thoracic sympathetic chain lies on the heads of the succeeding ribs, posterior to the costal pleura. It leaves the thorax behind the medial arcuate ligament to become continuous with lumbar part of the sympathetic chain.

**Branches of Sympathetic Chain (Fig. 33.4)**

1. The upper five ganglia supply the thoracic aorta and its branches.
2. The pulmonary branches arise from second to sixth ganglia.
3. The cardiac branches arise from second to fifth ganglia.
4. The branches to the esophagus and trachea reach either directly or indirectly from plexuses.
5. The greater, lesser and least splanchnic nerves leave the thorax to supply the abdominal organs. They carry preganglionic sympathetic fibers for relay in the celiac ganglion in the abdomen.
   i. The greater splanchnic nerve arises from fifth to ninth ganglia and perforates the crus of diaphragm to enter the abdomen.
   ii. The lesser splanchnic nerve arises from ninth to tenth ganglia and pierces the diaphragm along with greater splanchnic nerve.
   iii. The least splanchnic nerve from the lowest ganglion enters the abdomen with the sympathetic chain.

**Visceral Afferent Fibers**

The visceral afferent fibers (from thoracic viscera) accompany the preganglionic and postganglionic sympathetic fibers and terminate in the dorsal root ganglia of the thoracic spinal nerves. They mediate pain and other nociceptive impulses to the spinal cord.

**Autonomic Plexuses in Thorax**

The autonomic plexuses are composed of the postganglionic sympathetic fibers, preganglionic parasympathetic fibers and small parasympathetic ganglia. The preganglionic parasympathetic fibers either synapse in these ganglia or synapse in the ganglia which are located in the wall of the viscera. Besides these, the plexuses contain visceral fibers.

**Superficial Cardiac Plexus**

This plexus is located on the ligamentum arteriosum below the arch of aorta. The superior cervical cardiac branch of left sympathetic chain and inferior cervical cardiac branch of left vagus nerve take part in its formation. This plexus is in communication with the deep cardiac plexus, right coronary plexus and left anterior pulmonary plexus.

**Deep Cardiac Plexus**

This plexus is located in front of the bifurcation of trachea. A large number of sympathetic and parasympathetic nerves take part into its formation as follows:

i. The middle and inferior cervical cardiac branches of left sympathetic chain and the superior, middle and inferior cervical cardiac branches of right sympathetic chain join the deep cardiac plexus.

ii. The cardiac branches of upper five thoracic ganglia from both sides join the deep plexus.

iii. The superior cervical cardiac branch of left vagus and superior and inferior cervical cardiac branches of right vagus contribute to the deep plexus.

iv. The cardiac branches of the right and left recurrent laryngeal nerves and the direct cardiac branches of right and left vagus nerves contribute to the deep plexus.

v. The deep cardiac plexus contains pain fibers from the ischemic myocardium. The pain impulse is carried in the cardiac branches of middle and inferior cervical sympathetic ganglia and cardiac branches of the thoracic ganglia to the upper thoracic spinal nerves and finally to the spinal cord via the dorsal root ganglia.

**Coronary Plexuses**

The right half of the deep cardiac plexus directly supplies branches to the right atrium and is in communication with right coronary plexus. The left half of the deep cardiac plexus is connected with superficial cardiac plexus and gives direct branches to the left atrium. It continues as the left coronary plexus.

**Pulmonary Plexuses**

The anterior and posterior pulmonary plexuses are located in respective relation to the hilum of the lungs. The thoracic branches of vagus and sympathetic trunk (upper four or five ganglia) take part in their formation. The two plexuses are interconnected. The network of nerves arising from the plexuses enters the lung along the bronchi, pulmonary and bronchial vessels. There are small ganglia in tracheobronchial tree, in which preganglionic vagal fibers synapse.

**Esophageal Plexus**

This plexus is composed of esophageal branches of fifth to ninth sympathetic ganglia, esophageal branches of both vagi and branches of the recurrent laryngeal nerves. The neurons in myenteric and Auerbach’s plexuses in the wall of the esophagus are the relay stations for parasympathetic fibers. Congenital absence of these neurons results in achalasia or cardiospasm.
The esophagus is a muscular tube about 25 cm long. It is continuous above with the laryngopharynx at the lower border of cricoid cartilage and below with the cardiac orifice of stomach. The main function of the esophagus is to transport food from the pharynx to the stomach.

Course (Fig. 34.1)
The esophagus passes through three regions of the body namely, neck, thorax and abdomen. Its thoracic part is the longest and the abdominal part the smallest. The course of the esophagus is not straight as it shows three curves. The esophagus follows the concavity of the thoracic vertebral column. At the root of the neck, it inclines to the left by 0.5 to 1 cm from the midline. It comes back in the midline at the level of fifth thoracic vertebra. Again, it deviates to the left below the seventh thoracic vertebra and inclines anteriorly to pass through the muscular part of diaphragm at the level of tenth thoracic vertebra.

Constrictions (Fig. 34.1)
There are four sites of constrictions or narrowing in the esophagus. The distance of each constriction is measured from the upper incisor teeth.

i. The first constriction at a distance of 15 cm is the pharyngoesophageal junction.

ii. The second constriction at a distance of 22.5 cm is produced by the arch of aorta.

iii. The third constriction at a distance of 27.5 cm is produced by left bronchus.

iv. The fourth constriction at a distance of 40 cm is the esophageal opening in the diaphragm.

Fig. 34.1: Distances of esophageal constrictions from incisor teeth (Note that vertebral extent of esophagus is from C6 to T11)
The constrictions are the likely sites where swallowed foreign bodies get stuck. These are the sites, where strictures develop after ingestion of caustic substances.

**Relations of Cervical Esophagus**

i. Anteriorly, the esophagus is related to the trachea and to the recurrent laryngeal nerves.

ii. Posteriorly, it is related to the prevertebral fascia and vertebral column.

iii. The common carotid artery and lateral lobe of thyroid are its lateral relations. In addition, on the left side it is related to the thoracic duct at the root of the neck.

**Relations of Thoracic Esophagus (Figs 34.2A and D)**

1. Anterior relations (from above downwards) are trachea, arch of aorta, right pulmonary artery, left principal bronchus, fibrous pericardium and oblique sinus (separating it from left atrium) and diaphragm. The close anterior relation of esophagus to left atrium is useful for trans-esophageal echography to examine the base of the heart.

2. The left lateral relations of esophagus are as follows:
   i. In the upper part of the superior mediastinum, it is related to left subclavian artery, thoracic duct, left recurrent laryngeal nerve and left pleura and upper lobe of left lung.
   ii. In the lower part of the superior mediastinum, its left edge is related to the arch of aorta.

3. In the posterior mediastinum, the descending aorta is on the left side in the upper part. The esophagus is also related to the left lung and pleura, where it makes an impression on the mediastinal surface of left lung behind the lower end of pulmonary ligament.

4. The right lateral relations of esophagus are as follows:
   i. The esophagus produces a shallow vertical groove behind the hilum and pulmonary ligament of right lung.
   ii. The arch of azygos vein is related at the level of sternal angle.
   iii. The descending thoracic aorta is related at the level of fifth thoracic vertebra.

5. The posterior relations of esophagus are as follows:
   i. In the superior mediastinum, the esophagus is related to thoracic vertebrae.
   ii. In the posterior mediastinum at the level of fifth thoracic vertebra, the thoracic duct crosses behind the esophagus.
   iii. Lower down, the descending aorta, thoracic duct and the azygos vein are posterior to the esophagus.
(Note: The esophagus has triple relations with descending aorta because it crosses in front of the aorta. It has triple relations with the thoracic duct because the duct crosses behind the esophagus. The esophagus comes in contact with the left lung twice but with the right lung only once).

**Relations to Vagus Nerves**

Below the level of pulmonary hilum, the right vagus is in contact with the posterior surface and the left vagus in contact with the anterior surface of the esophagus. These branches unite to form esophageal plexus along with the sympathetic branches.

**Relations at Esophageal Aperture in Diaphragm**

The esophagus passes through the muscular part of right crus of diaphragm at the level of tenth thoracic vertebra. The left vagus (now called anterior gastric nerve) is related anteriorly and the right vagus (now called posterior gastric nerve) is related posteriorly to it. The esophagus is also related to the esophageal branches of left gastric vessels.

**Abdominal Part of Esophagus**

This part is about two centimeter long and is the only part of the esophagus covered with peritoneum. It is related to the posterior surface of left lobe of liver anteriorly and to the left crus of diaphragm posteriorly. The right and left gastric nerves enter the abdomen lying along the posterior and anterior surfaces respectively.

**Lower Esophageal Sphincter**

There is no anatomical sphincter at the gastro-esophageal junction. There are two mechanisms that are believed to operate for preventing the gastro-esophageal reflux.

i. The lower esophageal sphincter shows a specialized area of circular smooth muscle, which possesses the physiological properties of the sphincter. The muscle in this area is maintained under tonic contractions by the intramural plexuses of enteric nervous system.

ii. The muscle fibers of the right crus of the diaphragm, which surround the terminal portion of the esophagus provide external sphincter.

iii. This combination provides an adequate antireflux barrier. This barrier is lowered momentarily during swallowing under normal conditions. It is also lowered during vomiting. If the intragastric pressure rises sufficiently, the acidic contents of the stomach regurgitate into the lower end of the esophagus, to be returned to the stomach by reflex peristalsis. The stratified squamous non-keratinized epithelium of the esophagus has no protective properties against gastric acid. This leads to reflux esophagitis, which causes burning pain behind the sternum, known as heartburn.

**Arterial Supply**

Several arteries at different levels supply the esophagus through an anastomotic chain on its surface.

i. The inferior thyroid arteries supply the cervical part of esophagus.

ii. The descending thoracic aorta and bronchial arteries supply the thoracic part of esophagus.

iii. The left gastric and left inferior phrenic arteries supply the abdominal esophagus.

**Venous Drainage**

i. The cervical part of esophagus drains into inferior thyroid veins.

ii. The thoracic part of esophagus drains into the azygos and hemiazygos veins.

**Clinical insight ...**

**Venous Drainage of Abdominal Part of Esophagus**

The abdominal part of esophagus is drained by left gastric vein, which is a tributary of portal vein. The veins of the lower thoracic part are systemic. Therefore, there is a potential portosystemic anastomosis between the two sets of veins at the lower end of esophagus in the submucosa. In patients with portal hypertension, the submucous venous plexuses are enlarged. Such dilated venous plexuses covered with mucosa are called esophageal varices. They protrude into the lumen of lower esophagus. They are asymptomatic until they rupture causing a large bout of blood vomiting (hematemesis).

**Lymphatic Drainage**

The cervical part of esophagus drains into deep cervical lymphnodes, its thoracic part drains into posterior mediastinal nodes and its abdominal part drains into left gastric nodes.

**Nerve Supply**

The sympathetic efferent fibers are vasoconstrictors. The parasympathetic efferent fibers are motor to the musculature of esophagus as well as to the esophageal glands. The striated muscle in the upper two-thirds receives nerve supply from vagus while the smooth muscle in the lower part receives nerve supply through the esophageal plexus. The sympathetic afferent fibers carry pain sensations. Most painful sensation from the esophagus originates from lower thoracic and abdominal parts since these parts are vulnerable to acid peptic esophagitis. The pain impulses reach T4 and T5 segments of the spinal cord along the afferent sympathetic paths. Hence, the esophageal pain is referred to the lower thoracic region and epigastric region of abdomen. In some cases, it is difficult to distinguish the esophageal pain from anginal pain.
The esophagus develops from the endoderm of the foregut. There are two crucial events in the development of the esophagus.

i. Separation from the laryngo-tracheal tube by formation of a laryngo-tracheal septum.
ii. Recanalization of obliterated lumen.

(Note: The muscle of the upper third of esophagus is striated like that of pharynx, the muscle of the middle third is the mixture of both striated and non-striated and that of the lower third is non-striated only).

**Anomalies**

i. Esophageal atresia is due to failure of recanalization of the esophagus. It is associated with hydramnios because the fetus is unable to swallow the amniotic fluid.

ii. Tracheoesophageal fistula or TEF (Fig. 25.6) is due to maldevelopment of the septum between the esophagus and the trachea. They are invariably associated with localized atresia of esophagus and hence hydramnios is a constant feature. In one type of fistula, the upper segment of the esophagus is blind but the lower segment communicates with the trachea just above the bifurcation by a narrow channel. This type occurs in 90 percent of cases. This fistula is characterized by cyanotic coughing attacks in neonate. The infant may cough up bile and the stomach is distended with air. In another type, the upper segment of esophagus communicates with the trachea and the lower segment ends blindly.

iii. Anomalous blood vessels (aberrant right subclavian artery shown in Figure 28.5) may cause dysphagia or may remain symptomless.

**Clinical insight ...**

i. Radiological examination of esophagus by barium swallow (Fig. 34.3) is used for detection of the enlargement of left atrium in mitral stenosis and also for esophageal diseases.

ii. Esophagoscopy is performed to directly inspect the interior of the esophagus. Utmost care should be exercised while passing the esophagoscope at the sites of constrictions.

iii. Dysphagia means difficulty in swallowing. Extrinsic causes of dysphagia are, pressure from aneurysm of aortic arch, enlarged lymph nodes, aberrant right subclavian artery (passing posterior to the esophagus), retrosternal goiter and enlarged left atrium. Intrinsic causes are strictures and carcinoma of esophagus.

iv. Carcinoma of esophagus (Fig. 34.4) usually spreads by lymphatics and involves posterior mediastinal nodes.

(contd...)
The direct spread through the wall of the esophagus can lead to involvement of lung, bronchi and aorta. The cancer from lower third of esophagus spreads to the gastric and celiac nodes in the abdomen.

v. The hiatus hernia (Fig. 26.8) is an acquired condition in which the stomach herniates into the posterior mediastinum through the esophageal hiatus in the diaphragm. The sliding variety of hiatus hernia is due to short esophagus. In this condition, the abdominal part of esophagus, cardioesophageal junction and part of fundus of the stomach enter the thorax. This may produce symptoms and the regurgitation of the acid contents in the esophagus results in peptic esophagitis. In rolling or paraesophageal hiatus hernia a part of the stomach enters the thorax but the cardioesophageal junction is normal in position. This type is usually symptomless.

vi. Achalasia cardia is primarily the disease in which lower esophageal sphincter fails to relax in response to swallowing. There is ineffective peristalsis or absence of peristalsis in the esophagus. This leads to impaired emptying and gradual dilation of proximal esophagus. The basic pathology is loss of parasympathetic ganglia in myenteric plexuses, formation of fibrous tissue in the wall of esophagus and thickening of lower esophageal sphincter. The symptoms consist of difficulty in swallowing solid foods and liquids, regurgitation of food and liquid during or after meals, feeling of fullness behind sternum after meals and retrosternal pain or heartburn. The barium swallow examination reveals the typical bird’s beak appearance or rat tail appearance of esophagus (Fig. 34.5) in which the dilated proximal segment represents the bird’s head and the tapered lower end its beak.

vii. Barrett’s esophagus is characterized by metaplasia (abnormal change) of esophageal epithelium from non-keratinized stratified squamous type to simple columnar type of intestinal epithelium in the lower esophagus. It is a complication of gastroesophageal reflux disease. The metaplastic changes are considered to be premalignant stage as there is a strong association between Barrett’s esophagus and adenocarcinoma (a lethal cancer) of esophagus.
Case 1
A 35-year-old man came to the hospital with complaints of severe pain in the right side of chest. The pain radiated down to the anterior abdominal wall. Auscultation of chest revealed absent breath sounds over the inferior lobe of the right lung and X-ray chest confirmed the presence of fluid in the pleural cavity on the right side.

Questions
1. Name the condition in which there is accumulation of fluid in the pleural cavity.
   Pleural effusion

2. Give the boundaries of the pleural cavity and its normal content.
   The pleural cavity is a potential space that is bounded by visceral and parietal layers of pleura. Normally, it contains very small quantity of serous fluid.

3. Name the various parts of parietal pleura giving nerve supply of each.
   The parietal pleura is subdivided into four parts, costal (costovertebral), mediastinal, diaphragmatic and cervical. The costal pleura is supplied by intercostal nerves, mediastinal by phrenic nerves and diaphragmatic by both intercostal and phrenic nerves.

4. Enumerate the differences in parietal and visceral pleura.
   The visceral pleura is adherent to the lung surface and dips into the fissures of the lung. It develops from splanchnopleuric mesoderm, hence it is supplied by autonomic nerves. It is pain insensitive. It shares its blood supply and lymph drainage with lung. The extensive parietal pleura lines the internal surface of thoracic wall, mediastinum and upper surface of diaphragm. It develops from somatopleuric mesoderm, hence it is supplied by somatic nerves (intercostal and phrenic nerves). It is pain sensitive. It shares its blood supply and lymph drainage with body wall.

5. Give explanation for radiation of pain to the anterior abdominal wall in this case.
   The parietal pleura lining the lower part of the thoracic cavity is supplied by lower five intercostal nerves, which also supply the anterior abdominal wall. In this case, the presence of fluid in the pleural cavity causes irritation of parietal pleura. Therefore, the pain from the chest is referred to the anterior abdominal wall.

6. Describe the pleural recesses.
   There are two pleural recesses, costomediastinal and costodiaphragmatic, which are described in chapter 25.

7. Name the layers (from outer to inner direction), which will be pierced by the needle inserted in the midaxillary line in 6th intercostal space to aspirate fluid from pleural cavity.
   The layers pierced by the needle are, skin, superficial and deep fasciae, serratus anterior muscle, intercostal muscles, endothoracic fascia and costal pleura.

Case 2
A 50-year-old male with a history of chronic smoking consulted the doctor because he had complaints of weight loss, persistent cough and blood in the sputum. He also noticed absence of sweating on the right side of face. On examination, partial ptosis and constriction of pupil were noted in the right eye. PA view of chest X-ray showed a lesion in the apex of right lung.
Questions

1. Name the clinical condition and the site of lesion.
   Malignancy (Cancer) of apex of right lung.

2. Name the posterior relations of apex of the lung in medial to lateral order.
   Sympathetic chain, highest intercostal vein, first posterior intercostal artery and ascending branch of T1 ventral ramus are related from medial to lateral side to the apex of lung.

3. Involvement of which of these is responsible for partial ptosis and constricted pupil?
   Sympathetic chain (producing Horner’s syndrome).

4. Draw a diagram to show the lymphatic drainage of the lungs.
   Refer to Fig. 25. 30.

5. Write briefly on the bronchopulmonary segments of right lung.
   The right principal bronchus divides into eparterial and hyparterial bronchi before entering the lung. Inside the lung, the eparterial bronchus divides into anterior, posterior and apical tertiary bronchi for upper lobe. Hence, in the upper lobe there are corresponding three segments. The hyparterial bronchus divides into middle lobar and inferior lobar bronchi inside the lung. The middle lobar bronchus divides into medial and lateral segmental bronchi for the corresponding bronchopulmonary segments of the middle lobe. The inferior lobar bronchus divides into five segmental bronchi, apical, superior basal, inferior basal, lateral basal and medial basal, corresponding to the five bronchopulmonary segments.

6. Which bronchopulmonary segment is most dependent in supine position?
   Apical (superior) bronchopulmonary segment of the lower lobe is most dependent in supine position.

7. Give the origin of bronchial arteries on right and left sides.
   i. On the right side, a single bronchial artery takes origin from right third posterior intercostal artery.
   ii. On the left side, two bronchial arteries take origin from descending thoracic aorta.

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Case 3

A 38-year-old man was brought to the casualty because of sudden onset of severe chest pain. On examination, his respiration and pulse were rapid. On auscultation, the heart sounds were faintly audible. X-ray chest showed a globular enlarged shadow suggestive of fluid around heart.

Questions

1. Name the space in which the fluid is accumulated giving its boundaries.
   Pericardial cavity is bounded by parietal and visceral layers of pericardium.

2. Name the outermost layer surrounding the heart and give its nerve supply.
   The fibrous pericardium is the outermost layer surrounding the heart. The phrenic nerve supplies it.

3. Give the boundaries of transverse sinus and its surgical importance.
   Transverse sinus is the space between the visceral pericardium covering the atria and the common sleeve of visceral pericardium surrounding ascending aorta and pulmonary trunk. It is a passage connecting the right and left halves of pericardial cavity hence lined by visceral pericardium only. It provides a space to the cardiac surgeon during ligation of ascending aorta and pulmonary trunk in the coronary artery bypass surgery.

4. Describe costoxiphoid approach to pericardial cavity.
   In costoxiphoid approach, the needle is inserted through the left costoxiphoid angle in upward and backward direction. It passes through the rectus sheath and the central tendon of diaphragm to enter the pericardial cavity. The advantage of this approach is that it avoids pleura since the line of pleural reflection does not cross the costoxiphoid angle on left side.

5. What is area of cardiac dullness?
   The area of cardiac dullness is the bare area of pericardium, which is dull on percussion. It is located to the left of the sternal margin from 4th to 6th costal cartilages. This area is not covered with lung due to the presence of cardiac notch in the anterior margin of left lung. Hence, it is dull on percussion.
Case 4
A 30-year-old woman with a history of rheumatic fever in childhood came to the hospital with complaints of dyspnea (shortness of breath) for three months. On auscultation, a prominent mid diastolic murmur was heard. Echocardiography confirmed the narrowing of mitral orifice and dilatation of left atrium.

Questions

1. What is the probable condition involving the mitral valve?
   Mitral stenosis

2. Give the surface marking of the mitral valve.
   The mitral valve is marked on the left half of sternum at the level of 4th costal cartilage.

3. What is the posterior relation of left atrium?
   Esophagus

4. What is the significance of this relationship in mitral stenosis?
   The enlarged left atrium compresses the esophagus, which can be detected in barium swallow radiograph. The compression of esophagus results in dysphagia.

5. Give the developmental sources of left atrium.
   The left atrium develops from left half of primitive atrium, absorbed parts of pulmonary veins and left half of atrioventricular canal.

Case 5
An elderly patient presented with a pulsating swelling protruding from the upper margin of the sternum. On examination, the sign of tracheal tug was positive. The CT scan of chest and aortic angiography showed localized dilatation of aortic arch.

Questions

1. Name the clinical condition.
   Aneurysm of aortic arch

2. What is the location of arch of aorta in thoracic cavity?
   Superior mediastinum

3. What are the boundaries of this location?
   i. Anteriorly - Manubrium sterni.
   ii. Posteriorly - Upper four thoracic vertebrae.
   iii. Superiorly - Thoracic inlet.
   iv. Inferiorly - Lower limit is the plane passing through the disc between the fourth and fifth thoracic vertebrae.
   v. Laterally - Mediastinal pleura.

4. Name the structures, which are likely to be compressed by the dilated aortic arch.
   The structures likely to be compressed are superior vena cava, trachea, esophagus, phrenic nerves, left recurrent laryngeal nerve, etc.

5. Describe the relations of the arch of aorta with the help of diagram.
   For relations of arch of aorta refer to chapter 32.

6. Give the developmental sources of the arch of aorta.
   The arch of aorta develops from aortic sac, left horn of aortic sac, left fourth arch artery and left dorsal aorta

7. Name the connection between the arch of aorta and the left pulmonary artery in the fetus and in the adult.
   In the fetus, the arch of aorta is connected to left pulmonary artery by means of ductus arteriosus and in the adult the two are connected by ligamentum arteriosum, which is a remnant of the ductus arteriosus.

Case 6
A 58-year-old woman complained of dysphagia (difficulty in swallowing) for the duration of one month. Ba-swallow and esophagoscopy were performed. A biopsy taken from the lesion in the lower-third of esophagus confirmed the diagnosis of malignancy.

Questions

1. What is the vertebral extent of esophagus?
   Vertebral extent is from C6 to T11

2. Name the structures that produce constrictions in the esophagus.
   First constriction located at upper end of esophagus is produced by cricopharyngeus muscle, second by arch
of aorta, third by left bronchus and the lowest at the esophageal hiatus in diaphragm.

3. **Describe the lymphatic drainage of esophagus.**
   Refer to chapter 34

4. **Name the congenital vascular anomalies, which give rise to dysphagia.**
   Double aortic arch and aberrant right subclavian artery (chapter 28).

5. **Describe the arterial supply of esophagus.**
   The cervical part of esophagus receives branches from inferior thyroid arteries and the thoracic esophagus receives branches from bronchial arteries and from descending aorta. The lower part of esophagus receives branches from left gastric artery.

6. **What is the length of abdominal esophagus?**
   Two centimeter

7. **Give clinical importance of lower esophageal sphincter.**
   The failure of LES to relax during swallowing results in achalasia cardia. Achalasia cardia is primarily the disease of esophagus in which lower esophageal sphincter fails to relax in response to swallowing. There is ineffective peristalsis or absence of peristalsis in the esophagus. This leads to impaired emptying and gradual dilatation of proximal esophagus. The basic pathology is loss of parasympathetic ganglia in myenteric plexuses in the wall of esophagus. The symptoms include gradually increasing difficulty in swallowing solid foods and liquids, regurgitation of food and liquid during or after meals, a feeling of fullness behind sternum after meals and retrosternal pain or heartburn. The barium swallow examination reveals the typical bird's beak appearance or rat tail appearance of esophagus (dilated proximal segment representing the bird's head and the tapered lower end its beak). Achalasia cardia is treated with pneumatic dilation of lower esophageal sphincter or endoscopic balloon dilation or myotomy.

**Case 7**

A 15-year-old girl came to the hospital with complaints of reduced exercise tolerance (feeling weak after slight exertion), leg cramps on walking and shortness of breath. On examination, radiofemoral delay was noted and BP in upper limb was 120/70 mm of Hg and in lower limb was 90/60 mm of Hg. Chest X-ray showed rib notching. Echocardiography showed narrowing of arch of aorta beyond attachment of ligamentum arteriosum.

**Questions**

1. **Name the condition in which there is localized narrowing in the arch of aorta.**
   Coarctation of aorta

2. **Explain how the descending aorta is filled with blood in this condition.**
   In postductal type of coarctation, the descending aorta receives blood from enlarged and tortuous posterior intercostal arteries of third to ninth spaces. These arteries receive blood from the anastomoses with anterior intercostal arteries from internal thoracic and its musculophrenic branch.

3. **In which arteries there is reversal of blood flow in this condition?**
   There is reversal of blood flow in posterior intercostal arteries.

4. **Give reason for notching of ribs.**
   The dilated and tortuous posterior intercostal arteries erode the ribs in the costal groove.

5. **Give the origin of anterior and posterior intercostal arteries in upper eleven intercostal spaces.**
   The first and second spaces receive posterior intercostal arteries from superior intercostal artery (branch of costocervical trunk of subclavian artery).
   The third to eleventh spaces receive posterior intercostal arteries directly from descending aorta.
   The first to sixth spaces receive a pair of anterior intercostal arteries from the internal thoracic artery.
   The seventh, eighth and ninth spaces receive anterior intercostal arteries from musculophrenic artery.

6. **Name an important visceral branch of right third intercostal artery.**
   Right bronchial artery

**CASE 8**

A newborn baby had difficulty in breathing. On examination, the child was cyanotic and breath sounds were feeble on left side. There was mediastinal shift towards right
(causing compression of the right lung). The abdomen of the baby was concave (scaphoid shaped). X ray chest showed intestinal shadows into the left half of chest cavity.

1. Which anatomical structure showed the defect through which intestines herniated in chest?
   Diaphragm

2. Name the common site of defect.
   Costovertebral triangle on left side (Bochdalek’s foramen).

3. Explain the embryological basis of the above defect.
   The diaphragm is composite, since it develops from four different sources.
   i. Septum transversum
   ii. Pleuroperitoneal membranes (right and left)
   iii. Dorsal mesentery of esophagus
   iv. Body wall mesoderm
   The muscle of diaphragm develops from third, fourth and fifth cervical myotomes. This is the reason why phrenic nerve with root value (C3, C4, C5) supplies the muscle of diaphragm.
   The site of the defect is between the vertebral and costal origin of diaphragm. This is the site of pleuroperitoneal canal connecting the embryonic pleural and peritoneal cavities. During development of diaphragm, these canals are closed by development of pleuroperitoneal membranes. Failure of the pleuroperitoneal canal to close by nondevelopment of pleuroperitoneal membrane (usually on the left side) leads to deficiency at this site and the herniation of abdominal contents into the thoracic cavity. This is known as posterolateral hernia.

4. Write briefly on the attachments of the defective structure.
   The origin of diaphragm is circumferential coinciding with thoracic outlet. It is subdivided into three parts, sternal, costal and vertebral.
   i. The sternal origin is by two fleshy slips from back of xiphoid process.
   ii. The costal origin is from inner surfaces of lower six ribs (7th to 12th ribs).
   iii. The vertebral origin is from bodies of lumbar vertebrae by crura and by arcuate ligaments.
   The longer right crus is attached to anterior surface of the bodies of first three lumbar vertebrae and the intervening discs. The shorter left crus is attached similarly to the first two lumbar vertebrae and intervening disc. There are three arcuate ligaments (median, medial and lateral) that give origin to diaphragm. The median arcuate ligament is the one that connects the two crura. The medial arcuate ligaments (medial lumbarcostal arches) are a pair of ligaments on either side formed by thickening of psoas fascia. Each medial arcuate ligament extends from the body of first lumbar vertebra to the tip of transverse process of the same vertebra. The lateral arcuate ligaments (lateral lumbarcostal arches) are a pair of ligaments on either side formed by thickening of anterior layer of thoracolumbar fascia. Each lateral arcuate ligament extends from the tip of transverse process of first lumbar vertebra to the lower border of twelfth rib.
   The diaphragm is inserted into the central tendon of diaphragm. The central tendon is shaped like trefoil leaf and is located closer to the sternal origin. It blends superiorly with the base of fibrous pericardium.

5. Through which of the openings of this structure, herniation cannot occur and what is the reason for it?
   Diaphragmatic herniation cannot occur through vena caval opening because this opening is in the central tendon of diaphragm and the wall of the vena cava is firmly attached to the central tendon.

CASE 9
A 48-year-old bank manager used to spend his evenings watching TV and eating fried delicacies and ice-cream. One day in the middle of watching football match, he went down to the kitchen to bring chips. While climbing the steps he felt uneasiness in the left side of his chest. He felt better after resting. When he consulted his doctor he was advised coronary angiogram.

1. What is the origin of coronary arteries?
   The coronary arteries are the branches of ascending aorta. The right coronary artery begins at anterior aortic sinus and left coronary artery begins at left posterior aortic sinus.

2. Mention the physiological peculiarity of these arteries.
   Unlike other systemic arteries, coronary arteries fill during diastole.

3. What is the purpose of coronary angiography?
   Coronary angiography is a radiological procedure by which dye is injected into them to visualize the blocks or narrowing in the main arteries and their branches.
4. Describe the commonly used anatomical path to reach the coronary arteries to inject the dye.

The femoral artery is relatively superficial in position in the thigh, hence it is preferred for coronary angiography. The catheter is introduced into the femoral artery and then in succession it ascends in the external iliac artery, common iliac artery, abdominal aorta, descending thoracic aorta, arch of aorta and the ascending aorta to reach the aortic sinuses. Here, the dye is injected into the coronary ostia. The radiographs are taken after this procedure to study the anatomy of coronary arteries.

5. What is the difference between angina pectoris and myocardial infarction?

In angina pectoris, there is mismatch between demand and supply of blood to myocardium. It means due to temporary narrowing of coronary arteries the myocardium does not receive sufficient blood, hence pain is felt. In myocardial infarction, the arterial supply to myocardium is totally cut off, which results in infarction (necrosis).

6. Which blood vessels from patient’s body can be used for coronary artery bypass?

Long saphenous vein, internal mammary artery and radial artery are used for coronary artery bypass.

7. Write briefly on venous drainage of heart.

There are three major veins, which drain blood from the myocardium.

i. The coronary sinus is the chief vein of the heart. It collects venous blood from the myocardium and empties it into the right atrium.

ii. There are three or four anterior cardiac veins, which directly open into the anterior part of the right atrium.

iii. The venae cordis minimae (Thebesian veins) are scattered all over the myocardium and open directly in all the cardiac chambers.

Coronary Sinus

This is a short and wide venous channel located in the posterior part of coronary sulcus between the left atrium and left ventricle. The myocardial fibers from the atrium often cover it superficially.

Origin and Termination

The coronary sinus begins as the continuation of the great cardiac vein at the left end of the coronary sulcus. It opens into the smooth part of right atrium. The opening of the coronary sinus is guarded by a small valve (Thebesian) and is located between the IVC opening and the right A-V orifice.

Tributaries

i. Great cardiac vein
ii. Middle cardiac vein
iii. Small cardiac vein
iv. Posterior vein of left ventricle
v. Oblique vein of left atrium or oblique vein of Marshall

CASE 10

A 10-year-old girl was referred to cardiologist after finding a systolic murmur over pulmonary area by a general practitioner. On echocardiography, an atrial septal defect (ASD) was noticed. Cardiac catherization showed the pulmonary blood flow much greater than aortic blood flow. The girl was posted for surgical repair.

1. Describe the internal features of right atrium

The cavity of the right atrium is divisible into three parts (sinus venarum or smooth part, rough part, and vestibule or floor).

a. The sinus venarum is the smooth posterior part, which receives venous blood and hence shows following openings:

i. The superior vena caval opening is located at the roof of the right atrium. An intervenous tubercle located below this opening, directs the superior vena caval blood to the tricuspid orifice in fetal life.

ii. The inferior vena caval opening (guarded by a small Eustachian valve) is at the lowest and posterior part of the atrium.

iii. The opening of coronary sinus is located between the opening of IVC and the tricuspid orifice.

iv. There are multiple small openings of venae cordis minimae scattered all over the atrial walls.

b. The right atrium proper and the auricle, which is its rough anterior part presents important features, such as:

i. The crista terminalis is a C-shaped muscular ridge. It starts on the upper part of the interatrial septum, passes in front of the SVC opening and then turns along its lateral margin downward to reach the opening of the IVC. It demarcates the rough and smooth parts of the right atrium and coincides with the sulcus terminals on the outer aspect of the atrium.

ii. The musculi pectinati (so called because of resemblance to comb) are the parallel muscular ridges extending from the crista into the right auricle. The dense trabeculations of musculi pectinati
inside the right auricle makes it a potential site for thrombi formation. The thrombi dislodged from the right atrium enter the pulmonary circulation and may produce pulmonary embolism.

iii. The SA node is located in the right atrial wall in subepicardial position at the upper end of the sulcus terminalis close to the opening of the superior vena cava.

iv. The anterior cardiac veins open into the anterior aspect (rough part) of the atrium.

c. The vestibule of the tricuspid valve is the anteroinferior part (floor) of the right atrium, which leads into the tricuspid orifice. It shows three features:

i. The Koch’s triangle is an identifiable landmark in the right atrium during surgery. Its three boundaries are: The valve of coronary sinus (posteriorly), tendon of Todaro (superiorly), and the attached margin of the septal cusp of tricuspid valve (anteriorly). The AV node lies at the apex of this triangle. However, the majority of texts describe its location in the lower part of interatrial septum.

ii. The atrioventricular membranous septum is located anterosuperior to the tendon of Todaro. It intervenes between the right atrium and the left ventricle.

iii. The torus aorticus is the bulge in the atrial wall above the atrioventricular membranous septum, produced due to the adjacent noncoronary aortic sinus at the base of ascending aorta.

**Interatrial Septum**

The interatrial septum forms the septal or posteromedial wall of the right atrium. The septal wall shows fossa ovalis, which is an ovoid, membranous and depressed portion. A curved ridge called the limbus fossa ovalis forms the superior, right and left margins of the fossa ovalis.

2. **Describe the development of interatrial septum.**

   i. At first, a thin septum primum from the roof of the common atrium near the midline, grows down gradually towards the septum intermedium. The steadily narrowing gap between the septum primum and septum intermedium is called foramen primum or ostium primum.

   ii. Before the fusion of septum primum and septum intermedium and consequent closure of the foramen primum, the upper part of the septum primum breaks down to form foramen secundum or ostium secundum.

   iii. A thick septum secundum (to the right of the septum primum) grows from the roof of the atrial chamber, in the downward direction until it covers the foramen secundum on its right side.

   iv. The oblique gap between the lower margin of septum secundum and the upper margin of septum primum is called foramen ovale. This foramen short circuits the inferior vena caval blood to the left atrium. The flow of blood is unidirectional from the right atrium to the left atrium only. The septum primum acts as a flap valve since the pressure is greater in the right atrium than in the left in the fetal life. The foramen ovale closes after birth. This is accomplished as follows. The rise in the left atrial pressure soon after establishment of pulmonary circulation keeps the septum primum pressed against the septum secundum until they fuse. The septum primum becomes the floor of fossa ovalis and the lower margin of the septum secundum forms the limbus fossa ovalis. The functional closure of the foramen ovale occurs immediately after birth while the anatomical closure occurs 6 to 12 months after birth.

3. **Explain embryological types of ASD.**

   There are three types of ASD resulting in left to right shunts.

   i. The ostium secundum defect is one of the most common congenital heart defects. The persistence of the foramen secundum is due to excessive resorption in the septum primum or due to failure of development of septum secundum.

   ii. The ostium primum defect is due to either the failure of the septum primum to reach the endocardial cushions or due to defect in the endocardial cushions, so that foramen primum persists.

   iii. Patent foramen ovale is due to failure of the septum primum and secundum to fuse after birth. This is extremely rare.

   In ASD, there is increased load on the right side of the heart leading to progressive enlargement of right atrium, right ventricle and the pulmonary trunk. The disease manifests as effort intolerance (fatigue and breathlessness on exertion) in the third or fourth decade of life and thereafter. The atrial septal defects can be corrected by surgery.

4. **What is the significance of the finding of cardiac catheterization in this case?**

   In normal persons, the aortic blood flow is significantly higher than pulmonary trunk blood flow. In the presence of ASD, blood flows from left atrium to right atrium overloading the pulmonary trunk.

5. **What is the arterial supply of SA and AV nodes?**

   The SA node is supplied by SA nodal branch of right coronary artery. The AV node is supplied by septal branches of right coronary artery.
1. Which of the following is a typical intercostal nerve?
   a. 1st
   b. 2nd
   c. 3rd
   d. 7th

2. The right bundle branch (RBB) travels in
   a. Triangle of Koch
   b. Moderator band
   c. Membranous interventricular septum
   d. Supraventricular crest

3. Crista terminalis is a feature of
   a. Right ventricle
   b. Left ventricle
   c. Right atrium
   d. Left atrium

4. The phrenic nerve supplies all the following except
   a. Fibrous pericardium
   b. Parietal layer of pericardium
   c. Pulmonary pleura
   d. Mediastinal pleura

5. The most anterior valve of the heart is
   a. Mitral
   b. Tricuspid
   c. Pulmonary
   d. Aortic

6. Conducting tissue of the heart is a modification of
   a. Epicardium
   b. Myocardium
   c. Endocardium
   d. Nerve fibers

7. Which of the following is related to the arch of aorta on its right side?
   a. Left phrenic nerve
   b. Right phrenic nerve
   c. Left recurrent laryngeal nerve
   d. Right recurrent laryngeal nerve

8. The lower margin of the lung cuts the following rib in midaxillary line.
   a. 6th
   b. 8th
   c. 10th
   d. 12th

9. The horizontal fissure runs along
   a. Right 4th rib anteriorly
   b. Left 4th rib anteriorly
   c. Right 5th rib posteriorly
   d. Left 5th rib posteriorly

10. The right margin of cardiac shadow in a radiograph is formed by all the following except
    a. Superior vena cava
    b. Right brachiocephalic vein
    c. Right ventricle
    d. Right atrium

11. The ductus arteriosus develops from
    a. Proximal segment of right sixth arch artery
    b. Proximal segment of left sixth arch artery
    c. Distal segment of right sixth arch artery
    d. Distal segment of left sixth arch artery

12. What is not true regarding the carina?
    a. Mucosa most sensitive
    b. Located at tracheal bifurcation
    c. Is the mucosal thickening
    d. Visible in bronchoscopy

13. Which of the following is not related to superior surface of first rib?
    a. Ventral ramus of T1
    b. Lower trunk of brachial plexus
    c. Subclavian artery
    d. Subclavian vein

14. Foramen secundum is present in
    a. Septum secundum
    b. Septum primum
    c. Septum intermedium
    d. Septum spurium

15. The thymus is located in the following
    a. Superior and anterior mediastinum
    b. Superior and middle mediastinum
    c. Anterior and middle mediastinum
    d. Middle mediastinum

16. The diaphragmatic hernia can occur in the following sites except
    a. Esophageal opening
    b. Bochdalek triangle
    c. Foramen of Morgagni
    d. IVC opening
17. An unconscious patient involved in a major car accident was brought to the casualty with an injury of sharp object on his chest in the middle of the sternum at the level of fourth costal cartilage. Which chamber of his heart is likely to be punctured?
   a. Left atrium  
   b. Left ventricle  
   c. Right atrium  
   d. Right ventricle

18. The greater splanchnic nerve carries following fibers
   a. Preganglionic parasympathetic 
   b. Preganglionic sympathetic 
   c. Postganglionic parasympathetic 
   d. Postganglionic sympathetic

19. The acute margin of heart is
   a. Inferior  
   b. Superior  
   c. Left  
   d. Right

20. The foramen of Bochdalek occurs due to failure of formation of
   a. Septum transversum  
   b. Mesoderm of body wall  
   c. Ventral mesentery of esophagus  
   d. Pleuroperitoneal membrane

21. A man was stabbed in the back with a knife. The tip of the knife pierced the left lung halfway between apex and base. The part of the lung that is pierced is
   a. Hilum  
   b. Lingula  
   c. Inferior lobe  
   d. Superior lobe

22. A stethoscope placed on the left second intercostal space just lateral to the sternal margin is best positioned to hear sounds of which cardiac valve?
   a. Mitral 
   b. Tricuspid 
   c. Pulmonary 
   d. Aortic

23. Postoperatively, a 50-year-old woman suddenly developed respiratory distress and cyanosis. She had blood in sputum. These signs and symptoms are indicative of embolism in which blood vessel?
   a. Pulmonary artery  
   b. Bronchial artery  
   c. Bronchial vein  
   d. Pulmonary vein

24. Which of the following pleura forms the pulmonary ligament?
   a. Visceral  
   b. Mediastinal  
   c. Costal  
   d. Diaphragmatic

25. The following structures pass along with aorta at aortic orifice of diaphragm.
   a. Vagus nerves and hemiazygos vein  
   b. Vagus nerves and accessory hemiazygos vein  
   c. Thoracic duct and azygos vein  
   d. Thoracic duct and hemiazygos vein

Key to MCQs
1-c, 2-b, 3-c, 4-c, 5-c, 6-b, 7-c, 8-b, 9-a, 10-c, 11-d, 12-c, 13-a, 14-b, 15-a, 16-d, 17-d, 18-b, 19-a, 20-d, 21-c, 22-c, 23-a, 24-b, 25-c
HEAD AND NECK
The skull protects the brain and meninges and also forms facial skeleton. The skull is divided into three parts, calvaria or brain box, facial skeleton and mandible. The cranium is skull minus the mandible. The skull consists of twenty-two bones of which eight belong to calvaria and fourteen belong to facial skeleton.

**Bones of Calvaria**
1. Paired parietal bones
2. Paired temporal bones
3. Frontal
4. Occipital
5. Ethmoidal

**Bones of Facial Skeleton**
1. Paired maxillae
2. Paired zygomatic
3. Paired nasal
4. Paired lacrimal
5. Paired palatine
6. Paired inferior conchae (or turbinate)
7. Vomer
8. Mandible.

The cranial bones unite with each other by joints. The most common type of joint encountered in skull is suture (a subtype of fibrous joint). The joint between the rostrum of sphenoid and the ala of vomer is a special type of fibrous joint called schindylesis. The body of sphenoid bone and basilar part of occipital bone unite by primary cartilaginous joint. This joint allows the growth in anteroposterior direction of the base of the cranium. It is ossified during 18 to 25 years.

The mandible is the only mobile bone of the skull as it articulates by bilateral synovial temporomandibular joints with the mandibular fossa of temporal bone.

**External Features of Skull**
The external features of skull are studied by subdividing the skull into various regions named as follows:
1. Norma verticalis or superior view
2. Norma frontalis or anterior view
3. Norma occipitalis or posterior view
iv. Norma lateralis or lateral view
v. Norma basalis or inferior view.

**Norma Verticalis**
The norma verticalis is the vault of the skull. It is covered with scalp. It consists of three bones, frontal bone, parietal bones and occipital bone in anteroposterior order.

Characteristic Features of Norma Verticalis
i. Sagittal suture intervenes between the two parietal bones.
ii. Coronal suture intervenes between the frontal bone in front and the parietal bones behind.
iii. Lambdoid suture is present between the parietal bones and occipital bone posteriorly.
iv. Vertex is the highest point of the skull on sagittal suture.
v. Bregma is the meeting point of coronal and sagittal sutures. It corresponds to the anterior fontanelle of fetal skull.
vi. Lambda is the meeting point of the sagittal and lambdoid sutures. It corresponds to posterior fontanelle of fetal skull.
vii. The parietal emissary foramen is seen on each side of midline in front of the lambda.
viii. The superior and inferior temporal lines begin at the zygomatic process of frontal bone as a single line. Soon the single line divides into superior and inferior temporal lines, which arch backwards crossing the coronal suture and the parietal bone (temporal lines are mainly present on parietal bone). The superior temporal line provides attachments to temporal fascia and galea aponeurotica. The inferior temporal line marks the upper limit of the origin of temporalis muscle.

**Norma Frontalis (Fig. 36.1)**
The facial aspect of the skull is called norma frontalis.

Bones of Norma Frontalis
i. The frontal bone is the skeletal basis of forehead. The metopic suture separates the two frontal bones up to the age of six to eight years.
ii. The maxillae take part in forming the margins of orbit, nasal cavity and oral cavity.
iii. The body of zygomatic bone (cheekbone) forms the prominence of cheek.
iv. The nasal bones form the nasal bridge, which is located in between the two orbits.
v. The movable mandible (lower jaw) is the lower part of norma frontalis.

Prominent Features
The orbits (two bony sockets for the eyeballs) and the bony anterior nasal aperture between the orbits are the prominent features of the norma verticalis.

i. Each orbital opening is quadrangular in shape. It has four margins. The supraorbital margin is palpable. At the junction of its lateral two-thirds and medial one-third it presents the supraorbital notch or foramen for the passage of supraorbital nerve and vessels. The compression of supraorbital nerve at the foramen causes intense pain. This fact is utilized to determine the depth of anesthesia or to arouse an unconscious patient. The lateral orbital margin has frontozygomatic suture, which is a palpable landmark useful in surface marking of middle meningeal artery.

ii. The anterior nasal aperture is in the midline. It is bounded superiorly by lower margins of nasal bones and inferolaterally by nasal notches of right and left maxillae. The margins of the nasal aperture give attachment to nasal cartilage.

General Features of Norma Frontalis
i. The superciliary arch is a curved elevation in the frontal bone just above the medial part of the upper margin of the orbit. It is more prominent in males.
ii. The glabella is a median elevation connecting the right and left superciliary arches.
iii. The nasion is an important landmark useful in surface marking. It is a meeting point of the frontonasal and internasal sutures at the root of the nose.

iv. The maxilla is present on either side of nasal cavity. Its anterior surface presents, infraorbital foramen.

v. The canine fossa is present below the infraorbital foramen and is used for anterior approach to the maxillary sinus through the vestibule of mouth. The incisive fossa is present above the upper incisor tooth.

vi. The infraorbital foramen gives passage to infraorbital nerve and vessels.

vii. The zygomatic bone is located below and lateral to the orbit. It is marked by zygomaticofacial foramen, through which nerve and vessels of the same name emerge.

**Norma Occipitalis**

The posterior portion of the skull is known as norma occipitalis.

**Features**

i. The lambdoid suture is a prominent landmark.

ii. The occipitomastoid suture is present between the occipital and mastoid bones.

iii. Asterion is the meeting point of lower end of lambdoid suture, parietomastoid suture and the occipitomastoid suture.

iv. The external occipital protuberance is a palpable landmark at the upper limit of the median furrow at the back of neck. It gives origin to trapezius and attachment to ligamentum nuchae.

v. Inion is the most prominent point of the external occipital protuberance.

vi. The superior nuchal line extends from the protuberance on each side. Its medial third gives origin to trapezius and lateral part provides insertion to sternomastoid and splenius capitis muscles.

vii. The highest nuchal line, which is more arched, extends from the protuberance on either side above superior nuchal line. The galea aponeurotica is attached to its medial one-third and occipital belly of occipitofrontalis originates from its lateral two-thirds.

viii. The external occipital crest extends below the protuberance to the foramen magnum and gives attachment to ligamentum nuchae.

ix. The inferior nuchal lines go laterally from the middle of the crest on each side.

x. Mastoid emissary foramen is located near occipitomastoid suture.

**Norma Lateralis (Fig. 36.2)**

The features of the bones of skull seen from the lateral side of the skull constitute the norma lateralis. Several bones take part in its formation.

**Features**

The temporal lines are the common features of norma verticalis (vide supra) and norma lateralis.

![Fig. 36.2: Features of norma lateralis](image)
Temporal Fossa
The temporal fossa is the region between the temporal lines above and the zygomatic arch below. It is in communication with infratemporal fossa behind the zygomatic arch. A tiny zygomaticotemporal foramen is present on the surface of zygomatic bone facing the temporal fossa. The temporal fossa gives origin to temporalis muscle.

Pterion
The pterion is situated in the floor of temporal fossa. It is an H-shaped suture, where four bones, namely, the greater wing of sphenoid, squamous temporal, frontal and antero-inferior angle of parietal meet each other. The central point of pterion is situated 4 cm above the zygomatic arch and 3.5 cm behind the frontozygomatic suture. This point is known as Sylvian point. The cranium is very thin at this point. Its immediate deep relations are the frontal branch of middle meningeal artery, its accompanying vein and stem of lateral sulcus of brain. Fracture or even a blow at this point may injure middle meningeal artery or vein and give rise to extradural bleeding.

Zygomatic Arch
The zygomatic arch is prominent. The lateral surface of this arch is subcutaneous. It is formed by temporal process of the zygomatic bone and the zygomatic process of temporal bone. The weakest point of the arch is just behind temporo-zygomatic suture. The superficial temporal vessels and the auriculotemporal nerve cross the root of the zygomatic arch just in front of the auricle. The artery can be felt at this site (especially by the anesthetist, who sits at the head end of the patient during operation). The posterior end of its lower border presents a tubercle (of root of zygoma). At the root of zygoma the arch divides into anterior and posterior roots. The anterior root turns downwards and medially to form the articular tubercle, which lies in the anterior boundary of mandibular fossa. The posterior root continues with supramastoid crest. The zygomatic arch gives origin to masseter muscle and attachment to temporal fascia.

External Acoustic Meatus
It is located below the posterior root of zygoma and behind the mandibular fossa. It is formed by the tympanic plate of the temporal bone on all sides except the posterosuperior margin, which is formed by the squamous temporal bone. Its irregular margin gives attachment to cartilaginous part of external acoustic meatus.

Suprameatal Triangle (Macewen’s Triangle)
It is located posterosuperior to external acoustic meatus (Fig. 51.8). Its boundaries are as follows:

i. Superiorly by supramastoid crest.
ii. Anteriorly by posterosuperior margin of the external acoustic meatus.
iii. Posteriorly by a vertical tangent to the posterior margin of meatus. Since, the suprameatal triangle forms the lateral wall of the mastoid antrum, pus in the antrum can be drained through it.

Mastoid Process
The mastoid process (a projection from the mastoid part of the temporal bone) is located below and behind the external acoustic meatus. It is absent in fetal skull and appears by the age of two years. Apart from muscular attachments (sternomastoid, splenius capitis, longissimus capitis and posterior belly of digastric) the important vascular relation of the mastoid process is the occipital artery, which grooves the bone on its inner aspect.

Styloid Process
It is an elongated process below the external meatus and in front of mastoid process. It provides attachments to two ligaments (stylomandibular and stylohyoid) and three muscles (stylohyoid, styloglossus and stylopharyngeus). It is related to facial nerve. An unusually long styloid process comes in contact with lateral wall of oropharynx. Hence, it is felt through tonsillar fossa and is surgically approached through the same fossa.

Stylomastoid Foramen
This foramen is located between the styloid process medi ally and mastoid process laterally. It transmits the facial nerve. Immediately after its exit the facial nerve is related to the base of styloid process on its lateral aspect. The osteology of infratemporal fossa and pterygopalatine fossa is described in chapter 45.

Norma Basalis (Fig. 36.3)
The basal aspect of the cranium is called norma basalis.

Subdivisions
For descriptive purposes the norma basalis is subdivided into three parts: anterior, intermediate (middle) and posterior.

Anterior Part of Norma Basalis
1. The hard palate is the prominent feature anteriorly. It is composed of the palate processes of maxillae (anterior two-thirds) and the horizontal processes of the palatine bones (posterior one-third). These four processes are joined by a cruciform suture. The free posterior margin of the hard palate presents the
posterior nasal spine in the middle. The musculus uvulae muscle is attached to this spine.

2. The alveolar arch is formed by alveolar processes of the maxillae containing sockets for upper teeth.
   i. The triangular area of alveolar arch carrying the upper four incisor teeth is called premaxilla. The latter develops from palatal part of globular process of frontonasal process as against the rest of hard palate. This is the reason for separation of premaxilla in congenital cleft palate.
   ii. The incisive fossa is present in the midline behind the sockets of the incisor teeth. The walls of fossa present two incisive foramina. Each foramen transmits the greater palatine vessels (from the palate to the nasal cavity) and the nasopalatine (sphenopalatine) nerve (from the nasal cavity to the palate).
   iii. The greater palatine foramen is present posteriorly nearer the alveolar process. It transmits greater palatine nerves and vessels, which travel anteriorly in a groove towards the incisive fossa.
   iv. The lesser palatine foramen is seen in the pyramidal process of the palatine bone. It transmits nerves and vessels of the same name.

Intermediate Part of Norma Basalis
The norma basalis is described under two subdivisions, midline area and lateral areas.

1. The midline area presents following features from before backwards:
   i. The posterior free margin of vomer separates the two posterior nasal apertures (choanae).
   ii. Inferior margin of the vomer articulates with the superior surface of hard palate.
   iii. The superior margin of vomer splits into two alae, which articulate with the rostrum of sphenoid projecting from the body of sphenoid.
   iv. The midline bar of bone posterior to the alae is the union between the body of sphenoid and the basilar part of the occipital bone. This area extends up to foramen magnum and forms the roof of nasopharynx and hence related to pharyngeal tonsil.
   v. The basilar part of the occipital bone shows a pharyngeal tubercle in front of the foramen magnum. This tubercle indicates the posterior limit of the nasopharynx at the base of cranium. It gives attachment to highest fibers of superior constrictor muscle and pharyngeal raphe.

Lateral Parts of Norma Basalis
The pterygoid process from sphenoid bone projects downwards behind the third molar tooth on each side. It divides into medial and lateral pterygoid plates, which enclose the pterygoid fossa. The pterygoid plates are fused anteriorly but present free posterior margins.
**Medial Pterygoid Plate**

i. The lateral surface of medial pterygoid plate forms part of pterygoid fossa while its medial surface forms the boundary of posterior nasal aperture (choanae).

ii. The posterior margin of medial pterygoid plate shows scaphoid fossa at its upper end. This fossa gives origin to tensor palati.

iii. The entire posterior margin gives attachment to pharyngobasilar fascia while its lower part gives origin to superior constrictor.

iv. The pterygoid hamulus is a hook shaped process extending downward and laterally from the lower end of its posterior margin. The tendon of tensor palati winds round the hamulus.

**Lateral Pterygoid Plate**

i. Lateral surface of lateral pterygoid plate gives origin to lower head of lateral pterygoid muscle.

ii. Medial surface of lateral pterygoid plate gives origin to deep head of medial pterygoid.

**Infratemporal Surface of Greater Wing of Sphenoid**  
(roof of infratemporal fossa)

i. The infratemporal crest gives origin to upper head of lateral pterygoid muscle.

ii. The spine of the sphenoid projects into the infratemporal nerve and medially to the chorda tympani nerve. This relationship explains why the fracture of the spine can lead to the cessation of secretion of the parotid, submandibular and sublingual salivary glands. The spine gives attachments to the spheno-mandibular ligament, anterior ligament of malleus and the tensor palati muscle.

iii. The foramen spinosum is present in front of the sphenoidal spine. It transmits middle meningeal artery and nervus spinosus (a branch of mandibular nerve supplying dura mater).

iv. The foramen ovale is located anteromedial to the foramen spinosum. The structures passing through it are mandibular nerve, accessory meningeal artery, lesser petrosal nerve and emissary vein.

v. The foramen innominatum (emissary sphenoidal foramen of Vesalius) is occasionally present between scaphoid fossa and foramen ovale. It transmits emissary vein connecting the pterygoid venous plexus to cavernous sinus.

**Sulcus Tubae**

It is a groove between the greater wing of sphenoid and the petrous part of temporal bone. It lodges the cartilaginous part of the auditory tube (pharyngotympanic tube).

**Mandibular Fossa**

i. The mandibular fossa articulates with head of mandible at TMJ. It is present in the squamous part of temporal bone. It is limited anteriorly by the articular tubercle. It consists of anterior articular part (squamous temporal) and posterior nonarticular part (tympanic plate). The squamotympanic fissure demarcates the articular and nonarticular parts of the fossa.

ii. The squamotympanic fissure is subdivided into two fissures by projecting lower end of tegmen tympani from the petrous temporal bone. The anterior fissure is called petrosquamous and the posterior fissure is called petrotympanic. The latter fissure transmits three structures (anterior ligament of malleus, anterior tympanic vessels and chorda tympani nerve).

iii. The tympanic part of the temporal bone is a triangular bony plate positioned between petrous and squamous parts of temporal bone. It takes part in formation of the floor and anterior wall of the external acoustic meatus.

**Inferior Surface of Petrous Temporal Bone**

It is bounded by greater wing of sphenoid in front, basilar part of occipital bone medially and the styloid process laterally. It shows a number of features. Its anteromedial end represents the apex of the petrous temporal bone. The levator palati is attached near the apex.

i. The lower opening of carotid canal is located behind the area of origin of levator palati. It opens superiorly into the posterolateral wall of the foramen lacerum. The internal carotid artery surrounded by sympathetic plexus passes through the carotid canal, through which the artery is brought to the foramen lacerum.

ii. The foramen lacerum is an irregular gap between the apex of the petrous temporal bone, greater wing and body of the sphenoid. Its construction is peculiar in that it is closed at its lower end (at norma basalis) in life by fibrocartilage but it opens above into the middle cranial fossa. Its other peculiarity is that two canals open into it. The carotid canal opens into its posterior wall and the pterygoid canal begins at its anterior wall and ends into pterygopalatine fossa. The carotid canal brings internal carotid artery to the foramen lacerum. The artery travels in the upper part of the foramen lacerum to enter into the middle cranial fossa. The foramen lacerum is the site of union of deep petrosal nerve (sympathetic plexus) and greater petrosal nerve to form nerve of pterygoid canal (Vidian nerve), which reaches pterygopalatine fossa for terminating in the pterygopalatine ganglion.
The meningeal branch of ascending pharyngeal artery (branch of external carotid artery) and emissary vein pierce its closed lower end to pass through the entire extent of foramen lacerum.

**Posterior Part of Norma Basalis**

1. The median area of this part shows following features:
   i. The foramen magnum is the largest foramen in the skull, is present in the midline in the occipital bone. It connects the posterior cranial fossa to the vertebral canal. A large number of structures pass through its anterior and posterior compartments. The structures passing through the posterior compartment are medulla oblongata, tonsils of cerebellum, meninges, spinal accessory nerve, vertebral arteries, posterior spinal arteries, anterior spinal artery and internal vertebral venous plexus. The structures passing through its anterior part are apical ligament of dens and membrana tectoria (continuation of posterior longitudinal ligament).
   ii. The external occipital crest and the external occipital protuberance are referred in norma occipitalis.

2. The lateral area of the posterior part of norma basalis shows, condylar part of occipital bone, squamous part of occipital bone and the jugular foramen between the petrous temporal and occipital bones.
   i. The kidney-shaped occipital condyles articulate with the reciprocal superior articular facets of atlas to form atlanto-occipital joints, which permit nodding movements.
   ii. The anterior condylar canal pierces the bone anterosuperior to the occipital condyles and transmits the hypoglossal nerve.
   iii. The squamous part of occipital bone in the norma basalis presents following features.
      The area between the nuchal lines and below the inferior nuchal line gives attachment to four muscles of suboccipital triangle (Fig. 53.1).

**Jugular Foramen**

The jugular foramen is bounded by the petrous part of temporal bone in front and jugular process of occipital bone behind.

i. Its anterior part transmits inferior petrosal sinus.
   ii. The middle part gives passage to the ninth, tenth and eleventh cranial nerves.
   iii. The posterior part transmits the continuation of sigmoid sinus as internal jugular vein.

**Jugular Fossa**

At the posterior end of jugular foramen the anterior wall (formed by petrous temporal) is hollowed out to form jugular fossa. The superior bulb of the IJV is lodged in it. The jugular fossa forms the floor of the middle ear. The tympanic canaliculus (through which tympanic branch of ninth cranial nerve enters the middle ear) pierces the jugular fossa.

**Clinical insight ...**

**Jugular Foramen Syndrome**

This syndrome consists of involvement of the ninth, tenth and eleventh cranial nerves in the jugular foramen due to neurofibroma of the nerves or extension of the intracranial meningioma through the jugular foramen or thrombosis of the superior bulb of internal jugular vein.

**Interior of Cranium (Fig. 36.4)**

The interior of the cranium is divided into three cranial fossae (anterior, middle and posterior).

**Features of Anterior Cranial Fossa**

i. The frontal crest (giving attachment to falx cerebri) is located in the midline in the anterior wall of the fossa.
   ii. The cribriform plate of the ethmoid bone lies in the midline in the floor. It is perforated by 15 to 20 filaments of olfactory nerves (which terminate on olfactory bulbs). The olfactory bulb is located in contact with the groove just lateral to crista galli on each side. On either side of the cribriform plate, anterior and posterior ethmoidal foramina are present. The anterior ethmoidal nerve (continuation of nasociliary) and vessels (branches of ophthalmic vessels) enter the anterior cranial fossa via the slit by the side of the crista galli to enter the nasal cavity. The posterior ethmoidal foramen gives passage to posterior ethmoidal vessels only, which leave the anterior cranial fossa via the slit by the side of the crista galli to enter the nasal cavity. Fractures of the anterior cranial fossa may cause escape of CSF into the nose or bleeding into the orbital roof leading to black eye.
   iii. The crista galli is a projection from it just posterior to frontal crest. The anterior end of falx cerebri is attached to crista galli.
   iv. The foramen cecum is seen between the frontal crest and crista galli. It may occasionally transmit an emissary vein from nasal cavity to superior sagittal sinus.
   v. The orbital plates of the frontal bone form the floor on either side of cribiform plate. The orbital surface of the frontal lobe of cerebrum is in close contact with the orbital plate of the frontal bone.
   vi. The body of the sphenoid (jugum sphenoidale) is located posterior to the cribiform plate of ethmoid.
vii. The jugum sphenoidale continues laterally as lesser wing of the sphenoid. The posterior margin of the lesser wing fits into the stem of the lateral sulcus of cerebrum and is related to sphenoparietal sinus.

viii. The anterior clinoid process is the medial end of posterior margin of lesser wing of sphenoid. The anterior end of free margin of tentorium cerebelli is attached to it.

Features of Middle Cranial Fossa (Fig. 36.4)

This fossa is at a lower level compared to the anterior cranial fossa. The overhanging free margin of the lesser wing of sphenoid is the anterior boundary of the fossa and the sloping anterior surface of the petrous temporal bone is its posterior boundary. The greater wing of the sphenoid and the cerebral surface of the squamous temporal bone form its floor. The floor of the middle cranial fossa is in contact with the tentorial surface of the temporal lobe of the cerebrum.

i. The sulcus chiasmaticus is a groove leading into optic canals and is placed just behind jugum sphenoidale.

ii. The optic canal (enclosed by the two roots of lesser wing and the body of sphenoid) opens into the orbit and transmits optic nerve to the middle cranial fossa and the ophthalmic artery to the orbit.

iii. The body of the sphenoid is located in the median part of the fossa. The sella turcica (Turkish saddle) is the hollowed out upper surface of the body of the sphenoid. It consists of three parts, tuberculum sellae in front, hypophyseal fossa in the middle and the dorsum sellae behind. The hypophysis is located in the hypophyseal fossa.

iv. The carotid sulcus is present on each side of the body of sphenoid. It starts from the foramen lacerum and is limited by lingula on its posterolateral aspect. The intracavernous part of the internal carotid artery produces the carotid sulcus.

Superior Orbital Fissure (Fig. 46.2)

This fissure is bounded by the body, greater wing and lesser wing of sphenoid. It communicates the middle cranial fossa to the orbit. It is triangular in shape with apex directed laterally and base medially. It is subdivided into three parts by inclusion of its middle part inside the tendinous ring.

i. Its tapering lateral part transmits three nerves one vein and one artery (lacrimal nerve, frontal nerve, trochlear nerve, superior ophthalmic vein and anastomotic branch of middle meningeal and lacrimal arteries).

ii. Its middle part (which is inside the tendinous ring) transmits two divisions of oculomotor nerve, nasociliary nerve and abducent nerve.

iii. The wide medial part transmits inferior ophthalmic veins.
Foramina in Greater Wing of Sphenoid
The greater wing of sphenoid presents foramen rotundum for maxillary nerve, foramen ovale for mandibular nerve and foramen spinosum for middle meningeal artery.

Foramen Lacerum
The foramen lacerum is bounded by apex of petrous temporal bone, body of sphenoid and the adjacent greater wing of sphenoid. The internal carotid artery enters the middle cranial fossa through it.

Anterior Surface of Petrous Temporal Bone
i. The anterior surface of the petrous temporal bone presents trigeminal impression near the apex for the trigeminal ganglion.
ii. The grooves for greater and lesser petrosal nerves are identifiable.
iii. The arcuate eminence (produced due to underlying superior semicircular canal) indicates the position of internal ear.
iv. The thin tegmen tympani, which is lateral to the arcuate eminence indicates the position of the middle ear and the mastoid antrum.
v. The proximity of the middle ear and mastoid antrum to the middle cranial fossa is responsible for spread of infection to the cranial cavity in otitis media and mastoiditis. Fracture of the middle cranial fossa gives rise to bleeding and discharge of CSF through ear.

Features of Posterior Cranial Fossa
The posterior cranial fossa is very large and deep compared to the other two fossae. The anterior wall of the fossa is formed by the clivus, which is sloping surface formed by fusion of the basilar part of occipital bone and the body of the sphenoid.
i. The anterior surfaces of the medulla oblongata and the pons are in direct contact with the clivus.
ii. Behind the foramen magnum the posterior fossa is walled by squamous part of occipital bone. On either side of the foramen magnum the squamous part of the occipital bone is directly in contact with the cerebellar hemisphere below the transverse sulcus and to the occipital lobe of the cerebrum above the sulcus.
iii. It has a midline crest called internal occipital crest, the upper end of which is called the internal occipital protuberance. The three dural folds (falx cerebri, falx cerebelli and tentorium cerebelli) meet at this site, which is indicated on the external surface by the inion.
iv. From the internal occipital protuberance the transverse sulcus extends laterally and becomes continuous with the deep sigmoid sulcus, which houses sigmoid sinus. The inferior vermis of the cerebellum is in contact with the vermian fossa at the lower end of the internal occipital crest.
v. On each side of the foramen magnum anterior condylar or hypoglossal canal lies above the anterior part of the lateral margin of the foramen.
vi. The jugular tubercle is an elevation above the anterior condylar foramen. It is crossed by ninth, tenth and eleventh cranial nerves, which enter the jugular foramen.
vii. The tonsil of the cerebellum is usually in contact with the foramen magnum.

Internal Acoustic Meatus
The posterior aspect of the petrous temporal bone presents the medial opening of internal acoustic meatus, through which facial nerve; statoacoustic nerve and labyrinthine artery enter the canal of the meatus in the petrous temporal bone. The lateral end of the meatus (fundus of meatus) contains the vestibular ganglion. A bony plate at the lateral end of the meatus shows a number of foramina. Its upper part gives passage to the facial nerve. Through, the superior and inferior vestibular areas enter the dendrites of the bipolar neurons of the vestibular ganglion into the inner ear. The anterior part of the lower area is called the tractus spiralis foarminosus, through which exit the peripheral processes of the bipolar neurons of the spiral ganglion (located inside the osseous labyrinth).

Fetal Skull (Fig. 36.5)
The size and shape of fetal skull is adapted to the maternal pelvis. The non-ossified membranous areas

Fig. 36.5: Fetal skull (norma frontalis)
called fontanelles join the flat bones of the vault of skull to each other.

Functions of Fontanelles
i. The fontanelles permit gliding movements (molding of skull) of one bone over the other during the passage of head through the birth canal.
ii. The fontanelles provide for the postnatal rapid growth in the size of brain.

Fontanelles (Fig. 36.6)
There are six fontanelles that are situated at the angles of parietal bones at the time of birth. They are, anterior, posterior, right sphenoidal, left sphenoidal, right mastoidal and left mastoidal.

i. Anterior fontanelle is the largest (2.5 x 2.5 cm). It is diamond-shaped. It reduces gradually in size. At the end of first year, it is of the size of the tip of finger. It closes (ossifies), when the child attains the age of 18 months. After closure, its site is indicated by the bregma of adult skull.
ii. The posterior fontanelle closes by the age of two to three months. The lambda of adult skull indicates its site.
iii. The sphenoidal fontanelles close by two to three months and their sites are denoted by pterion.
iv. The mastoidal fontanelles close by twelve months and their site is indicated by asterion.

Clinical insight ...

Importance of Anterior Fontanelle
i. Delayed closure of fontanelles may occur in rickets, hydrocephalus, cretinism and Down’s syndrome.
ii. Bulging fontanelle indicates increase intracranial tension.
iii. Depressed fontanelle indicates dehydration.
iv. Anterior fontanelle provides a route to approach the interior of cranium.
v. Samples of CSF can be obtained by passing a long needle obliquely through the scalp and anterior fontanelle into the subarachnoid space.
vi. The superior sagittal sinus can be approached via the anterior fontanelle (in cases where the peripheral veins are not accessible).

Characteristic Features of Fetal Skull
i. Frontal bone is in two halves joined by metopic suture.
ii. The mandible is in two halves.
iii. The jaw bones are edentulous.
iv. The occipital bone is in four parts.
v. The primary cartilaginous joint between the basilar part of occipital bone and body of sphenoid permits postnatal growth in the base of skull.
vi. The tympanic plate of temporal bone is absent. It is represented by tympanic ring (Fig. 36.7). In the absence of tympanic plate, there is no bony external acoustic meatus in fetal skull.
vii. The styloid and mastoid processes are absent.
viii. The parietal tubercle or eminence is prominent. The interparietal diameter (distance between the parietal tubera) is of obstetric importance and can be assessed before delivery.
ix. The paranasal air sinuses are rudimentary. The frontal sinus is absent at birth. The maxillary sinus is the first to develop and identifiable at birth as a small groove.

Individual Cranial Bones
Parietal Bone
The right and left parietal bones are large quadrilateral bones. Each parietal bone has four angles. The antero-superior (frontal) angle takes part in bregma, the anteroinferior (sphenoidal) angle forms the pterion, the posterosuperior (occipital) angle takes part in lambda and posteroinferior (mastoid) angle in asterion. The inner aspects of the four angles have vascular relations. The bregma and lambda are related to superior sagittal sinus. The asterion is related to sigmoid sinus and pterion is intimately related to anterior division (frontal branch) of middle meningeal artery.
Occipital Bone
It is a single bone occupying the back of the cranium. It is characterized by presence of a large foramen called foramen magnum.

i. The bone is composed of four parts, squamous (above and behind foramen magnum), basilar part (basio- ciput in front of the foramen magnum) and two lateral or condylar parts on each side of the foramen.

ii. The internal surface of occipital bone is marked by four fossae. The upper cerebral fossae lodge the occipital lobes of the cerebrum and the lower cerebellar fossae house the cerebellar hemispheres.

iii. Each cerebellar tonsil lies in contact with the posterior margin of the foramen magnum. The nasopharyngeal tonsil is a midline structure, which is in contact with the inferior surface of the basilar part of the occipital bone.

iv. The occipital bone articulates with adjacent bones by means of three types of joints, with sphenoid by synostosis or primary cartilaginous joint, with atlas by synovial joints and with parietal and temporal bones by suture type of fibrous joints.

v. The upper part of squamous part ossifies in membrane. Rest of the occipital bone ossifies in cartilage. (For external features of occipital bone refer to norma occipitalis).

Frontal Bone
i. The frontal bone forms the anterior part of the vault of skull (forehead). The orbital plates are separated by a U-shaped ethmoidal notch which is occupied by cribiform plate of ethmoid. The frontal bone has two asymmetrical air sinuses inside it. The frontal air sinuses are absent at birth but are well developed by the age of puberty.

ii. The inner aspect of the bone including the superior surface of orbital plate is in contact with the frontal lobe of cerebrum.

iii. The frontal bone ossifies in membrane from two primary centers, which appear one on each side in the region of frontal tuber. At birth the frontal bone is in two parts, separated by interfrontal or metopic suture. The suture fuses by eighth year.

Ethmoidal Bone

i. It is the lightest among the cranial bones.

ii. It ossifies in cartilage.

iii. It consists of a pair of labyrinths (containing ethmoidal air cells), cribiform plate and a perpendicular plate.

iv. The perpendicular plate projects downwards from the undersurface of the cribiform plate in the nasal cavity to take part in the bony nasal septum.

v. The labyrinths of the ethmoid are two masses filled with air cells. They are situated on each side of the perpendicular plate.

vi. The medial surface of the labyrinth presents superior and middle nasal conchae or turbinates, which project into the nasal cavity from the lateral wall.

vii. The labyrinth contains three groups of ethmoidal sinuses, which open into the lateral wall of nasal cavity. A noteworthy feature is that ethmoid bone contributes to the skeleton of roof, lateral wall and medial wall of the nasal cavity.

viii. The lateral surface of the ethmoid labyrinth is known as lamina papyracea because it is very thin. This forms part of the medial wall of the orbit.

Sphenoid Bone

i. The sphenoid bone resembles the shape of a butterfly or bat with outstretched wings.

ii. It has a body, a pair of greater wings, a pair of lesser wings and a pair of pterygoid processes.

iii. The body of the sphenoid contains a pair of sphenoidal sinuses, which open into the sphenethmoidal recess of the nasal cavity. The superior surface of the body presents sella turcica for the pituitary gland. The inferior surface of the body forms the roof of the nasal cavity and of the nasopharynx. The transnasal and trans-sphenoidal surgical approach to the pituitary gland is based on the inferior relations of the body of the sphenoid.
iv. The greater wing of sphenoid lies mainly in the floor of the middle cranial fossa internally and in the roof of the infratemporal fossa and the floor of temporal fossa, externally. It presents foramen rotundum, foramen ovale and foramen spinosum besides other foramina for emissary veins.

v. The lesser wing of sphenoid projects laterally from anterior part of the body to which it is connected by two roots (which enclose the optic canal). Its free posterior margin fits into the stem of the lateral sulcus of cerebrum.

vi. The pterygoid processes project vertically downward from the junction of greater wing and the body.

vii. The sphenoidal sinus is rudimentary at birth. It extends in the body of sphenoid during early childhood and attains normal size by the age of puberty.

viii. The sphenoid is ossified in cartilage except upper parts of greater wings and pterygoid processes (which ossify in membrane).

**Temporal Bone**

The temporal bone is intimately related to the ear and houses a number of structures. It is made of five parts, squamous, mastoid, petrous, tympanic and styloid process.

**Squamous Part**

i. Its outer surface presents grooves for middle temporal artery (a branch of superficial temporal artery).

ii. The suprameatal triangle is present on this surface.

iii. The articular part of mandibular fossa is contributed by squamous temporal bone.

iv. It gives off the zygomatic process for articulation with temporal process of zygomatic bone (thus forming the zygomatic arch).

v. The inner surface faces the middle cranial fossa and hence shows impressions of cerebral sulci and gyri and the grooves for the middle meningeal vessels.

**Mastoid Part**

i. The mastoid part encloses the mastoid air cells in the mastoid process.

ii. The medial surface of the mastoid process is marked by a vascular groove for occipital artery.

**Petrosous Part**

This is the hardest part of the temporal bone. It contains several delicate structures as follows:

i. The air filled spaces are middle ear and mastoid antrum and fluid filled spaces are endolymph containing membranous labyrinth and perilymph containing bony labyrinth of internal ear.

**Tympanic Part**

i. This is a curved plate of bone located below the squamous part and in front of the mastoid part.

ii. It forms the floor, anterior wall and lower part of posterior wall of the bony external acoustic meatus.

iii. At its medial end it gives attachment to the tympanic membrane.

iv. Its anterior surface forms the posterior non-articular part of the mandibular fossa.
**Temporal Bone in Newborn**

The appearance of the temporal bone at birth is different than adult. The middle ear, mastoid antrum, tympanic membrane and ear ossicles are of adult size. The inner ear is of adult size. The tympanic part is represented by tympanic ring hence the bony external acoustic meatus is absent. The mastoid process and mastoid air cells are absent.

**Maxilla**

i. The two maxillae are the large bones, which are located one on each side of the nose below the orbit.

ii. The alveolar processes of the two maxillae form the upper jaw.

iii. Each maxilla has a body and four processes, the frontal, zygomatic, alveolar and palatine.

iv. The body is triangular in shape. Its base is directed medially towards the nasal cavity and the apex is directed laterally at the zygomatic process. It encloses a large maxillary sinus.

v. The maxillary sinus is the first to develop during the fourth month or earlier in intrauterine life.

**Sensory Nerves in Relation to Maxilla**

Refer to Figure 45.4

**Maxillary Hiatus**

i. The maxillary hiatus is a large opening (maxillary hiatus) by which the maxillary sinus opens into the middle meatus of nasal cavity. The size of the hiatus is reduced in the living by the uncinate process of ethmoid from above, descending process of lacrimal bone from above, inferior nasal concha from below and perpendicular plate of palatine bone from behind.

ii. The position of maxillary hiatus is higher compared to the floor of the sinus. This position is not favorable for natural drainage of sinus. Therefore, in maxillary sinusitis pus tends to collect inside the sinus. Even in frontal sinusitis, the pus from frontal sinus tends to collect into the maxillary sinus by gravity (position of opening of frontal sinus being higher than that of maxillary hiatus).

iii. Therefore, the maxillary sinus is surgically approached through the canine fossa or through inferior meatus to drain the pus.

**Mandible**

The mandible is the bone of lower jaw. It is the only movable bone of the facial skeleton. It develops in membrane from the perichondrium of the cartilage of the first arch (Meckel’s cartilage).
anterior belly of digastric muscle). The investing layer of deep cervical fascia and platysma are attached to the base. The upper and lower genial or mental tubercles are seen as irregular elevations on the inner surface of body nearer the midline. The upper tubercle gives origin to genioglossus and lower tubercle gives insertion to geniohyoid.

The body of mandible is traversed by a bony canal called mandibular canal. The mandibular foramen leads into it. The canal contains inferior alveolar nerve and inferior alveolar vessels for the supply of lower teeth.

The angle of mandible is the meeting point of posterior margin and lower margin of the ramus. It is typically everted in males and inverted in females.

**Relation to Salivary Glands (Fig. 36.8)**

The mandible is related to three salivary glands.

i. The parotid gland is related to the posterior border of the ramus of mandible.

ii. The submandibular gland is in contact with the submandibular fossa.

iii. The sublingual gland is in contact with the sublingual fossa.

**Nerves Closely Related to Mandible**

i. The inferior alveolar nerve (a branch of mandibular nerve) enters the mandibular foramen and travels in the mandibular canal.

ii. Lingual nerve (a branch of mandibular nerve) is in direct contact behind the posterior end of the mylohyoid line.

iii. The masseteric nerves (branches of mandibular nerve) pass through the mandibular notch to reach the masseter, which is attached to the lateral surface of the ramus.

iv. The auriculotemporal nerve (branch of mandibular nerve) is related to the medial side of the neck of the mandible.

v. The mylohyoid nerve (a branch of inferior alveolar nerve) lies in the mylohyoid groove.

vi. The mental nerve comes out of the mental foramen on the outer surface of the body of the mandible.

**Relation to Facial Artery**

The facial artery can be palpated at the base of mandible at the anteroinferior angle of the masseter.

**Ligaments Attached to Mandible**

i. The stylomandibular ligament, which is the thickened part of the deep cervical fascia, is attached to the angle of mandible.

ii. The sphenomandibular ligament gains attachment to the lingula.

iii. The pterygomandibular raphe is attached to the inner surface behind the third molar tooth.

iv. The lower end of the lateral temporomandibular ligament is attached to the lateral surface of neck of the mandible. (Muscles attached to outer surface are shown in Figure 36.9).

**Age Changes in Mandible**

i. At birth, the mandible is in two halves. Fusion occurs at symphysis menti by first year. The mental foramen is near the lower margin because the bone is made of only the alveolar sockets (no alveolar process). The mandibular canal runs nearer the lower margin. The jaw is edentulous. The mandibular angle is obtuse (around 140°). because the head is in line with the body. The coronoid process projects upward above the condylar process.

ii. In adults, the mental foramen opens midway between the upper and lower margins. The mandibular canal runs parallel to the mylohyoid line. The angle of mandible reduces to about 110° because the ramus is almost vertical. There are teeth in the alveolar sockets. The condylar process projects above the coronoid process.

iii. In old age, the teeth fall and hence the alveolar processes are absorbed. Hence, the height of the mandible is reduced. The mental foramen and mandibular canal shift toward the upper margin. The angle of mandible becomes obtuse (140°).

**Zygomatic Bone**

This bone produces the prominence of cheek. It is also called malar bone. The clinical sign ‘malar flush’ means redness of skin over the prominence of cheek found in diseases like tuberculosis, rheumatic fever, etc.

i. Each zygomatic bone has two processes, frontal and temporal. The frontal process articulates with zygomatic process of frontal bone superiorly at frontozygomatic suture in lateral wall of orbit.

ii. The zygomatic arch is formed by the union of temporal process of zygomatic bone and zygomatic process of temporal bone. The term zygoma is used as an alternative to zygomatic arch.

iii. The lateral surface of zygomatic bone presents zygomaticofacial foramen. The zygomaticus major and minor muscles originate below the above foramen.

iv. The temporal surface presents zygomaticotemporal foramen.

v. The zygomatic bone ossifies in membrane.
Nasal Bones
The right and left nasal bones unite with each other to form bridge of the nose. The free inferior margin of nasal bones is continuous with lateral nasal cartilage. It is notched for passage of external nasal nerve (continuation of anterior ethmoidal nerve).

The nasal bones are usually fractured due to forceful direct blow (like for example, a delivery from fast bowler hitting a batsman’s nasal bridge). This fracture may alter the shape of the nose.

Hyoid Bone (Figs 36.10A and B)
It is a U-shaped bone, which is an important landmark in the midline of the front of the neck. It lies opposite C3 vertebra at rest. The hyoid bone consists of a body and a pair of greater and lesser horns or cornua. The hyoid bone has no articulations with other bones. It is suspended from the skull by stylohyoid ligaments.

Attachments of Hyoid Bone
It is attached to styloid process by stylohyoid muscle, to mandible by mylohyoid and geniohyoid muscles, to tongue by hyoglossus muscles, to pharynx by middle constrictor, to thyroid cartilage by thyrohyoid muscles, to sternum by sternohyoid muscles and to the scapula by omohyoid muscles. The intermediate tendon of the digastric muscle is fixed to the greater horn by a fibrous pulley.

The thyrohyoid membrane passes posterior to the hyoid bone to be attached to its upper margin. A subhyoid bursa facilitates the movements of hyoid bone.

Medicolegal Importance
The fracture of hyoid bone suggests death by strangulation or throttling (in suspected cases of death).

Cervical Vertebrae
There are seven cervical vertebrae. Third to sixth cervical vertebrae are typical. First, second and seventh cervical vertebrae are atypical.

i. All cervical vertebrae are characterized by the presence of foramen transversarium in each transverse process.

ii. The foramina of the transverse processes of upper six vertebrae transmit the second part of the vertebral artery and vertebral venous plexus.

iii. The features of typical cervical vertebra are shown in Figure 36.11.

Atlas (Fig. 36.12)
The first cervical vertebra is known as atlas. It is ring shaped vertebra.

i. It is composed of large lateral masses joined anteriorly by a short anterior arch and posteriorly by a longer posterior arch.

ii. Atlas has no body and spine.

iii. The relations of superior aspect of atlas are shown in Figure 36.12.

iv. The kidney shaped superior articular processes articulate with occipital condyles to form atlanto-occipital joint (nodding movement suggesting ‘yes’ or good morning).

v. There are three atlantoaxial joints, right and left and median.
The circular inferior articular processes of atlas articulate with superior articular processes of axis to form lateral atlantoaxial joints. The facet on inner aspect of anterior arch is for articulation with dens of axis to form median atlantoaxial joint (which is of pivot type and allows rotation of head as in shaking movement suggesting ‘no’). vi. The superior surface of the posterior arch shows a groove for the third part of the vertebral artery. vii. The anterior arch provides attachment to the anterior longitudinal ligament at the anterior tubercle and to the anterior atlanto-occipital membrane at the upper margin. The posterior arch provides attachment to the highest pair of ligamenta flava at its lower margin. Its posterior tubercle gives attachment to the ligamentum nuchae and to its lower margin is attached the posterior atlanto-occipital membrane.

viii. The transverse ligament of atlas divides the vertebral foramen into a large posterior part containing spinal cord, meninges, spinal arteries and spinal accessory nerve and a smaller anterior part containing the dens of the axis (Fig. 36.12).

**Relations of Transverse Processes**
The transverse processes are very long and hence, the atlas vertebra is the widest among the cervical vertebrae. The tip of the transverse process can be felt in the living in front of and below the mastoid process (at the midpoint between the mastoid process and the angle of the mandible). The occipital artery, internal jugular vein and the spinal accessory nerve are the anterior relations of the transverse process.

**Lateral Masses**
The transverse ligament of atlas is attached on each side to the tubercle on the medial surface of the lateral mass. It is a very strong ligament responsible for retaining the dens in contact with the anterior arch of atlas. In death by hanging the dens dislocates backwards by tearing the transverse ligament and impinges on the lower medulla and upper spinal cord. This is due to atlantoaxial dislocation without fracture of dens.

**Clinical insight ...**

**Jefferson’s Fracture**
This is the fracture of atlas at the anterior or the posterior arch (fracture at two or three places) causing separation of the lateral masses. The spinal cord is not compressed in this fracture.

**Axis (Fig. 36.13A)**
The axis is the second cervical vertebra. It is identified by the presence of a tooth-like upward projection from the body of axis. This projection is called the dens or odontoid process, which represents the body of atlas vertebra. The apical ligament is attached to the apex of the dens and alar ligaments are attached to its sides. The anterior surface of the body gives attachment to the anterior longitudinal ligament. The lower margin of the posterior surface of the body gives attachment to the posterior longitudinal ligament. The membrana tectoria, which is the upward continuation of the posterior longitudinal ligament, is attached to the posterior surface of the body. The radiological appearance of axis is shown in Figure 36.13B.

**Seventh Cervical Vertebra**
The seventh cervical vertebra has a prominent spine, which is not bifid. Hence, the seventh vertebra earns the name vertebra prominence. The tip of the spine of this vertebra is easily felt in the back of the neck. This allows the tips of the subsequent spines to be numbered. Another peculiarity of the seventh vertebra is that only the vertebral venous plexus passes through its foramen transversarium.

**Fig. 36.12:** First cervical vertebra (Atlas)

**Fig. 36.13A:** Second cervical vertebra (Axis)
Fractures of Axis

i. The dens or the pedicle of the axis may be fractured in road traffic accidents (RTA) or a fall from the height. These may be fatal injuries if the spinal cord is compressed.

ii. The fracture of the dens is accompanied with rupture of the transverse ligament. This causes dislocation of the dens posteriorly in the vertebral column towards the spinal cord.

iii. The Hangman’s fracture occurs at the interarticular part of the pedicle, which is long and thin in axis. There is a double break in the axis, which may cause posterior dislocation of the median atlantoaxial joint.

Sixth Cervical Vertebra

The anterior tubercle of the transverse process of sixth cervical vertebra is large and palpable. It is called carotid tubercle of Chassaignac. The common carotid artery can be compressed against it, medial to the anterior margin of the sternomastoid muscle.
ANATOMY OF SCALP

The scalp is the soft tissue covering the cranial vault. The forehead, though not covered with hair, is included in the scalp.

Extent
i. The scalp is limited anteriorly by the eyebrows.
ii. The superior nuchal lines and the external occipital protuberance of occipital bone limit the scalp posteriorly.
iii. The superior temporal lines are the lateral limits on each side.

Subdivisions
A line extending from the auricle to the vertex on each side divides the corresponding half of scalp into anterior and posterior quadrants.

Layers of Scalp (Fig. 37.1)
The scalp consists of five layers: Skin, superficial fascia, musculoaponeurotic layer, subaponeurotic layer and pericranium from outer to inner side.
1. The skin of scalp is characterized by plenty of hair follicles, sebaceous glands and sweat glands.
2. The superficial fascia is characterized by dense connective tissue. It contains the blood vessels and nerves of the scalp. The fibrous strands in the superficial fascia are fixed to the walls of the blood vessels. This factor prevents retraction of the blood vessels, when injured. Hence, scalp wounds bleed profusely. The bleeding in the scalp is controlled by application of direct pressure of the digit or by placing the surgical sutures.

3. The musculoaponeurotic layer consists of two parts:
   i. Epicranial aponeurosis (galea aponeurotica)
   ii. Muscular part composed of frontal and occipital bellies of the occipitofrontalis muscle.

Galea Aponeurotica
The galea aponeurotica covers the vault like a helmet. Posteriorly between the occipital bellies it is attached to the occiput and the superior nuchal line. Anteriorly, it merges with the superficial muscles between the two frontal bellies. Laterally, it is attached partially to the superior temporal line and fuses with the temporal fascia in the temporal region via small extensions.

Muscular Part
i. The frontal belly has no bony attachments. Posteriorly, it is attached to the galea aponeurotica and anteriorly its fibers merge with those of superficial muscles of the forehead and the orbicularis oculi. It is inserted in...
to the superficial fascia of the eyebrow. The action of the frontal bellies is to raise the eyebrows and produce horizontal wrinkles on the forehead.

ii. The occipital belly of each side takes origin from the highest nuchal line and the mastoid part of the temporal bone and is inserted into the galea aponeurotica.

The first, second and third layers of the scalp are fused with each other and move as a single unit. The alternate contraction of occipital and frontal bellies moves the scalp forwards and backwards.

4. The subaponeurotic layer (fourth layer) forms a potential space filled with loose areolar tissue beneath the aponeurotic layer. The emissary veins, which communicate the veins of the scalp with the intracranial venous sinuses, pass through this space. This space is closed on all sides except anteriorly, where it extends into the upper eyelid (Fig. 37.2). It is known as the dangerous area of scalp.

5. Pericranium is the outer periosteum of the bones of the vault. It forms a loose covering for the bones except at the sutures, where it is continuous with the endocranium. Cephalhematoma is the collection of blood underneath the pericranium in fracture of the bones of the vault. Cephalhydrocele is accumulation of CSF beneath the pericranium due to tear of dura mater and arachnoid mater. Such swellings are restricted to the bones of the vault and are of the shape of the related bone.

### Nerves of Anterior Quadrant (Fig. 37.3)

One motor and four sensory nerves are present in the anterior quadrant of the scalp.

1. The motor nerve is the temporal branch of the facial nerve for the supply of the frontal belly of the occipitofrontalis.

2. The following sensory nerves are present:
   i. Supratrochlear
   ii. Supraorbital
   Both are the terminal branches of frontal branch of ophthalmic nerve.
   iii. Zygomaticotemporal nerve is a branch of zygomatic branch of maxillary nerve.
   iv. Auriculotemporal nerve is a branch of mandibular nerve.

### Nerves of Posterior Quadrant (Fig. 37.3)

One motor and four sensory nerves are present in the posterior quadrant of the scalp.

1. The motor nerve is the posterior auricular branch of the facial nerve for the supply of the occipital belly of occipitofrontalis.

2. The following sensory nerves are present:
   i. Great auricular nerve (C2, C3)
   ii. Lesser occipital nerve (C2)
   Both are the branches of the cervical plexus.
   iii. Greater occipital nerve is a branch of dorsal ramus of C2. It is the thickest cutaneous nerve in the body and supplies the skin as far forward as the vertex.
   iv. Third occipital nerve is a branch of dorsal ramus of C3. It lies inferomedial to the greater occipital nerve and supplies the skin covering the external occipital protuberance.

### Arterial Supply (Fig. 37.3)

The scalp is richly supplied with blood through the extensive anastomoses between the branches of internal and external carotid arteries. The advantage of the profuse blood supply is that the wounds of scalp heal faster. However, if the lacerations of the scalp include galea aponeurotica the wound gapes due to the pull exerted by occipitofrontalis muscles. Hence, gaping wounds of scalp are always treated by surgical suturing to control bleeding and facilitate healing.
The following arteries supply the anterior quadrant:

i. Supratrochlear

ii. Supraorbital

The above two arteries are the branches of the ophthalmic artery (a branch of internal carotid artery).

iii. Superficial temporal artery is the terminal branch of external carotid artery. The anterior branch of superficial temporal artery appears wavy particularly in the elderly. The superficial temporal artery pulse can be felt against the zygomatic process of the temporal bone in front of the tragus of the ear.

The following arteries supply the posterior quadrant of scalp:

i. Posterior auricular

ii. Occipital artery

The above two arteries are branches of external carotid artery.

Venous Drainage

The veins of scalp begin in the venous network. The supratrochlear and supraorbital veins unite to form the facial vein near the medial angle of eye. The supraorbital vein communicates with the superior ophthalmic vein by a communicating vein. The superficial temporal vein receives middle temporal and transverse temporal veins and then enters the substance of the parotid gland, where it unites with the maxillary vein to form the retromandibular vein. The posterior auricular vein joins the posterior division of retromandibular vein to form the external jugular vein. The occipital veins draining the posterior part of the scalp turn in the suboccipital triangle to join the vertebral and deep cervical veins. The parietal and mastoid emissary veins connect the venous network of scalp to the venous sinuses inside the cranium. The scalp veins are used for intravenous infusion in early childhood, since these veins are constant in location. The preferred veins are superficial temporal, posterior auricular, supratrochlear veins.

Lymphatic Drainage

The lymph vessels of the anterior quadrant drain in the superficial parotid lymph nodes and those from the posterior quadrant drain in the occipital and retroauricular lymph nodes. In infections and infestations (e.g. by lice), these lymph nodes are enlarged.

Caput Succedaneum

Caput succedaneum is the formation of swelling in the newborn skull due to stagnation of fluid in the scalp layers. This is a temporary swelling since it results from the venous congestion of the scalp due to compression through the birth canal. The swelling of caput succedaneum is diffuse because it is not restricted to any particular bone. It disappears within 24 hours after delivery. The caput succedaneum should be distinguished from cephalhematoma, which is the collection of blood between the pericranium and the parietal bone. It is due to rupture of the emissary vein as a result of fracture of the bone during forceps delivery. The cephalhematoma is restricted to the parietal bone. This swelling gradually subsides over a period of few months.
The face extends from the hairline to the base of the mandible. The forehead is common to both the face and the scalp.

**DEVELOPMENT OF FACE**

The face develops from five facial prominences or processes, which surround the stomodeum (future mouth region) of the embryo during the fifth week of intrauterine life. These facial processes are composed of mesenchymal proliferations covered by ectoderm. Each facial process has its own sensory nerve, which supplies the derivatives of respective process.

**Facial Processes**

i. The frontonasal process is located on the cranial side of the stomodeum.

ii. The bilateral mandibular processes are located on the caudal side of the stomodeum.

iii. The bilateral maxillary processes (arising from the mandibular processes) are seen laterally.

**Frontonasal Process (Fig. 38.1A)**

i. The olfactory pits appear on each side of the midline in the frontonasal process.

ii. As a result, the frontonasal process is divided into median nasal process and lateral nasal processes (Fig. 38.1B).

iii. The median nasal process grows caudally much longer than the lateral nasal processes. The projecting part of the median nasal process forms a globular process (Fig. 38.1C), which is also described as intermaxillary segment.

iv. The globular process has a labial, upper jaw and palatal components.

v. The lateral nasal process fuses with maxillary process.

**Derivatives of Frontonasal Process**

i. The forehead and upper eyelids are derived from the cranialmost undivided part of frontonasal process.

ii. The philtrum of upper lip and the premaxilla develop from globular process (of the median nasal process).

iii. The crest and tip of nose (and nasal septum) are derived from the rest of the median nasal process intervening between the two olfactory pits.

iv. The ala of the nose develops from respective lateral nasal process.

All the derivatives of frontonasal process receive sensory supply from ophthalmic division of trigeminal nerve.

**Maxillary Processes**

Each maxillary process grows in medial direction below the developing eye to meet and fuse with lateral nasal process. At the line of fusion, the deeper cells of the ectoderm form a solid cellular cord, which canalizes to form nasolacrimal duct.
Derivatives of Maxillary Process

i. The lower eyelid and the upper cheek develop from the maxillary process.

ii. The upper lip lateral to the philtrum is derived from the maxillary process (which fuses with the globular process on its side).

All the derivatives of maxillary process receive sensory supply from maxillary division of trigeminal nerve.

Developmental Sources of Upper Lip

i. The philtrum develops from the globular process.

ii. The right and left sides of the lip develop from the respective maxillary processes (Fig. 38.1D).

Correlation of Nerve Supply and Development of Upper Lip

The labial branches of infraorbital nerve alone supply the skin of the entire upper lip although the upper lip develops from both frontonasal and maxillary processes. This is explained by the fact that the ectoderm of the maxillary processes grows over the globular process on either side and carries the maxillary innervation to the philtrum.

Cleft Lip or Hare Lip

This is a common congenital anomaly of upper lip. The name harelip is used for the defects of upper lip because the upper lip of hare (rabbit) normally shows a cleft. The cleft lip may be an isolated defect or in combination with cleft palate. In isolated cleft lip, the defect may be in the central part or it may be on one side or both sides of the lip. Accordingly, three types of defects are recognized.

i. The central cleft lip develops due to failure of fusion of the globular swellings of each other.

ii. Unilateral cleft lip develops due to failure of fusion of maxillary process of one side with the corresponding globular swelling (Fig. 38.2).

iii. Bilateral cleft lip is caused due to failure of fusion of the maxillary and globular processes on both sides.

Effects of Cleft Lip

i. Cosmetic disfigurement of face

ii. Difficulty in sucking

iii. Defective dentition and speech.

Surgical repair is usually done by the age of three to six months.
Chapter Derivatives of Mandibular Processes

i. The lower lip is formed from the fusion of the two mandibular processes.
ii. The lower part of the cheek is also formed from this process.

The derivatives of mandibular process receive sensory supply from mandibular division of trigeminal nerve.

Size of Oral Orifice

The angles of the mouth are originally placed laterally close to the developing auricle. Subsequently with fusion of the maxillary and mandibular processes the angle of the mouth shifts its position medially.

Anomalies of Oral Orifice

i. Failure of fusion or arrest of fusion of maxillary and mandibular processes results in macrostoma or large mouth.
ii. Excessive fusion of these two processes results in a very small mouth called microstoma.

Nerve Supply

The face is richly supplied by sensory branches of the trigeminal nerve. The muscles of facial expression are innervated by facial nerve.

Sensory Nerves of Face (Fig. 38.4)

The skin of the face mainly receives branches from the three divisions of trigeminal nerve. Only a small area of skin covering the angle of mandible and the parotid gland is supplied by great auricular nerve (C2, 3). Thus, the C2 dermatome lies adjacent to the trigeminal area in the lower part of the face. These nerves carry general sensations (touch, pain and temperature) from the facial skin and the proprioceptive sensations from the muscles of facial expression. There are free anastomoses between the sensory nerves of the face and the motor branches of facial nerve.

Branches of Ophthalmic Nerve

i. Supraorbital nerve is one of the terminal branches of frontal nerve. It ascends through the notch on the supraorbital ridge. It is the longer and larger nerve supplying the skin of the forehead, upper eyelid and the scalp as far back as the vertex. The position of supraorbital nerve can be found out by palpation of supraorbital notch. If pressure is applied here, it is very painful.

ii. Supratrochlear nerve is the other terminal branch of the frontal nerve. It lies medial to the supraorbital nerve and supplies the medial part of the forehead and the upper eyelid.
iii. Palpebral branch of lacrimal nerve supplies the lateral part of upper eyelid.

iv. Infratrochlear branch of the nasociliary nerve supplies the medial part of upper eyelid, the root of the nose and medial part of lower eyelid.

v. External nasal branch of the anterior ethmoidal nerve (from nasociliary nerve) supplies the midline of the nose including its tip.

Branches of Maxillary Nerve

i. Zygomaticofacial nerve, a branch of the zygomatic nerve, appears on the face through the zygomaticofacial foramen and supplies the skin of the prominence of cheek.

ii. Zygomaticotemporal nerve, a branch of zygomatic nerve enters the temporal region through the foramen of the same name to supply the skin of the temple just lateral to the lateral angle of eye.

iii. The infraorbital nerve enters the face by emerging through the infraorbital foramen, which lies between the origin of levator labii superioris above and levator anguli oris below. It immediately divides in three branches, which diverge in three directions. The palpebral branches supply the lower eyelid, the nasal branches supply the side of the nose and the labial branches supply the upper lip.

Clinical insight ...

**Infraorbital Nerve Block**
The infraorbital nerve is infiltrated with anesthetic solution by passing the needle through the skin and the levator labii superioris at the position of infraorbital foramen (Fig. 38.5).

**Branches of Mandibular Nerve**

i. Buccal branch of mandibular supplies the cheek covering the buccinator.

ii. Mental nerve arising from the inferior alveolar nerve comes out through the mental foramen of mandible and supplies the skin of the lower lip, chin and that covering the base of the mandible.

iii. Auriculotemporal nerve enters the temple at the side of the face and supplies the area in front of the auricle and the temple.

Blood Supply

The branches of following arteries provide rich blood supply to the face:

i. Facial artery
ii. Superficial temporal artery
iii. Supratrochlear and supraorbital (from ophthalmic artery)
iv. The arteries accompanying the sensory nerves of the face.

There are extensive anastomoses between the arteries of the two sides. Therefore, wounds of the face bleed profusely but heal rapidly.

**Facial Artery (Figs 38.6 and 38.7)**

This is the anterior branch of the external carotid artery, given off in the carotid triangle in the neck. The course of the facial artery is divided into two parts, the cervical and the facial. The facial artery is tortuous throughout its extent. The cervical part is tortuous to adapt to the movements of pharynx during deglutition. The facial part is tortuous to adapt to the movements of mandible, lips and cheek.

**Surface Marking**

i. The cervical part of facial artery is marked by joining the tip of the greater horn of hyoid bone to the anteroinferior angle of the clenched masseter muscle.
ii. The facial part of facial artery is marked by joining three points (related to three angles), anteroinferior angle of the clenched masseter, a point close to the angle of mouth and the medial angle of the eye.

**Facial Artery Pulse**

The facial artery is felt on the base of the mandible at the anteroinferior angle of the masseter. The anesthetists often feel the facial pulse for monitoring the patient during surgery.

**Course and Relations**

1. The cervical part of the facial artery is intimately related to the submandibular salivary gland. It gives following four branches in the neck:
   i. Ascending palatine artery
   ii. Tonsillar artery
   iii. Glandular branches to submandibular gland
   iv. Submental artery (the largest branch)
   v. Angular artery is the continuation of the facial artery (Fig. 38.6).
2. The facial part of the facial artery begins at the base of the mandible at the anteroinferior angle of masseter. It ascends in the superficial fascia of the face and lies on the superficial aspect of the buccinator and the levator anguli oris. Then the facial artery lies superficial or passes through the levator labii superioris to ascend embedded in the levator labii superioris alaeque nasi. The facial vein is posterior to the facial artery. The facial part of facial artery gives off following four branches:
   i. Inferior labial artery
   ii. Superior labial artery
   iii. Lateral nasal artery
   iv. Angular artery
Arterial Anastomoses

i. There are anastomoses between the right and left superior labial and right and left inferior labial arteries are by main trunks. Hence, deep wounds of the lips and incisions on the lips bleed freely from either end.

ii. The facial artery anastomoses with the transverse facial artery (from superficial temporal artery) in the cheek.

iii. The superior labial artery gives off a septal branch, which anastomoses with septal branches of nasopalatine and anterior ethmoid arteries inside the nasal cavity.

iv. The angular branch of facial artery anastomoses with dorsal nasal branch of ophthalmic artery at the medial angle of eye.

Superficial Temporal Artery (Fig. 59.2)

This artery is one of the terminal branches of the external carotid artery, given off in the substance of the parotid gland at the level of neck of the mandible. It emerges from the base of the parotid gland along with the auriculo temporal nerve. It enters the anterior quadrant of the scalp and divides in to its terminal branches, frontal and parietal. In the substance of the parotid gland, it gives transverse temporal artery. Its other branches are, orbitalzygomatic, anterior auricular and middle temporal artery.

Clinical insight ...

Superficial Temporal Pulse

This artery is felt anterior to the tragus of the ear against the zygomatic process of the temporal bone. The anesthetists usually feels the facial pulse or the superficial temporal pulse of the patient during surgery.

Venous Drainage

The veins of the face correspond to the arteries. The facial vein is clinically important because of its connections with the cavernous venous sinus.

Facial Vein (Figs 38.8)

The facial vein is formed by the union of supratrochlear and supraorbital veins at the medial angle of the eye.

i. It descends posterior to the facial artery (less tortuous than artery). The vein runs downwards and laterally on the surface of levator labii superioris alaeque nasi and then on the buccinator muscle and the body of mandible.

ii. At the anteroinferior angle of masseter, it enters the neck and pierces the deep fascia of the neck. It crosses the submandibular gland, the posterior belly of digastric muscle and stylohyoid muscle.

iii. It joins the anterior division of retromandibular vein to form the common facial vein a little anteroinferior
to the angle of mandible. The common facial vein opens into the internal jugular vein.

**Tributaries**

The facial vein has a number of tributaries. It receives the supratrochlear and supraorbital veins at the medial angle of the eye. It collects blood from the ala of nose. The superior and inferior labial veins drain into the facial vein. The deep facial vein from pterygoid venous plexus opens into its posterior aspect. In the neck, it receives submental and submandibular veins. The external palatine or paratonsillar vein is its tributary from the tonsil.

**Lymphatic Drainage**

i. The greater part of forehead, temple, lateral half of eyelid and lateral half of cheek drain into the preauricular lymph nodes.

ii. The lower medial forehead, medial half of eyelid, nose, upper lip, lateral part of lower lip and medial part of cheek drain into the submandibular nodes.

iii. The central part of the lower lip and chin drain into the submental nodes.

**Muscles of Facial Expression**

The muscles of the face arise from the facial bones and are inserted into the skin of the face. They are placed in the superficial fascia of the face.

(Note: There is no deep fascia on the face except for the parotidomasseteric fascia, which is the deep fascia of neck covering the parotid gland in the face).

The muscles of the face are able to express the various emotions through their contractions. They are arranged around the eyes, mouth and nose. The muscles around the mouth give rise to a variety of facial expressions. The facial muscles develop from the mesoderm of the second branchial arch, hence are supplied by the facial nerve.

**Classification (Fig. 38.9)**

1. Orbicularis oculi muscles are attached to the eyelids.
2. Nasal muscles are those attached to the nose.
3. Buccolabial muscles include oral muscles and buccinator.

**Orbicularis Oculi**

This muscle is the sphincter of the eyelids. So, it has protective function. Its shape is elliptical. It is divided into orbital, palpebral and lacrimal parts.

i. The orbital part arises from the medial palpebral ligament and adjoining part of frontal bone. From the

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**Communications of Facial Vein**

The facial vein and its communicating veins do not possess valves. Therefore, blood flows in them in both directions. The facial vein communicates with the cavernous sinus by two routes.

i. The deep facial vein connects the facial vein to pterygoid venous plexus, which communicates with cavernous sinus by emissary vein. The infective thrombi from a boil on dangerous area of face spreads via this route to cavernous sinus causing cavernous sinus thrombosis (Fig. 38.8)

ii. The superior ophthalmic vein (a tributary of cavernous sinus) may also carry infection to the sinus.

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**Fig. 38.8:** Dangerous area of face and its venous communications to cavernous sinus via superior ophthalmic vein (A) Deep facial vein; (B) Pterygoid plexus-emissary vein route. (The figure also shows formation, tributaries and termination of facial vein)
origin, the fibers pass laterally in a series of concentric loops around the orbital margin to come back for insertion to the medial palpebral ligament and the frontal process of maxilla below it. There is no bony attachment on the lateral side. The upper orbital fibers blend with the fibers of frontal belly of occipitofrontalis and with corrugator supercilii. Some fibers are inserted into the skin of the eyebrow. The lower orbital fibers blend with or overlap the attachments of levator labii superioris alaeque nasi and levator labii superioris.

ii. The palpebral part is present in both the eyelids. It takes origin from the medial palpebral ligament. The fibers pass through the eyelids and interlace laterally to form the lateral palpebral raphe.

iii. The lacrimal part (Horner’s muscle) takes origin from the lacrimal fascia, lacrimal crest and lateral surface of lacrimal bone. It passes laterally behind the lacrimal sac and divides into upper and lower slips, which enter the corresponding eyelids. Some fibers are inserted into the tarsus near the lacrimal canaliculi while others interlace with palpebral part.

Actions
i. The orbital part screws up the eye to give partial protection from the bright light (winking).

ii. The palpebral part closes the eye lightly, as in blinking or in sleep.

iii. The orbital and palpebral parts together close the eye forcibly as in protecting it from a blow or in strong expiratory effort.

iv. The lacrimal part draws the eyelids medially, thereby increasing the flow of tears towards the lacrimal puncta. It expands the lacrimal sac thereby creating the vacuum inside the sac, which aids in sucking the lacrimal fluid towards it.

v. The action of the entire muscle is to draw the skin of the eyebrow, temple and cheek towards the medial angle of eye for tight closure of eyelids. This has the effect of producing radiating skin folds from the lateral angle of eye. These skin folds may become permanent in old age giving rise to ‘crow’s feet’ appearance.

Nerve Supply
The temporal and zygomatic branches of facial nerve supply the orbicularis oculi muscle.

Clinical insight ...

Paralysis of Orbicularis Oculi
The paralysis of orbicularis oculi due to facial nerve injury, results in inability to close the eye. The lower eyelid sags down from the eyeball (called ectropion), which results in epiphora or spilling of tears on the cheek.

Contd...
Nasal Muscles

The nasal muscle group consists of the following small muscles.

i. **Procerus** is a small muscle partially blended with the medial end of frontal belly of occipitofrontalis and covers the glabella. Its contraction produces the transverse wrinkles on the bridge of nose.

ii. **Nasalis**

iii. **Depressor septi**

iv. **Nasal part of levator labii superioris alaeque nasi.**

Buccolabial Group

This is an important group of muscles, which acts on the oral orifice and alters the shape of the lips. This muscular complex consists of sphincter and dilator muscles of the mouth. The intrinsic muscles of the lips comprise the sphincter. The extrinsic muscles arising from other sites are inserted into the lips.

**Elevators, Retractors, Evertors of Upper Lip**

i. Labial part of levator labii superioris alaeque nasi

ii. Levator labii superioris (raises and everts the upper lip)

iii. Zygomaticus minor (elevator of upper lip)

iv. Zygomaticus major (draws the angle of mouth upwards and laterally)

v. Levator anguli oris (raises the angle of mouth)

vi. *Risorius*

vii. *Malaris* (if present)

**Depressors, Retractors, Evertors of Lower Lip**

i. **Depressor labii inferioris** (draws the lower lip downwards)

ii. **Depressor anguli oris** (draws the angle of mouth downwards and laterally)

iii. **Mentalis** (the only muscle, which is not directly inserted in the lower lip or modiolus but acts on lower lip by raising the base of the lower lip, so as to protrude or evert it).

iv. **Platysma** (draws down the lower lip and angle of mouth).

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**Compound Sphincter of the Mouth**

i. **Orbicularis oris**

ii. **Incisivus labii superioris**

iii. **Incisivus labii inferioris**

**Modiolus**

The modiolus is a common point of insertion of as many as nine or ten muscles. It lies about 10 to 12 mm lateral to the angle of mouth on each side. It is a fibromuscular condensation, where the extrinsic and intrinsic muscles of lips converge. It can be palpated between the opposed thumb compressing the skin at the angle of mouth and index finger simultaneously compressing the oral mucosa at the same point. The shape of the modiolus is like that of the hub of a cart-wheel, but the muscles radiating from it lie in different planes. The complex integrated movements of modiolar muscles help in biting, chewing, drinking, sucking, swallowing and speaking apart from their role in facial expressions.

**Orbicularis Oris**

This is a sphincter muscle of the oral orifice. It is located within the upper and lower lips and is attached to both right and left modioli.

i. In the upper lip, its fibers intermingle with incisivus superioris (taking origin from incisive fossa of maxilla), maxillary and lower pterygomandibular fibers of buccinator and levator anguli oris.

ii. In the lower lip, its fibers intermingle with incisivus inferioris (taking origin from the incisive fossa of the mandible), mandibular and upper pterygomandibular fibers of buccinator and depressor anguli oris.

iii. The muscle fibers are attached to the skin as well as to the mucosa of the lip.

iv. The main action of the muscle is to close the mouth.

**Nerve Supply**

Lower buccal and marginal mandibular branches of facial nerve supply the muscle.

**Buccinator (Fig. 38.9)**

The meaning of the word buccinator is ‘trumpeter.’ So, this muscle is active in blowing through the mouth. It is grouped along with muscles of facial expression, since it shares its development and nerve supply with them. Functionally, it is an accessory muscle of mastication because it helps in chewing food. It is a deeply placed
muscle of the cheek lying in the interval between the maxilla and the mandible.

**Attachments**

i. It originates from a C-shaped line from the outer surface of maxilla opposite to the molar teeth, a tendinous band between the maxillary tuberosity and pterygoid hamulus, anterior border of pterygomandibular raphe and outer surface of mandible opposite to third molar tooth.

ii. It is inserted into the lips as follows. The fibers converge towards the modiolus. The maxillary fibers pass into the upper lip whereas the mandibular fibers pass into the lower lip. The pterygomandibular fibers cross at the modiolus so that the upper fibers travel in the lower lip to join the fibers of the opposite side and the lower fibers travel in the upper lip to join the fibers of the opposite side.

**Relations (Fig. 49.2)**

i. Posteroinferiorly, the buccinator is related to the anterior margin of superior constrictor muscle of pharynx (which also takes origin from the pterygomandibular raphe).

ii. Its deep surface is covered with mucosa of the vestibule of oral cavity.

iii. Superficially, it is covered with buccopharyngeal fascia and buccal pad of fat.

iv. The facial vessels and branches of facial nerve and buccal branch of mandibular nerve lie superficial to the muscle.

v. The parotid duct and the buccal branch of mandibular nerve pierce the muscle.

**Nerve Supply**

The lower buccal branches of facial nerve supply the buccinator.

**Actions**

i. The buccinator compresses the cheeks against teeth and gums. This action is helpful in mastication, as it prevents food from collecting in the vestibule.

ii. It compresses the blown-out cheeks and raises the intraoral pressure. This action is helpful in playing wind instruments and in whistling.

**Facial Muscles and Expressions**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Facial expression</th>
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<tbody>
<tr>
<td>Frontalis</td>
<td>Surprise</td>
</tr>
<tr>
<td>Procerus</td>
<td>Concentration</td>
</tr>
<tr>
<td>Zygomaticus major and levator anguli oris</td>
<td>Smiling and laughing</td>
</tr>
<tr>
<td>Zygomaticus minor, levator labii superioris and depressor anguli oris</td>
<td></td>
</tr>
<tr>
<td>Depressor labii inferioris and depressor anguli oris</td>
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<tr>
<td>Depressor labii inferioris and depressor anguli oris</td>
<td>Sadness and sorrow</td>
</tr>
<tr>
<td>Risorius</td>
<td>Grinning</td>
</tr>
<tr>
<td>Mentalis</td>
<td>Doubt</td>
</tr>
<tr>
<td>Platysma</td>
<td>Horror and terror</td>
</tr>
<tr>
<td>Corrugator supercilii</td>
<td>Frowning</td>
</tr>
</tbody>
</table>

**Testing Function of Facial Muscles**

i. To test the frontal belly of occipitofrontalis (frontalis), ask the subject to raise the eyebrows. Normally, horizontal wrinkles are seen on the forehead.

ii. To test orbicularis oculi, ask the subject to close the eyelids tightly against resistance.

iii. To test levator anguli oris, ask the subject to show the teeth so that angles on both sides move equally.

iv. To test orbicularis oris, ask the subject to purse the lips tightly against resistance.

v. To test orbicularis oris, ask the subject to blow out the cheeks keeping the mouth shut. Then tap on the cheek to see if air escapes from closed mouth.

vi. To test the platysma, ask the subject to clench teeth and simultaneously depress the angles of mouth. Normally longitudinal folds of skin become obvious in the neck, when platysma contracts.

**Paralysis of Buccinator**

In paralysis of buccinator, food tends to collect between the teeth and cheek (in vestibule of mouth) on the affected side. When the patient attempts to hold water in the mouth, the water escapes from the affected side quite unexpectedly.

**Extracranial Course of Facial Nerve (Fig. 38.10A)**

The facial nerve leaves the cranium through the stylomastoid foramen. Immediately after the exit, it gives following three branches:

i. Posterior auricular branch for the supply of the occipital belly of occipitofrontalis and posterior auricular muscles.
ii. Digastric branch for the supply of posterior belly of digastric.

iii. A branch to stylohyoid muscle.

**Relation to Styloid Process**

To reach the parotid gland, the facial nerve courses forwards in lateral relation to the styloid process. This part of the trunk of the facial nerve can be exposed surgically between the mastoid process and the external acoustic meatus.

**Intraparotid Course**

The facial nerve enters the posteromedial surface of the parotid gland. Within the gland, it runs forwards for a short distance superficial to the retromandibular vein and external carotid artery and then divides into temporofacial and cervicofacial trunks.

i. The temporofacial trunk divides into temporal and zygomatic branches.

ii. The cervicofacial trunk divides into buccal, marginal mandibular and cervical branches. The five terminal branches radiate like a goose’s foot (pes anserinus) from the anterior border of the parotid gland.

**Branches in the Face**

The terminal branches of facial nerve provide motor supply to the facial muscles. They travel in the superficial fascia, hence are vulnerable to damage in facial lacerations.

i. The temporal branch leaves the gland through its upper surface and passes upwards and forwards in front of the auricle across the zygomatic arch to reach the temple. It supplies the anterior and superior auricular muscles, orbicularis oculi, frontalis and corrugator supercilii.

ii. The zygomatic branch runs along the zygomatic arch and supplies the orbicularis oculi. Figure 38.10B shows the selective injection of local anesthetic into the zygomatic branch of facial nerve to immobilize orbicularis oculi muscle during eye surgery.

iii. The buccal branches are two in number. The upper buccal branch passes above the parotid duct and supplies the procerus, zygomaticus major and minor, levator anguli oris, levator labii superioris, levator labii superioris alaeque nasi and nasal muscles. The lower buccal branch passes below the parotid duct and supplies the buccinator and orbicularis oris.

iv. The marginal mandibular branch has unusual course. It first descends to the digastric triangle under the platysma and then curves upwards and forwards across the base of mandible at the anteroinferior angle of masseter and reaches the face after crossing the facial vessels. It supplies the risorius, depressor anguli oris, depressor labii inferioris and mentalis. The marginal mandibular branch is in danger of injury while placing incision for removal of submandibular gland.
v. The cervical branch enters the anterior part of the neck through the apex of the gland and supplies the platysma.

**External Features of Eyelids**

i. Each eyelid has a free or palpebral margin from which cilia or eyelashes project.

ii. The space between the free margins of the two eyelids is called palpebral fissure.

iii. The meeting points of the two eyelids are called lateral and medial canthi or angles.

iv. At the margin of the eyelid, the skin and the conjunctiva are continuous with each other.

v. The lateral five-sixth of the margin of the eyelid bears cilia and hence is called the ciliary part. The medial one-sixth is devoid of cilia but contains the lacrimal canaliculus and hence is called the lacrimal part. At the junction of the two parts the lacrimal punctum is located. The lacrimal canaliculus begins at the punctum. It is embedded in the medial one-sixth of the margin and ends medially in the lacrimal sac.

vi. The triangular area at the wide medial angle of eye is called the lacus lacrimalis. It contains a reddish body called the lacrimal caruncle (which is considered to be detached part of the eyelid). The plica seminularis is a fold of conjunctiva that is situated lateral to the caruncle.

**Structure of Eyelids (Fig. 38.11)**

The eyelids consist of five layers from outer to inner side.

**Skin and Superficial Fascia**

The skin of the eyelid is extremely thin and loosely attached to the dermis. It contains sweat glands and sebaceous glands. The large-sized sebaceous glands at the lid margin are called Zeis’s glands and the large-sized sweat glands near the lid margin are called Moll’s glands. The ducts of the Moll’s glands open into the hair follicles or in the ducts of the sebaceous glands. The inflammation of Zeis’s gland is called stye, in which the gland becomes swollen, hard and painful.

The superficial fascia of the eyelid is devoid of fat. It is composed of loose connective tissue. Hence, edema of the eyelids is very common.

**Muscular Layer**

The muscular layer of upper eyelid is composed of both striated and nonstriated muscle fibers (see Fig. 38.11).

i. Palpebral part of orbicularis oculi (supplied by facial nerve).

ii. Levator palpebrae superioris (supplied by oculomotor nerve).

iii. Müller’s muscle or superior tarsal muscle (involuntary muscle receiving sympathetic innervation).
The muscular layer of the lower eyelid is composed of:

i. Palpebral part of orbicularis oculi.

ii. Inferior tarsal muscle (involuntary muscle).

Submuscular Space

It is a space deep to the muscular layer in the upper eyelid. It is filled with loose areolar tissue. It is continuous with the subaponeurotic space of the scalp (Fig. 37.2). This continuity is responsible for the appearance of black eye in bleeding injury to the scalp. The submuscular layer contains the sensory nerves of the eyelid, hence local anesthetic solutions are injected deep to the palpebral part of the orbicularis oculi.

Tarsus and Palpebral Fascia

The tarsus and palpebral fascia together form the fourth layer. The tarsal plate consists of dense fibrous tissue to give support to the eyelid. The tarsal plate of the upper eyelid is bigger and of almond shape whereas that of lower lid is smaller and of rod shape. The medial ends of the two tarsal plates are connected by the palpebral ligament to the lacrimal crest of the maxilla in front of the lacrimal sac. The lateral ends of the two tarsi are connected by the palpebral fascia (or the orbital septum). The tarsal glands (or Meibomian glands) are embedded in the deep surface of the tarsus. Their ducts open on the lid margins by minute openings. The tarsal glands secrete oily fluid, which forms a thin film on the conjunctiva. This reduces the evaporation of tears. The inflammation of tarsal glands is called hordeolum internum. The chalazion is the cystic swelling of the tarsal gland.

Palpebral Conjunctiva

The palpebral conjunctiva forms the innermost layer of the eyelids.

- The conjunctiva is a transparent mucous membrane, which lines the inner surface of the eyelids and the front of the sclera of the eyeball.
  - The part lining the lids is called palpebral conjunctiva.
  - The palpebral conjunctiva is highly vascular.
  - The part lining the sclera is called the ocular or bulbar conjunctiva.

The space between the palpebral and bulbar conjunctiva is called the conjunctival sac. At the sclerocorneal junction, the epithelium of conjunctiva is continuous with the corneal epithelium. The superior and inferior fornices of the conjunctival sac are located at the line of reflection of the conjunctiva from the lid to the eyeball. The superior fornix receives the ducts of the lacrimal gland.

Blood Supply

i. The eyelid receives the arterial supply from the lateral palpebral branches of the lacrimal artery and the medial palpebral branches of the ophthalmic artery.

Nerve Supply

i. The upper eyelid including its palpebral conjunctiva are supplied by the supratrochlear, supraorbital, infratrochlear and the lacrimal, which are branches of the ophthalmic nerve.

Clinical insight ...

i. The drooping of the upper eyelid is called ptosis. The drooping is due to paralysis of levator palpebrae superioris. The oculomotor palsy is one of the causes of ptosis.

ii. Partial ptosis is due to paralysis of Müller’s muscle as occurs in Horner’s syndrome.
Head and Neck

Section

Lacrimal Apparatus

The lacrimal apparatus consists of the lacrimal glands that secrete the lacrimal fluid (tears) and the lacrimal passages that drain the lacrimal fluid into the nasal cavity. A film of lacrimal fluid is continuously distributed on the surface of conjunctiva and cornea by periodic blinking of the eyelids. The lacrimal fluid plays a role in protecting and nourishing the cornea.

Components of Lacrimal Apparatus
(Fig. 38.12)

i. Lacrimal gland
ii. Lacrimal ducts
iii. Conjunctival sac
iv. Lacus lacrimalis
v. Lacrimal puncta
vi. Lacrimal canaliculi
vii. Lacrimal sac
viii. Nasolacrimal duct.

Lacrimal Gland

The lacrimal gland is a serous gland and hence the tears are watery in consistency. It has two parts, larger orbital and smaller palpebral.

Location
i. The orbital part is situated in the lacrimal fossa on the inferior aspect of the orbital plate of frontal bone (or the medial aspect of the zygomatic process of frontal bone).
ii. The palpebral part is located inside the lateral part of the upper eyelid.

Relation to Levator Palpebrae Superioris

The orbital and palpebral parts are continuous with each other around the lateral margin of levator palpebrae superioris. Thus, the orbital part lies above the levator palpebrae superioris and the palpebral part lies below it.

The orbital part lies behind the orbital septum and the palpebral part lies in front of it.

Ducts of Lacrimal Gland

The ducts of the lacrimal gland are about a dozen in number. Some ducts drain the orbital part and others drain the palpebral part but all ducts traverse through the palpebral part. The ducts open into the lateral part of superior conjunctival fornix. When the palpebral part of the gland is surgically removed all the ducts are also removed, resulting in a condition, where production of lacrimal fluid takes place but its drainage is hampered.

(Accessory lacrimal glands are minute glands that lie near the fornices in both eyelids. If the lacrimal gland is surgically removed the accessory lacrimal glands are able to carry out its functions).

Secretomotor Innervation (Fig. 38.13)

The preganglionic fibers originate in the lacrimary nucleus in the pons and are carried in the nervus intermedius of facial nerve. They leave in the greater petrosal branch of the facial nerve and hence travel in the Vidian nerve or nerve of pterygoid canal (which is formed by the union of greater petrosal and the deep petrosal nerves). The

Contd...

iii. Bilateral ptosis is usually seen in myasthenia gravis.
iv. The sagging or eversion of the lower eyelid (ectropion) is due to paralysis of orbicularis oculi (in facial palsy). This results in spilling of the tears.
v. Inability to close the eyelids is due to paralysis of orbicularis oculi (as in facial palsy).
Chapter Vidian nerve carries the preganglionic fibers to the spheno-palatine ganglion for synapse. The postganglionic fibers are carried in the zygomatic nerve to the lacrimal gland via a communication with the lacrimal nerve.

Conjunctival Sac
The superior fornix of the conjunctival sac receives the lacrimal fluid from lacrimal ducts. The fluid is transferred to the conjunctival sac for spreading evenly to form a thin film over the cornea and conjunctiva. As the new fluid reaches the conjunctival sac the older fluid is gradually drifted toward the lacus lacrimalis.

Lacrimal Canaliculi
The superior and inferior lacrimal canaliculi begin at the respective lacrimal puncta, which are located on the lid margins about six millimeter lateral to the medial angle of the eye. Each canaliculus runs medially in the respective lid margin to open into the lacrimal sac. The course of the canaliculus is not straight but at first it turns downward (in upper eyelid) or upward (in lower eyelid) and then turns medially in both eyelids.

Lacrimal Sac
The lacrimal sac is located in the lacrimal groove just posterior to the medial margin of the orbit. Its upper end is blind and its lower end is continuous with the nasolacrimal duct. Nearer its upper end, it receives the lacrimal canaliculi laterally. The sac is closely covered with lacrimal fascia except on medial aspect. A few fibers of lacrimal part of orbicularis oculi take origin from the lacrimal fascia. So the contraction of this muscle exerts a pull on the fascia causing the expansion of sac thereby helping to suck the lacrimal fluid inside the sac. The lacrimal sac is related to the medial palpebral ligament anteriorly in front of lacrimal fascia. Posteriorly, it is in relation to the lacrimal part of orbicularis oculi with lacrimal fascia and a minute plexus of veins between them. The lacrimal groove lies medially and separates the sac from anterior ethmoidal cells and middle meatus of nasal cavity. Inflammation of lacrimal sac is called dacryocystitis. The main symptom in this common condition is epiphora (spilling of tears) because of block in the sac or the nasolacrimal duct.

Nasolacrimal Duct
This duct begins at the lower end of the lacrimal sac. It is narrowest at its upper end. It passes through an osseous canal in the lateral, posterior and downward direction to open into the inferior meatus of the nasal cavity. Its lower opening is guarded by a mucosal fold (called a lacrimal fold or valve of Hasner), which prevents air and nasal secretions from being carried upwards in the reverse direction during raised intranasal pressure.
ANATOMY OF PAROTID GLAND

The parotid gland is the largest among the salivary glands.

General Features

The parotid gland weighs about 25 gm and resembles in shape an inverted pyramid. It is a compound tubuloalveolar type of gland consisting mainly of serous acini. The parotid duct carries the watery secretion of the gland to the vestibule of the mouth. The secretion forms the saliva and helps in moistening the mouth and in the formation of the bolus of the food.

Location (Fig. 39.1)

The parotid gland is located below, in front and behind the ear lobule. It fills the hollow between the ramus of mandible and the mastoid process. It extends between the external acoustic meatus above to just posteroinferior to the angle of mandible. Posteriorly, it overlaps the sternocleidomastoid and anteriorly, it crosses the masseter.

Parts, Surfaces and Borders

i. The parotid gland has a narrow base and a rounded apex that points inferiorly.
ii. There are four surfaces namely, superficial or lateral, anteromedial, posteromedial and superior or base.
iii. There are three borders, namely medial, anterior and posterior.
iv. The medial border separates the anteromedial and posteromedial surfaces.
v. The anterior border separates the superficial and anteromedial surfaces.
vi. The posterior border intervenes between the superficial and posteromedial surfaces.

Processes

i. The glenoid process is the part of the base or superior surface of the gland lodged between the external acoustic meatus and the capsule of temporomandibular joint. Swelling and inflammation of glenoid process, e.g. in mumps, give rise to pain during eating.
ii. The pterygoid process is the extension of the deep part of the gland between the medial pterygoid muscle and the ramus of mandible.

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Fig. 39.1: Location and parts of parotid gland (Note the accessory parotid gland above the parotid duct)
iii. The facial process is the part that extends on the face along the duct. A part of it becomes separate above the duct as accessory parotid gland.

### Surface Marking (Fig. 39.2)

To draw the curved anterior border, three points are marked as follows. The first point coinciding with the head of the mandible is in front of the tragus of ear. The second point is marked on the center of the masseter muscle. Third point is just posteroinferior to the angle of mandible. The posterior border is drawn by joining the third point to the fourth point, which is marked at the upper end of the anterior margin of mastoid process. A line joining the first and fourth points represents the upper border of the parotid. This line is concave upwards and may be drawn either across the lobule of the ear or by lifting the lobule of the ear.

### Fascial Capsule

The parotid gland is enclosed in a fascial capsule derived from the investing layer of deep cervical fascia. At the lower end of the parotid, the fascia splits in superficial and deep layers. Extremely dense superficial layer is attached to the lower border of zygomatic arch. The inflammatory swellings of the parotid gland are very painful because of the unyielding nature of this dense fascia. This layer blends with the epimysium of masseter to form parotidomasseteric fascia. The deep layer of the fascial capsule is relatively thin and is attached to the styloid process, tympanic plate and the mandible. The fascial layer extending between the styloid process and the angle of mandible is called stylomandibular ligament, which intervenes between the parotid and the submandibular salivary glands.

### Relations (Fig. 39.3)

i. The superficial or lateral surface is covered by skin, superficial fascia including the posterior fibers of platysma and the dense capsule of the gland. The superficial parotid lymph nodes and cutaneous twigs of great auricular nerve are located in the superficial fascia.

ii. The anteromedial surface is closely related to the ramus of the mandible and to masseter muscle attached to its lateral surface and to medial pterygoid muscle attached to its medial surface.

iii. The posteromedial surface is very large and hence comes in contact with many structures. It is related to the mastoid process and the two muscles attached to it, namely, sternocleidomastoid and posterior belly of digastric. It is also related to the styloid process and the three muscles attached to it, namely, stylohyoid, styloglossus and stylopharyngeus. The internal carotid artery and internal jugular vein are separated from the parotid gland by the styloid apparatus. Last four cranial nerves are also located near these vessels. The external carotid artery grooves this surface before entering the gland.

iv. The medial border of the gland may project medially so much that it touches the lateral wall of the oropharynx. Hence, the medial border is also known as the pharyngeal border.

v. The narrow superior surface is related to the external acoustic meatus and the temporomandibular joint. The auriculotemporal nerve is embedded in the capsule near the superior surface.

vi. The apex lies between the sternocleidomastoid and the angle of mandible. It overlaps the posterior belly of digastric.

### Contents (Fig. 39.3)

i. The facial nerve enters the gland through its postero-medial surface. It divides, in the gland into two main divisions called temporofacial and cervicofacial, from which the terminal branches arise. The facial nerve and its branches lie in the superficial plane.

ii. The retromandibular vein is formed in the substance of the gland by the union of superficial temporal and maxillary veins. Towards the apex of the gland, the retromandibular vein divides in anterior and posterior divisions.

iii. The external carotid artery enters the gland through its postero-medial surface and divides in terminal
branches (superficial temporal and maxillary) at the level of and posterior to the neck of the mandible. The facial nerve is the most superficial structure inside the gland. The retromandibular vein is deeper to the facial nerve and the external carotid artery is the deepest. The nerve and the vein constitute a plane called faciovenous plane, which divides the gland into superficial and deep parts.

Apart from these three major structures, the parotid gland also contains deep group of parotid lymph nodes and auriculotemporal nerve.

Exit of Structures from the Gland (Fig. 39.4)

i. The structures that leave the anterior border are the zygomatic branch of facial nerve, transverse facial vessels, upper buccal branch of facial nerve, parotid duct, lower buccal branch of facial nerve and marginal mandibular branch of facial nerve.

ii. The base or superior surface gives passage to the temporal branch of facial nerve, auriculotemporal nerve and superficial temporal vessels.

iii. The apex gives passage to the cervical branch of facial nerve and the retromandibular vein or its two divisions.

iv. The maxillary artery leaves through the anteromedial surface (maxillary vein enters the gland via the same surface).

Parotid Duct or Stensen’s Duct

The parotid duct is 5 cm long. It drains the secretions of the gland to the vestibule of the mouth. It emerges from the anterior border of the parotid along with branches of facial nerve and crosses the masseter. At the anterior margin of this muscle, it turns sharply medially to pierce the buccal pad of fat, buccopharyngeal fascia, buccinator muscle and the buccal mucosa (Fig. 39.4). It opens in the vestibule of mouth at the level of the crown of the upper second molar tooth. The oblique course of the duct between the buccinator and the oral mucosa acts as a valve, which prevents distension of the parotid duct during forceful blowing. The resistant cases of chronic recurrent parotitis are treated by injecting antibiotic through the oral aperture of the duct.
Surface Marking of Parotid Duct

The middle-third of the line starting from the lower border of tragus to the point between the ala of the nose and the red margin of the lip represents the parotid duct.

Parotid Sialography

This is a radiological procedure for visualizing the parotid duct and its branching pattern. It is performed in cases where narrowing or obstruction of the main duct or its intraglandular branches are suspected. The contrast medium is injected into a small cannula passed through the oral aperture of the duct and the radiograph is taken.

Secretomotor Innervation of Parotid Gland

The preganglionic parasympathetic fibers taking origin in the inferior salivary nucleus in the medulla oblongata are carried in the glossopharyngeal nerve (Fig. 39.5). These fibers leave the glossopharyngeal nerve in its tympanic branch, which enters the middle ear. Here it breaks into tympanic plexus, which gives origin to lesser petrosal nerve. This nerve enters the middle cranial fossa, from where it enters the infratemporal fossa to terminate in the otic ganglion. The postganglionic fibers from the ganglion join the auriculotemporal nerve, which hands over the secretomotor fibers to the gland.

Lymphatic Drainage

The parotid gland drains into deep and superficial group of parotid lymph nodes. The deep nodes are within the substance of the gland while the superficial nodes lie in the superficial fascia covering the lateral surface of the gland. The parotid lymph nodes drain in the deep cervical nodes.
The parotid swellings (Fig. 39.6) may be due to inflammation of the gland or due to tumors (benign or malignant). Since, the gland is positioned below, behind and in front of the lobule of the ear its swellings obliterate the normal hollow just below the lobule of the ear, which is invariably lifted in the parotid swellings. The tumors of parotid gland are very common. A painless slow growing tumor is benign in nature. It does not damage facial nerve. On the contrary, the malignant growth is characterized by rapidly growing painful swelling, which involves the facial nerve producing facial palsy. Therefore, it is very essential to examine the function of facial nerve by testing the muscles of facial expression in parotid tumors. The palpation of the deep group of cervical lymph nodes for finding out the spread of cancer is also essential.

During surgical excision (Fig. 39.7) of benign tumors of parotid gland the facial nerve is preserved either by following the facial nerve (nerve is exposed in the interval between the bony external meatus and the mastoid process and then traced into the gland till its divisions are identified) or by following the faciovenous plane, which consists of facial nerve and retromandibular vein. Identification of this plane during surgery is done by following the external jugular vein towards the gland up to the posterior division of retromandibular vein in the substance of the gland. The facial nerve is not injured if the excision of parotid is done along the faciovenous plane.

The parotid abscess (Fig. 39.8) presents as a slight swelling with redness on the surface of the swelling accompanied by acute excruciating pain. It results from bacterial parotitis (the infection due to bad oral hygiene traveling from the mouth via the duct). The parotid abscess does not show fluctuation, when ripe due to its unyielding capsule. While draining the abscess the surgical incision on the parotid fascia is placed transversely in the direction of the branches of the facial nerve.

Mumps is a non-suppurative viral infection of the parotid gland, in which there is painless enlargement of the gland.
CERVICAL FASCIA

The cervical fascia is subdivided into superficial fascia and deep fascia.

Superficial Fascia

The superficial fascia of the neck is characterized by the platysma muscle anteriorly. It also contains cutaneous branches of cervical plexus, anterior jugular vein and external jugular vein.

Platysma

The platysma takes origin from the fascia covering the pectoralis major and the deltoid (Fig. 10.2). Passing upwards superficial to the clavicle the platysma spreads out as a thin sheet in the superficial fascia of the neck. The muscles of the two sides meet in the midline. The anterior fibers insert into the base of mandible. The posterior fibers cross the mandible and insert into the modiolus at the angle of mouth and into the lower lip.

Nerve Supply

The cervical branch of facial nerve supplies the platysma.

Actions

The platysma depresses the mandible and draws the angle of mouth in the inferior direction.

Deep Fascia of Neck

The deep fascia of the neck or fascia Colli is arranged in three layers (Fig. 40.1).

ATTACHMENTS OF INVESTING LAYER

The investing layer of deep fascia roofs the anterior and posterior triangles of the neck and splits to enclose two muscles (sternomastoid and trapezius) and two glands (submandibular and parotid salivary glands).

i. It is attached posteriorly to the ligamentum nuchae and the spine of the seventh cervical vertebra. It passes forwards on each side and splits to enclose the trapezius muscle. The two layers unite at the anterior margin of the trapezius to form a single layer, which roofs the posterior triangle. At the posterior margin of sternomastoid the fascia splits again to enclose the same muscle. The spinal part of the accessory nerve lies just beneath the investing layer of deep fascia.

Clinical insight ...

i. While suturing the skin incision in the neck the platysma also must be sutured, otherwise the skin scar will be stretched and healing will be delayed.

ii. The platysma is often tested in suspected Bell’s palsy (refer to chapter 38).
in the roof of the posterior triangle. At the anterior margin of the sternomastoid the two layers reunite to form a single layer, which roofs the anterior triangle.

ii. The fascial layers of the two sides are continuous with each other in the midline anteriorly.

iii. Superiorly, the fascia has very wide attachments. For descriptive purposes, upper attachments are subdivided into anterior and posterior.

**Upper Attachment Anteriorly**

In the midline it is attached to the hyoid bone and symphysis menti. Laterally, it is attached to the base and mylohyoid line of mandible by two layers that enclose submandibular gland. At the lower end of the parotid gland the fascia splits to enclose the parotid gland. The superficial layer is very strong and is called parotideomasseteric fascia, which is attached to the zygomatic arch. The deep layer is attached to the styloid process and the lower surface of tympanic plate at the base of the skull.

The part of the deep layer of fascia between the styloid process and the angle of the mandible is called the stylohyoid ligament, which intervenes between the parotid and the submandibular glands.

**Upper Attachment Posteriorly**

It is a linear attachment to the external occipital protuberance, superior nuchal lines, mastoid process and the cartilaginous part of external acoustic meatus.

**Lower Attachment**

The investing layer is attached to the suprasternal notch, upper surface of clavicle and acromion and spine of scapula. At its lower attachment the deep fascia splits twice to enclose two spaces, suprasternal and supraclavicular.

**Suprasternal Space of Burns**

This space is enclosed between the two layers of the investing fascia after it splits above the manubrium sterni. Its superficial layer is attached to the anterior border of suprasternal notch and the deep layer to the posterior margin. The space contains the sternal head of sternomastoid, the jugular venous arch connecting the anterior jugular veins, interclavicular ligament and occasional lymph node.

**Supraclavicular Space**

Above the middle-third of the clavicle the fascia splits to form two layers, which attach to the anterior and posterior margins of the superior surface of the clavicle and enclose the supraclavicular space in the lower part of the roof of posterior triangle. The space contains the terminal part of external jugular vein and the supraclavicular nerves.

**Attachments of Pretracheal Layer**

i. Superiorly, the pretracheal fascia is attached to the hyoid bone in the midline and to the oblique line of thyroid cartilage on each side.
ii. Inferiorly, (Fig. 25.9) it passes in front of the trachea and inferior thyroid veins and enters the superior mediastinum behind the suprasternal notch. Its lower end blends with the apex of the fibrous pericardium.

iii. Laterally, it covers the strap muscles and then forms the anterior wall of the carotid sheath, beyond which it merges with the loose fascia under the sternomastoid muscle.

Relation of Pretracheal Fascia to Thyroid Gland (Fig. 43.5)
The pretracheal fascia forms the false capsule for the thyroid gland. The ligament of Berry is the part of the fascia extending from the back of the thyroid lobe to the cricoid cartilage. The attachment of the pretracheal fascia to the cricoid and thyroid cartilages and the hyoid bone is responsible for movement of thyroid gland with deglutition.

Attachments of Prevertebral Fascia
This layer lies behind the pharynx and esophagus and in front of the prevertebral muscles.

i. Superiorly, it is attached to the base of the cranium.

ii. Inferiorly, it enters the thorax through thoracic inlet and blends with the anterior longitudinal ligament on the front of the bodies of the upper three thoracic vertebrae.

iii. Laterally, it forms the posterior wall of the carotid sheath and passes in front of the scalenus anterior, scalenus medius and levator scapulae, splenius capitis and semispinalis capitis muscles. It then passes over the deep muscles of the back to reach the ligamentum nuchae or it merges with the fascia under the trapezius.

Spaces in Relation to Prevertebral Fascia

i. Retropharyngeal space filled with loose areolar tissue lies in front of the prevertebral fascia and behind the pharynx and esophagus. It acts as a bursa for the pharynx to move. This extends inferiorly to the mediastinum. This space is divided in right and left parts by a midline fibrous septum that joins the prevertebral fascia to the buccopharyngeal fascia covering the pharynx. Each half of the space contains a few lymph nodes. In acute inflammation of these nodes a retropharyngeal abscess may form. Due to fascial continuity the pus from the abscess may track down in the superior mediastinum. It may spread laterally in the posterior triangle and give rise to a swelling or may project in the posterior wall of pharynx as a paramedian swelling.

Clinical insight ...

Contd...
Carotid Sheath

The carotid sheath is formed due to condensation of the deep cervical fascia.

i. It extends from the base of skull to the root of the neck.

ii. The lateral wall of the sheath is relatively thinner compared to the medial to allow for the expansion of the internal jugular vein.

iii. The pretracheal fascia fuses with its anterior wall and the prevertebral fascia lies in its posterior wall.

iv. The ansa cervicalis (C1, C2, C3) is embedded in its anterior wall.

v. The sympathetic trunk is closely related to its posterior wall.

vi. The deep cervical lymph nodes are embedded in the sheath. Therefore, during block dissection of the neck the carotid sheath is exposed for removal of the deep lymph nodes and the internal jugular vein.

Contents of Carotid Sheath

i. The carotid sheath contains the common carotid artery up to the upper border of thyroid cartilage and the internal carotid artery above this level.

ii. The internal jugular vein is present in the entire extent of the sheath in lateral relation to the arteries.

iii. The vagus nerve is present in the entire extent in posterior relation to the arteries and the vein.

iv. The superior and inferior cervical cardiac branches and the pharyngeal and superior laryngeal branches of vagus nerve originate inside the sheath.

Sternomastoid Muscle

The sternomastoid or sternocleidomastoid is a key muscle in the neck. It is useful landmark in dividing the neck into anterior and posterior triangles. It is enclosed in a fascial sheath of the investing layer of deep cervical fascia. The sternomastoid muscle becomes visible on turning the head to the opposite side.

Attachments (Fig. 40.3)

The muscle takes origin from the two bones of the shoulder girdle and is inserted into the two bones of the cranium.

Nerve Supply

The sternomastoid receives motor supply from spinal part of the accessory nerve. The proprioceptive sensation from the muscle is carried in C2 and C3 ventral rami.
Testing Muscle Function

i. To test the right muscle, place your hand on the subject’s chin on the left side and ask the subject to turn the head towards the left shoulder against resistance. The right sternomastoid becomes prominent and taut if its nerve supply is intact. The left muscle can be tested likewise.

ii. To test both muscles simultaneously place your hand on the point of the subject’s chin and ask him to press down against resistance. If functional, both muscles stand out.

Relations

The sternomastoid muscle presents superficial and deep surfaces and anterior and posterior margins.

1. The superficial surface is related to the external jugular vein, which descends on this surface. The great auricular nerve and transverse cutaneous nerve cross this surface.

2. The deep surface is related to structures in the anterior and posterior triangles of the neck. This surface is divided into three regions by superior belly of omohyoid and posterior belly of digastic muscles, which cross on the deep aspect of the muscle.

   i. The part below the superior belly of omohyoid is related to sternoclavicular joint, sternothyroid and sternohyoid muscles and the anterior jugular vein.

   ii. The part between the superior belly of omohyoid and posterior belly of digastic has following relations. Anteriorly this part is related to carotid arteries, internal jugular, facial and lingual veins, vagus nerve, ansa cervicalis and the deep cervical lymph nodes. Posteriorly this part is related to splenius, levator scapulae and scalene muscles, cervical plexus and upper part of brachial plexus, phrenic nerve and suprascapular and transverse cervical arteries. The occipital artery crosses the muscle just below the lower border of the posterior belly of digastic. At this point the accessory nerve passes deep to the muscle and pierces its deep surface to enter its substance.

   iii. Above the posterior belly of digastic, the deep surface is related to the mastoid process and the muscles inserted in it, namely, splenius, longissimus capitis.

3. The anterior margin of the sternomastoid bounds, the carotid triangle above and the muscular triangle below. The clinical importance of the anterior margin is as follows. The branchial cysts and branchial fistulae (congenital anomalies of cervical sinus, described in chapter 42) appear as swellings in relation to this margin.

   i. The branchial cyst appears at the junction of upper and middle one-third.

   ii. The branchial fistula opens at the junction of lower and middle-third.

4. The midpoint of the posterior margin is called the nerve point because the following nerves emerge around this point (Fig. 40.7), cutaneous branches of cervical plexus (great auricular, lesser occipital, transverse cervical, and three supraclavicular nerves) and the spinal accessory nerve. The lesser occipital nerve hooks round the accessory nerve and runs along the posterior margin above this point. The superficial lymph nodes are located around the nerves at this point. Enlargement of these nodes may be the cause of compression of the nerves.

Clinical insight ...

i. Torticollis or wryneck (Fig. 40.4) is the deformity in which head is bent to the affected side while the face (or chin) turns to the opposite side. There are several causes of this condition. Congenital torticollis occurs due to development of fibrous tissue tumor in the muscle before birth. The sternomastoid tumor is the swelling in the muscle as a result of birth injury. It subsides gradually in majority of cases but in a few instances it may cause shortening of the muscle, which results in muscular torticollis.

ii. Bezold abscess is the complication of acute mastoiditis. Because the muscle is inserted into the mastoid process, pus in the mastoid process breaks through its tip and enters the sheath of the muscle. The Bezold abscess appears as a swelling in the upper part of the neck.
TRIANGLES OF NECK

The sternomastoid muscle is a prominent landmark, which serves to divide the neck into anterior and posterior triangles (Fig. 40.5).

The posterior triangle is subdivided into an upper larger occipital triangle and lower smaller subclavian triangle by the inferior belly of omohyoid.

The anterior triangle is subdivided into four triangles by the superior belly of omohyoid and the digastric muscle as follows, the submental triangle, the digastric triangle, the carotid triangle, and the muscular triangle.

Posterior Triangle of Neck

The posterior triangle is an important region of the neck. It is in communication with the axilla via cervicoaxillary canal, which gives passage to the neurovascular structures from the posterior triangle to the axilla for onward transmission to the upper limb.

Boundaries (Fig. 40.6)

i. Anterior boundary is formed by the posterior margin of the sternomastoid muscle.

ii. Posterior boundary is formed by the anterior margin of the trapezius muscle.

iii. The base is formed by the middle-third of the clavicle.

iv. The apex is located superior nuchal line of the occipital bone between the attachments of the trapezius and sternomastoid.

Subdivisions

The inferior belly of omohyoid muscle divides the posterior triangle into:

i. A larger upper occipital triangle.

ii. A smaller lower subclavian or supraclavicular triangle (omoclavicular triangle).
Boundaries of Occipital Triangle
i. Inferior belly of omohyoid  
ii. Sternomastoid  
iii. Trapezius.

Boundaries of Supraclavicular Triangle
i. Inferior belly of omohyoid  
ii. Sternomastoid  
iii. Middle-third of clavicle.

Muscular Floor
The muscular floor consists mainly of three muscles from above downward, namely, semispinalis capitis, splenius capitis, levator scapulae and scalenus medius (Fig.40.6).

Fascial Roof
The investing layer of deep fascia roofs the posterior triangle. The spinal accessory nerve travels down in the fossa in close relation (almost adherent) to the fascial roof. The external jugular vein pierces the roof in the subclavian triangle.

Superficial Contents (Fig. 40.7)
The following cutaneous branches of the cervical plexus enter the posterior triangle by piercing the prevertebral fascia around the midpoint of the posterior border of the sternomastoid.

i. Great auricular nerve  
ii. Lesser occipital nerve  
iii. Transverse cervical nerve  
iv. Supraclavicular nerves.

Nerve Point
The junction of the upper and middle-third of the posterior margin of sternomastoid, where the above mentioned cutaneous nerves and the spinal accessory nerve bunch together is known as the nerve point of the neck. In cervical plexus nerve block, anesthetic solution is injected mainly at nerve point of the neck.

1. The spinal accessory nerve runs downwards and laterally lying in intimate relation to the fascial roof but between the roof and floor.
   i. It leaves the triangle by entering the anterior margin of the trapezius 5 cm above the clavicle.
   ii. A brief review about origin and course of accessory nerve is as follows:
   • The spinal accessory nerve takes origin by rootlets from the anterior horn cells of the C1 to C5 segments of the spinal cord.
   • The rootlets join in the cervical vertebral canal to form the nerve trunk, which enters the cranium through the foramen magnum.
   • The spinal part joins the cranial part of the accessory nerve in the posterior cranial fossa to form the accessory or the eleventh cranial nerve. This accessory leaves the cranium via the jugular foramen.
   • Immediately after the exit it divides into cranial and spinal parts. The spinal part crosses in front of the tip of the transverse process of atlas and descends laterally deep to the posterior belly of digastric to enter the carotid triangle and then into the substance of the sternomastoid muscle.
   • The lesser occipital nerve hooks round the accessory nerve at the nerve point. The accessory nerve is superficially placed in the posterior triangle and hence vulnerable to injury. It supplies the sternomastoid and the trapezius muscles.

iii. The surface marking of the accessory nerve is as follows:
• Draw a line from a point in front of the tragus of ear to a point midway between mastoid process...
and the angle of the mandible (this point coincides with transverse process of atlas).

- From here carry the line to the midpoint of the posterior margin of the sternomastoid muscle and further downward to a point on the anterior margin of the trapezius about 5 cm above the clavicle.

2. Branches of C3 and C4 ventral rami cross the triangle along with spinal accessory to supply proprioceptive fibers to the trapezius muscle.

**Deeper Contents (Fig. 40.8)**

1. The supraclavicular part of brachial plexus (trunk stage and a few branches) is located in the subclavian triangle (lower part of posterior triangle).
   
   i. The upper trunk of brachial plexus gives off suprascapular nerve and the nerve to subclavius here (accessory phrenic nerve carrying C5 fibers from nerve to subclavius may be present occasionally).
   
   ii. The branches from the root stage of brachial plexus are long thoracic nerve (C5, C6, C7) and dorsal scapular nerve (C5). The dorsal scapular nerve pierces the scalenus medius to appear at its lateral margin. It leaves the occipital triangle behind the anterior margin of the trapezius.
   
   iii. The C5 and C6 roots of the long thoracic nerve pierce the scalenus medius and unite on its surface to form the long thoracic nerve. This nerve enters the axilla through the cervicoaxillary canal, where its lowest root (C7) joins it.
   
   iv. The trunks of brachial plexus are very close to the surface in the subclavian triangle as the skin, platysma and the investing layer of deep fascia only cover them. The inferior belly of omohyoid, external jugular vein, transverse cervical artery and the supraclavicular nerves cross in front of the trunks. The upper and middle trunks lie above the subclavian artery but the lower trunk lies posterior to it.
   
   v. The brachial plexus and the subclavian artery are enclosed in the cervicoaxillary fascia, which is the extension of the prevertebral fascia. The subclavian vein is outside the fascial sheath.

2. The suprascapular and transverse cervical arteries are the branches of the thyrocervical trunk from the first part of subclavian artery. They turn in lateral direction to enter the posterior triangle.
   
   i. The suprascapular artery accompanies the suprascapular nerve.
   
   ii. The superficial branch of the transverse cervical artery accompanies the spinal accessory nerve.
   
   iii. The deep branch of the transverse cervical artery accompanies the dorsal scapular nerve (sometimes the dorsal scapular branch of the third part of subclavian artery replaces the deep branch of transverse cervical artery).

3. The third part of the subclavian artery and the subclavian vein are the contents of lowest part of the triangle.

4. The terminal part of the external jugular vein after piercing the fascial roof enters the subclavian triangle to open into the subclavian vein.

5. Occipital artery, which is a branch of external carotid artery, runs a part of its course near the apex of the posterior triangle.

6. A few cervical lymph nodes, belonging to superficial group, lie close to the accessory nerve along the posterior margin of the sternomastoid.

7. The supraclavicular lymph nodes belonging to the inferior deep cervical group are situated in the subclavian triangle in close relation to the posterior margin of the sternomastoid muscle.

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**Fig. 40.8:** Deeper contents of lower part of posterior triangle. The external jugular vein with its tributaries and inferior belly of omohyoid have been removed for better exposure of the contents.

(Note the trunks of the brachial plexus and branches of subclavian artery)
**External Jugular Vein (Fig. 40.9)**

The external jugular vein is a prominent vein visible on the surface of sternomastoid muscle.

i. It is formed just behind the angle of the mandible by the union of the posterior auricular vein and the posterior division of the retromandibular vein.

ii. It runs in the superficial fascia on the surface of sternomastoid muscle from medial to lateral side to reach its posterior margin and enter the superficial fascia of the roof of the subclavian triangle. It pierces the fascial roof about 2 to 3 cm above the clavicle at the posterior margin of sternomastoid. The wall of the vein at this point is adherent to the fascia. Therefore, if the external jugular vein is cut at this point, it cannot close due to the traction exerted by the attached fascia. This exposes the vein to the atmosphere, which may cause fatal venous air embolism (unless the cut end is occluded immediately). The vein runs for a short distance in the subclavian triangle before opening into the subclavian vein behind the clavicle. The vein shows valves at its termination and about 4 cm above the clavicle. The presence of valves and piercing the deep fascia are the two anatomical factors that make the external jugular vein liable to external compression.

Tributaries

i. Formative tributaries (anterior division of retromandibular vein and posterior auricular vein)

ii. Transverse cervical vein

iii. Suprascapular vein

iv. Anterior jugular vein

v. Veins that drain the posterior part of the scalp and neck

vi. Sometimes a communicating vein (running across the clavicle) from the cephalic vein to the external jugular vein.

**Surface Marking**

The external jugular vein is often visible in the living. It can be made more visible by blowing through the mouth against resistance or by applying digital pressure in the subclavian triangle gently. However, a line joining two points corresponding to its upper and lower ends represents the vein. The upper point is just below and behind the angle of mandible and the lower point is deep to the clavicle just behind the margin of the sternomastoid.

**Clinical insight ...**

**Clinical Use of Subclavian Triangle**

The supraclavicular triangle is important in the clinical examination of a patient. This region is inspected from the front but palpated from behind.

i. The trunks of the brachial plexus can be felt on deep palpation behind and just above the middle-third of the clavicle. For brachial plexus block the anesthetic agent is injected around the trunks just above the midpoint of clavicle. Injuries to the trunks of the brachial plexus are commonly due to trauma at birth or due to motorcycle accidents or stab wounds. Injury to the upper trunk causes Erb’s palsy and injury to the lower trunk results in Klumpke’s palsy.
Median Region of Front of Neck

The median region of the front of neck extends from the chin to the suprasternal notch. It is divided into suprahyoid region and infrahyoid region. The suprahyoid region contains the submental triangle (Fig. 40.11). The infrahyoid region contains the bilateral muscular triangles and the midline structures. The identification of the midline structures is essential during the operation of tracheostomy and during clinical examination of the midline swellings in the neck.

Suprahyoid Region

i. The superficial fascia in the suprahyoid region contains the submental lymph nodes.

Median Region of Front of Neck

The median region of the front of neck extends from the chin to the suprasternal notch. It is divided into suprahyoid region and infrahyoid region. The suprahyoid region contains the submental triangle (Fig. 40.11). The infrahyoid region contains the bilateral muscular triangles and the midline structures. The identification of the midline structures is essential during the operation of tracheostomy and during clinical examination of the midline swellings in the neck.

Infrahyoid Region

The following structures are found in this region from above downwards (Fig. 40.11):

i. The body of the hyoid bone is palpable despite the fact that the hyoid bone gives attachment to a number of muscles and ligaments. The hyoid is located one centimeter below and six centimeter behind the chin and is highly mobile. Its vertebral level is C3.

Clinical insight ...

ii. The supraclavicular lymph nodes are palpated at this site (Fig. 40.10). The left supraclavicular nodes are enlarged in cancer of the stomach, colon or testis. These nodes are called Virchow’s nodes. If the left supraclavicular lymph nodes are enlarged in cancer of stomach it is called Troisier’s sign. The cancer of the lung or breast spreads to the supraclavicular nodes of the side of the lesion.

iii. The subclavian vein at this site is often used for central venous access. Through the central venous catheter it is safe to give powerful drugs and it can also be used for long-term feeding in a serious patient (in cases where all the peripheral veins are thrombosed or collapsed).

iv. The pulsations of the subclavian artery can be felt on deep pressure behind the middle-third of the clavicle. The bleeding due to severe lacerations of the brachial or axillary artery can be controlled by compressing the third part of the subclavian artery downward and backward against upper surface of the first rib.

Fig. 40.10: Palpation of supraclavicular lymph nodes from behind

Fig. 40.11: Structures in the median region in anterior part of neck (Note that the left sternohyoid has been removed to expose the attachments of sternothyroid and thyrohyoid muscles)
ii. The thyrohyoid membrane extends from the upper margin of the thyroid cartilage. It passes deep to the body of hyoid bone to reach its upper margin for attachment. Its median part is called median thyrohyoid ligament, which is separated from the hyoid by a bursa. Internal laryngeal nerve and superior laryngeal vessels pierce the thyrohyoid membrane.

iii. Laryngeal prominence (Adam’s apple in male) is palpated and seen in the midline. The upper border of thyroid cartilage corresponds to C4 vertebra and the lower border to C5 vertebra.

iv. The cricoid cartilage is at the level of C6 vertebra. Its anterior arch is palpable in the midline.

v. Cricothyroid membrane extends between the arch of the cricoid and the thyroid cartilage. The cricothyroid branch of the superior thyroid artery runs across this membrane to anastomose with its counterpart.

vi. The cricothyroid muscle is present on the cricothyroid membrane on each side. This muscle is exceptional in that it is the only intrinsic muscle of the larynx, which is seen on the external aspect of the larynx. At the lower end of cricoid cartilage the larynx continues as the trachea.

vii. The first tracheal ring is palpable below the lower margin of cricoid arch.

viii. The isthmus of thyroid gland is located in front of the second to fourth (or second to third) tracheal rings. At times a small pyramidal lobe projects up from the isthmus and it may give rise to a slender slip of muscle called levator glandulae thyroidae or a fibrous band, which attaches the isthmus to the hyoid bone. The pyramidal lobe and the levator glandulae thyroidae are remnants of the embryological thyroglossal duct. Along the superior margin of the isthmus there is a rich anastomosis between the terminal parts of the anterior branches of superior thyroid arteries.

ix. The lateral lobes of the thyroid gland lie on the lateral aspects of trachea. Below the isthmus the anterior aspect of trachea is related to the inferior thyroid veins and thyroidea ima artery (if present). The trachea is deeply placed below the level of isthmus.

x. The suprasternal space of Burns with its contents (jugular venous arch, sternal head of sternomastoid, occasional lymph nodes and interclavicular ligament) is the lowest among the midline structures.

Infrahyoid or Strap Muscles (Fig. 40.12)

These muscles are called the ribbon muscles due to their shape. They are also called pretracheal muscles because of their position in front of the trachea. There are four pairs of muscles in this group (covering the trachea, larynx, thyroid gland and thyrohyoid membrane).

1. Sternohyoid
2. Sternothyroid
3. Thyrohyoid
4. Omohyoid.

i. The sternohyoid muscle takes origin from the posterior surface of manubrium sterni and adjacent part of clavicle and is inserted in the lower border of the body of the hyoid.

ii. The sternothyroid muscle takes origin from the posterior surface of the manubrium sterni and is inserted in the oblique line of the lamina of thyroid cartilage. It passes deep to the sternohyoid muscle and lies in direct contact with the lateral lobe of thyroid gland.

iii. The thyrohyoid muscle takes origin from the oblique line of the lamina of thyroid cartilage and is inserted in the lower border of the greater horn of the hyoid bone. Hence, it is the shortest muscle of this group.

iv. The omohyoid muscle has an inferior belly, intermediate tendon and a superior belly. The inferior belly arises from the margins of suprascapular notch and transverse scapular ligament. It passes upwards across the posterior triangle and deep to sternomastoid muscle to terminate in a tendon, which is strapped down to the clavicle by the deep fascia. The superior belly takes origin from the intermediate tendon and passes vertically across the anterior triangle for insertion in the lower border of the body of the hyoid bone.
Nerve Supply of Strap Muscles (Fig. 40.13)
The ansa cervicalis is a loop-shaped nerve plexus with the root value of C1, C2 and C3. The C1 fibers from the hypoglossal nerve form the superior limb or descendens hypoglossi. The C2 and C3 fibers from the cervical plexus form the inferior root or descendens cervicalis. The two roots are joined by a loop called ansa. The loop is plastered to the anterior wall of the carotid sheath. The branches to sternothyroid, sternohyoid and inferior belly of omohyoid muscles arise from the loop. The branch from the superior limb of the ansa supplies the superior belly of omohyoid. The thyrohyoid nerve, a direct branch of the hypoglossal nerve carrying C1 fibers, supplies the thyrohyoid muscle.

Actions
The strap muscles move the larynx and hyoid during speech and swallowing. They depress the hyoid bone or fix it when acting with suprathyroid muscles.

Carotid Triangle (Fig. 40.14)
The carotid triangle is so called because all the three carotid arteries (common, external and internal) are present inside it and moreover the carotid arteries are very superficial here. In the living person the triangle is visible as small depression anterior to sternomastoid muscle and behind the hyoid bone.

Boundaries of Carotid Triangle (Fig. 40.14)
The carotid triangle presents three boundaries (anterosuperior, anteroinferior and posterior), floor and roof.

i. The anterosuperior boundary is formed by posterior belly of digastric and the stylohyoid muscles.

ii. The anteroinferior boundary is formed by superior belly of omohyoid muscle.

iii. The posterior boundary is formed by anterior margin of the sternomastoid muscle.

iv. The floor consists of parts of four muscles, hyoglossus and thyrohyoid anteriorly and middle and inferior constrictors of the pharynx posteriorly.

v. The roof consists of skin, superficial fascia with platysma and the investing layer of deep fascia of neck. The hyoid bone is located at its anterior angle.
Contents (Fig. 40.15)

i. The bifurcation of common carotid artery into internal and external carotid arteries takes place at the level of upper margin of thyroid cartilage. The internal carotid artery is posterolateral to the external carotid artery in the triangle. The carotid arteries and internal jugular vein are inside the carotid sheath. The external carotid artery gives five of its branches here (see below).

ii. The carotid sinus is a localized dilatation of common carotid artery and adjacent internal carotid artery, at the point of bifurcation. The carotid sinus is supplied by the sinus branch of glossopharyngeal nerve. It is a baroreceptor for controlling intracranial blood pressure. The carotid body is a small neurovascular structure situated close to posterior wall of the carotid sinus. It acts as a chemoreceptor controlling the oxygen tension within the artery.

iii. The internal jugular vein passes through the carotid sheath lying in lateral position compared to the common carotid artery and the internal carotid arteries. It receives tributaries corresponding to the branches of the external carotid artery.

iv. The vagus nerve passes vertically downward in posterior position inside the carotid sheath. It gives superior laryngeal nerve, which divides into internal and external laryngeal nerves here.

v. The spinal accessory nerve crosses the superolateral angle of the carotid triangle to enter the sternomastoid muscle.

vi. The hypoglossal nerve enters the carotid triangle deep to the posterior belly of digastric between the internal jugular vein and internal carotid artery. It crosses superficial to internal carotid artery, external carotid artery and the loop of the lingual artery from lateral to medial side. Here, the nerve gives off superior root of ansa cervicalis and a branch to thyrohyoid muscle. The ansa cervicalis is formed in the anterior wall of the carotid sheath. The cervical sympathetic chain extends vertically posterior to the carotid sheath in front of the prevertebral fascia.

vii. The jugulodigastric and juguloomohyoid lymph nodes are located in the vicinity of the internal jugular vein.

Carotid Pulse

The carotid triangle contains a large number of arteries (three carotid arteries and five branches of external carotid artery) because of which a massive arterial pulsation is felt here to a palpating finger and hence is the preferred site for feeling carotid pulse (Fig. 40.16). The carotid pulse is palpable just lateral to the upper margin of thyroid cartilage.

Branches of External Carotid Artery

i. The ascending pharyngeal artery is the first branch of external carotid artery. It ascends between the internal carotid artery and the wall of the pharynx.
ii. The superior thyroid artery is the first anterior branch of the external carotid artery. It gives infrahyoid, superior laryngeal and sternomastoid branches in the triangle. The superior laryngeal artery accompanied by internal laryngeal nerve enters the larynx by piercing the thyrohyoid membrane. The superior thyroid artery leaves the triangle by descending deep to the superior belly of omohyoid towards thyroid gland.

iii. The lingual artery arises from the anterior aspect behind the tip of the greater horn of the hyoid. It forms a loop around the greater horn of the hyoid. The loop of the lingual artery is crossed by the hyoglossal nerve. The lingual artery passes deep to the hyoglossus.

iv. The facial artery arises from the anterior aspect just above the origin of lingual artery. It leaves the triangle by passing deep to the posterior belly of digastric to enter the digastric triangle.

v. The occipital artery takes origin at the level of facial artery. It passes backward and upward under cover of the posterior belly of digastric. It gives off upper and lower sternomastoid branches.

Deep Cervical Lymph Nodes
A chain of deep cervical lymph nodes lies in intimate relation to the internal jugular vein. The jugulodigasttric nodes lie above the posterior belly of digastric and jugulo-omohyoid below it. Painless enlargement of these nodes due to tuberculosis is quite common. Some times the affected lymph nodes liquefy due to degeneration and form a cold abscess. The pus remains confined deep to the investing layer of deep fascia. But eventually the deep fascia is eroded at one point and the pus flows in the superficial fascia giving rise to collar stud abscess.
The digastric triangle is the superficial part of the submandibular region.

**Boundaries (Fig. 41.1)**

This triangle presents anteroinferior, posteroinferior and superior boundaries besides the floor and roof.

i. The anteroinferior boundary is formed by anterior belly of digastric muscle.

ii. The posteroinferior boundary is formed by posterior belly of digastric muscle and stylohyoid muscle.

iii. The superior boundary is formed by base of the mandible and by an imaginary line from the angle of mandible to the tip of mastoid process.

iv. The floor is formed by mylohyoid and hyoglossus muscles and anterior part of the middle constrictor are in the roof (assuming the body to be in anatomical position).

v. The floor is formed by the skin, superficial fascia (including platysma) and the deep fascia from below upwards (assuming the body to be in anatomical position). The superficial fascia contains the cervical branch of facial nerve and cutaneous branches of transverse cervical nerve.

**Subdivisions**

The digastric triangle is subdivided into two parts:

i. Anterior part, which is located below the base of mandible.

ii. Posterior part, which is located behind the ramus of the mandible.
**Contents of Anterior Part**

i. Superficial lobe of submandibular salivary gland completely fills the triangle.

ii. Submandibular lymph nodes are embedded in the superficial surface of the salivary gland.

iii. Facial artery and its cervical branches are intimately related to the salivary gland.

iv. Common facial vein is formed by union of facial vein and anterior division of retromandibular vein.

v. The mylohyoid nerve enters the triangle and supplies the anterior belly of digastric and mylohyoid muscles.

vi. The hypoglossal nerve accompanied by lingual veins passes superficial to the hyoglossus to reach the tongue.

**Contents of Posterior Part**

i. Lower end of the parotid gland

ii. External carotid artery

iii. Carotid sheath with its contents

iv. Glossopharyngeal nerve

v. Muscles attached to the styloid process (stylohyoid, styloglossus and stylopharyngeus).

The submandibular region is located between the body of mandible and the hyoid bone.

Its superficial part includes submental and digastric triangles. Its deeper part includes the deep part of the submandibular gland, the submandibular duct, sublingual gland with its ducts, the hypoglossal nerve and lingual artery. The lingual nerve enters the region from the infratemporal fossa while the glossopharyngeal nerve enters from the posterior part of the digastric triangle. The hypoglossal nerve, glossopharyngeal nerve, lingual nerve and lingual artery pass through the submandibular region to reach the root of the tongue. The hyoglossus is the key muscle of this region.

**Digastric Muscle**

The digastric muscle consists of two bellies joined by an intermediate tendon.

**Attachments**

The anterior belly takes origin from the digastric fossa of the mandible and the posterior belly from the digastric groove on the medial aspect of the mastoid process.

The intermediate tendon is attached to the junction of body and greater horn of hyoid bone by a fibrous sling.

**Development and Nerve Supply**

i. The posterior belly develops from the mesoderm of second branchial arch, hence is supplied by the facial nerve.

ii. The anterior belly develops from the mesoderm of first branchial arch and hence supplied by mandibular nerve (via nerve to mylohyoid arising from inferior alveolar branch of mandibular nerve).

**Actions**

i. The digastic muscle assists in depression and retraction of the mandible (in opening the mouth).

ii. It assists in elevation of hyoid (in deglutition).

**Relations of Posterior Belly**

The posterior belly has numerous relations since it forms the boundary of both the digastic and carotid triangles of the neck.

i. The superficial structures that come in relation to the muscle are, retromandibular vein, common facial vein, great auricular nerve and cervical and marginal mandibular branches of facial nerve. The mastoid process and parotid salivary gland are its superficial relations posteriorly. The sternomastoid covers it and the submandibular salivary gland lies superficial to it in the anterior part.

ii. Its deep relations (Fig. 40.15) are the three great vessels of the neck, internal jugular vein, internal and external carotid arteries. The hypoglossal, vagus and spinal accessory nerves pass deep to it high up in the neck. The hypoglossal nerve passes deep to the posterior belly at the level of angle of the mandible to enter the carotid triangle. It once again passes deep to the intermediate tendon of digastric muscle to enter the digastric triangle.

iii. The stylohyoid muscle is closely related to the upper border of the posterior belly near the base of skull. The facial nerve lies between the stylohyoid and the posterior belly at its exit from the stylomastoid foramen.

iv. The occipital artery leaves the carotid triangle by passing upwards along the lower margin of the posterior belly.

**Stylohyoid Muscle**

This is a small muscle, which arises from the styloid process of the temporal bone. It is closely related to the upper border of the posterior belly of digastric muscle. It is inserted into the hyoid bone.

**Nerve Supply**

The stylohyoid is innervated by the facial nerve (soon after its exit from stylomastoid foramen).

**Action**

It draws hyoid bone upward and backward.
**Hyoglossus Muscle (Fig. 41.2)**

This is the key muscle of the submandibular region on account of its numerous relations. It is a quadrangular muscle having superficial (lateral surface), deep (medial surface), posterior margin and anterior margin.

**Attachments**

The hyoglossus takes origin from the upper surface of the greater horn and body of the hyoid bone. It passes upwards partially covered with the mylohyoid on the superficial aspect and partially covering the genioglossus on the deep aspect. It is inserted into the side of the root of the tongue.

**Relations**

1. The superficial or lateral surface shows following relations.
   i. Its anterosuperior part is covered with mylohyoid muscle.
   ii. The rest of this surface is related to the important structures from above downward, the lingual nerve, submandibular ganglion, deep part of submandibular gland with the submandibular duct and the hypoglossal nerve with accompanying veins. These structures and the hyoglossus are related to the medial surface of the submandibular gland.

2. The deep or medial surface is related to middle constrictor and genioglossus muscles. The lingual artery courses anteriorly along this surface lying on the middle constrictor. The glossopharyngeal nerve and stylohyoid ligament are the additional structures related to this surface.

3. The structures passing deep to the posterior margin are the lingual artery, glossopharyngeal nerve and stylohyoid ligament.

4. The structures passing deep to the anterior margin are the lingual artery and genioglossus muscle.

Thus, it is clear that the first part of the lingual artery is related to the posterior margin of the hyoglossus, the second part to its deep surface and the third part to its anterior border.

**Nerve Supply**

The hyoglossus receives branches from the hypoglossal nerve.

**Actions**

The hyoglossus depresses the side of the tongue.

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**Mylohyoid Muscle (Fig. 41.3)**

This muscle is positioned in the suprathyoid region in such a way that it forms the floor of the submental triangle and its posterior fibers form the anterior part of the roof of the digastric triangle.

**Surfaces and Borders**

The mylohyoid presents superior (internal) and inferior (external) surfaces. It presents a free posterior margin and attached medial margin.

**Attachments**

The mylohyoid muscle is triangular in shape with wide origin and narrow insertion. It takes origin from the entire mylohyoid line of the mandible. It goes backwards to insert

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**Fig. 41.2:** Relations of hyoglossus muscle  
(Note that the submandibular duct passes deep to sublingual gland on its way to floor of mouth)

**Fig. 41.3:** Mylohyoid muscle and some relations of its inferior surface  
(Note the wide origin from mandible and narrow insertion in hyoid bone)
into the central part of the body of the hyoid bone (note that the origin of mylohyoid is anteriorly placed compared to its insertion).

**Oral Diaphragm**

The muscles of the two sides meet and fuse in the midline at the median fibrous raphe to form a continuous muscular sheet in the floor of the mouth. Hence, the mylohyoid muscles together constitute the oral diaphragm.

**Relations to Submandibular Salivary Gland**

The submandibular salivary gland is related to the mylohyoid at three sites. The superficial and deep parts of the submandibular salivary gland are continuous with each other around the free posterior margin. The superficial part of the gland is in contact with the inferior surface and the deep part is in contact with the superior surface of the muscle. Thus, the mylohyoid gives the submandibular gland a U-shape.

**Relations of Inferior Surface**

The inferior surface of mylohyoid is partially related to the structures in the submental triangle and partially to those in the digastric triangle. Thus, it is related to platysma, anterior belly of digastric muscle, submental vessels and mylohyoid nerve and vessels. The medial surface of the superficial part of submandibular gland is also related to this surface.

**Relations of Superior Surface (Fig. 41.4)**

i. The geniohyoid muscle lies very close to the median fibrous raphe.

ii. The posterior part of mylohyoid is in relation to hyoglossus. There are certain structures separating the two muscles namely, lingual nerve with submandibular ganglion hanging from it and the deep part of the submandibular gland with the submandibular duct. The lowest structure is the hypoglossal nerve with accompanying lingual veins.

iii. The anterior part of mylohyoid is related to geniohyoid. The sublingual gland is located between the muscles and the third part of the lingual artery lies above the sublingual gland.

**Nerve Supply**

The mylohyoid nerve (a branch of inferior alveolar) supplies the mylohyoid muscle and the anterior belly of digastric.

**Actions**

The muscle elevates the floor of the mouth in the first stage of deglutition. Acting from below, it can depress the mandible.

**Geniohyoid Muscle (Fig. 41.4)**

This is a small muscle, which is located above the mylohyoid muscle but very close to the midline. It arises from the inferior mental spine or genial tubercle on the back of symphysis menti and is inserted into the anterior surface of the body of hyoid bone. The muscles of the two sides may fuse with each other. It receives twigs from C1 fibers brought to it in the branch from the hypoglossal nerve. The geniohyoid elevates the hyoid and draws it forwards.

**Clinical insight ...**

**Ludwig’s Angina**

Due to proximity to the oral cavity and submandibular region, the intraoral infections like for example cellulitis spread rapidly into the submandibular region through the mylohyoid clefts. This cleft is present between the mylohyoid and hyoglossus muscles, which is more on a posterior plane compared to the mylohyoid. The cellulitis causes swelling in the submandibular region due to rapid collection of pus, which remains confined within the rigid fascial barriers. This condition is called Ludwig’s angina. It is characterized by putrid halitosis (bad smell of breath). To drain the fluid, mylohyoid muscles are divided by surgical incisions.

**Geniohyoid Salivary Gland**

The submandibular salivary gland is a mixed type of compound racemose gland. It pours its relatively viscous secretion by the submandibular duct against gravity into the floor of the oral cavity.
Parts (Fig. 41.5)
The submandibular gland consists of two parts:
  i. A larger superficial part, which is located below the mylohyoid muscle and fills the digastric triangle
  ii. A smaller deep part, which is located above the mylohyoid muscle.
The two parts are continuous with each other around the free posterior margin of the mylohyoid muscle.

Fascial Capsule (Fig. 41.6)
The investing layer of deep fascia splits to enclose the submandibular salivary gland. The superficial layer covers the superficial surface of the gland and is attached to the lower border of the mandible. The deep layer covers the medial surface and is attached to the mylohyoid line of the mandible. The submandibular lymph nodes are almost embedded in the gland within the fascial capsule. If the lymph nodes are secondarily involved in cancer of the tongue or lip or primarily involved in tuberculosis, the excision of the lymph nodes along with submandibular gland is mandatory due to their close proximity.

Bidigital Palpation
The submandibular gland is palpated by the index finger placed in the floor of the mouth and the thumb placed below the floor, anteromedial to the angle of mandible. In this way, the deep part is felt in oral cavity and superficial part in digastric triangle.

Surface Marking
The upper margin of the gland is drawn by joining the point at the angle of mandible to a point on the middle of the base of the mandible. The lower margin is convex downwards. It is marked by a line joining the two ends of the upper margin and extending below the level of the greater horn of the hyoid bone.

Surfaces of Superficial Part of Gland
The superficial part has three surfaces:
  i. The superficial or inferior surface faces towards the skin.
  ii. The lateral surface is in contact with the submandibular fossa of the mandible.
  iii. The medial surface is the most extensive. The posterior end of the gland is in contact with the stylomandibular ligament, which separates it from the parotid gland.

Relations
1. The superficial surface is covered with the skin, superficial fascia with platysma, facial vein, cervical and marginal mandibular branches of facial nerve and investing layer of deep fascia. The submandibular lymph nodes are embedded in this surface (Fig. 41.6).
2. The lateral surface is in contact with the submandibular fossa on the inner surface of mandible. The posterior part of this surface is in contact with medial pterygoid muscle. Between the medial pterygoid and the medial surface, the facial artery passes forwards and inferiorly.
3. The relations of the medial surface (Fig. 41.7) are different in its anterior, intermediate and posterior parts.
   i. The anterior part is related to the mylohyoid muscle, mylohyoid nerve and vessels and submental vessels.
   ii. The intermediate part is related to the hyoglossus muscle and the structures resting on its superficial surface (styloglossus muscle, lingual nerve, submandibular ganglion and the hypoglossal nerve with accompanying veins). The submandibular duct begins on the middle of the medial surface of the superficial part of the gland.

Fig. 41.5: Continuity of two parts of submandibular gland around the posterior margin of mylohyoid muscle

Fig. 41.6: Fascial capsule and surfaces of submandibular salivary gland
iii. The posterior part of the medial surface beyond the hyoglossus muscle is related to the styloglossus muscle and stylohyoid ligament, glossopharyngeal nerve and middle constrictor muscle of pharynx.

Relation to Facial Artery (Fig. 41.8)
The facial artery is related to the gland twice. At first, it grooves the posterior end of the gland. Then it descends on the lateral surface of the gland to reach the base of the mandible at the anteroinferior angle of the masseter. This vascular relation is to be remembered during surgical removal of the gland.

Relations of Deep Part of the Gland (Fig. 41.9)
The smaller deep part of the gland extends forwards from the free margin of the mylohyoid muscle lying in the intermuscular interval between the mylohyoid laterally and hyoglossus medially. It is situated between the lingual nerve and the submandibular ganglion above and the hypoglossal nerve below. The submandibular duct passes through the deep part.

Submandibular or Wharton’s Duct
The submandibular duct is about five centimeter long. It begins on the medial surface of the superficial part of the gland (Fig. 41.9) near the posterior margin of the mylohyoid, where it enters the deep part of the gland. The duct emerges from the anterior end of the deep part and runs forwards and upwards between the sublingual gland and the genioglossus muscle to open into the floor of the mouth at the summit of the sublingual papilla by the side of the frenulum of tongue. As it traverses the deep part of the gland, it receives small ducts from it. The submandibular duct has triple relation with the lingual nerve (Fig. 41.10). The lingual nerve is at first above the duct. At the anterior border of the hyoglossus the nerve crosses the duct from lateral-to-medial side to reach the tongue. Thus the nerve is related to its lateral, inferior and medial aspects. The duct can be palpated in the floor of the mouth. Its narrowest part is the orifice by which it opens into the oral cavity.
Submandibular Region and Submandibular Gland

Secretomotor Nerve Supply (Fig. 41.11)
The preganglionic parasympathetic fibers originate from the superior salivatory nucleus in the pons. These fibers travel in the facial nerve and leave it through its chorda tympani branch. The latter joins the lingual nerve in the infratemporal fossa. The lingual nerve brings the preganglionic fibers to the submandibular ganglion. The postganglionic fibers directly enter the submandibular gland.

Clinical insight ...

i. Salivary calculi occur in submandibular duct due to stasis of the secretion. The gland swells during eating when the stone blocks the duct. It is possible to palpate the stone through the oral cavity or to demonstrate it radiologically by performing sialography. The impacted stone can be removed via oral orifice of the duct (Figs 41.12A to C).

ii. The submandibular salivary gland is usually removed because of calculi or tumor. A skin incision is placed about five centimeter below and parallel to the lower border of mandible, beginning at the angle of mandible. This is necessary to avoid cutting the marginal mandibular and cervical branches of the facial nerve. The facial artery is ligated in two places so that a segment of the artery is removed with the excised gland. While cutting the duct, care is taken not to injure the lingual nerve. After dissecting out the deep part of the gland, the entire gland is removed.

SUBLINGUAL SALIVARY GLAND

This salivary gland is of compound racemose and mixed type with predominantly mucous secretion. It is situated beneath the mucosa of the oral cavity in contact with the sublingual fossa on the inner surface of the mandible close to the symphysis menti. Occasionally the right and left glands are fused with each other. Each sublingual gland has eight to twenty ducts. The ducts open into the...
summit of the sublingual fold separately. A few open into the submandibular duct.

**Relations**

i. Superiorly, the sublingual gland is related to the mucosa of floor of the mouth.

ii. Inferiorly, it is related to the mylohyoid muscle.

iii. Posteriorly, it is related to the deep part of submandibular gland.

iv. Laterally, it is related to the sublingual fossa of mandible.

v. Medially, the submandibular duct and lingual nerve are related.

**Secretomotor Supply**

The branches of lingual nerve supply the postganglionic fibers from the submandibular ganglion.

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**Figs 41.12A to C:** Impaction of stone in submandibular duct and its surgical removal through floor of mouth (Note that the arrow in Fig. 41.2A indicates the submandibular gland indicates the opening of wharto’s duct)
In the four-week-old human embryo, the neck is not recognizable. Subsequently the neck develops by elongation of the region between the stomodeum and the pericardial bulge. This is achieved mainly by the appearance of a series of pharyngeal (branchial) arches in the lateral wall of developing pharynx at the end of the fourth week and during the fifth week. The arches appear in cranio-caudal order as thickenings of the mesoderm in the pharyngeal wall. The ectoderm covering the pharyngeal arches dips as pharyngeal clefts in the interval between the adjoining arches. Similarly, the endoderm lining the pharyngeal arches grows out as pharyngeal pouches in between the adjoining arches. The ectoderm of the clefts and the endoderm of the pouches meet each other to form bigerminial cleft membranes. Only the first cleft membrane is trigeminal because mesoderm enters in between the endoderm and ectoderm. This is the reason why the first cleft membrane persists.

**Components of Each Arch (Fig. 42.1)**

i. Mesodermal core (with its artery and nerve)
ii. Ectodermal cleft
iii. Endodermal pouch
iv. Cleft membrane

**Nerves of Arches**

A total of six branchial arches develop in human embryo but the fifth arch is transient in existence.

i. The first arch (mandibular arch) has two nerves, the post-trematic (mandibular nerve) and the pretrematic (chorda tympani nerve).

ii. The second arch (hyoid arch) contains facial nerve.

iii. The third arch contains glossopharyngeal nerve.

iv. The vagoaccessory complex is the nerve of fourth arch.

v. The recurrent laryngeal nerve belongs to sixth arch.

**Embryologic insight ...**

**Development of Cervical Sinus**

Due to development of branchial clefts, the neck of the embryo presents an uneven appearance. Subsequently, the ectoderm covering the second arch grows down faster overlapping the succeeding arches. The ectoderm-lined space between the overhanging second arch ectoderm and the rest of the arches is called the cervical sinus. The lower end of the growing second arch ectoderm fuses with the...
Derivatives of First Arch (Fig. 42.3)

1. The ectoderm of the first cleft forms the external acoustic meatus.
2. The first cleft membrane (consisting of three germ layers) persists to develop into tympanic membrane.
3. The mesodermal derivatives are skeletal and muscular.
   i. The first arch cartilage (Meckel’s cartilage) gives rise to malleus, incus, anterior ligament of malleus, sphenomandibular ligament and the mandible.
   ii. The muscles developed from the first arch mesoderm are the four muscles of mastication (temporalis, masseter, lateral pterygoid and medial pterygoid), tensor tympani, tensor palati, mylohyoid and anterior belly of digastric.

   The mandibular nerve supplies all the eight muscles.

Derivatives of Second Arch (Fig. 42.3)

i. The second arch cartilage (Reichert’s cartilage) gives rise to the stapes, styloid process of temporal bone, stylohyoid ligament, lesser horn of hyoid bone and the upper part of the body of hyoid bone.

ii. The muscles developed from this arch are, occipitofrontalis, muscles of facial expression including platysma, auricular muscles, stapedius, buccinator, posterior belly of digastric and the stylohyoid.

   The Facial nerve supplies all these muscles.

Derivatives of Third Arch (Fig. 42.3)

i. The cartilage of the third arch gives rise to greater horn of the hyoid bone and the lower part of its body.

ii. The stylopharyngeus muscle is the only one developed from the third arch and is supplied by the glossopharyngeal nerve.

Derivatives of Fourth and Sixth Arches

i. The cartilages of the larynx are derived from the fourth and sixth arches.

ii. The muscles developed from the fourth and sixth arches are the muscles of the pharynx (except stylopharyngeus), muscles of soft palate (except tensor palati) and the muscles of larynx. The nerves of these arches are derived from vagoaccessory complex and laryngeal branches of the vagus nerve.

Anomalies of Cervical Sinus (Fig. 42.2)

i. Branchial cyst develops if the cervical sinus does not obliterate completely. A part of the sinus may persist along the anterior margin of the sternomastoid muscle just below the angle of mandible. It presents as a painless fluctuant swelling in the neck.

ii. Branchial fistula develops when the cervical sinus remains open at its caudal end. The fistula may be of three types. An external fistula or branchial sinus is the branchial cyst that has an opening on the exterior, usually found along the anterior margin of the sternomastoid above the sternoclavicular joint. An internal fistula is the branchial cyst with an opening in the wall of the tonsillar fossa just in front of its posterior pillar. A complete fistula is a rare anomaly, where the branchial cyst communicates with the pharynx as well as with the skin.

The mandibular nerve supplies all the eight muscles.
Derivatives of Endodermal Pouches (Fig. 42.4)

i. The dorsal part of the first pouch unites with the dorsal part of the second pouch to form tubotympanic recess, which gives rise to the auditory (pharyngotympanic) tube, middle ear and tympanic (mastoid) antrum.

ii. The ventral part of the second pouch forms the palatine tonsil.

iii. The third pouch gives rise to the inferior parathyroid gland and thymus.

iv. The fourth pouch gives rise to the superior parathyroid gland.

v. Fusion of fifth pouch with part of fourth pouch forms the caudal pharyngeal complex or ultimobranchial body, which is believed to give rise to C-cells (parafollicular cells) of thyroid gland.

Anomalies of Pharyngeal Pouches

i. Di George syndrome also known as third and fourth pharyngeal pouch syndrome is due to failure of development of third and fourth pouches. This syndrome is characterized by, hypoplasia or absence of thymus (resulting in greatly reduced cell-mediated immunity) and absence of parathyroid glands (resulting in hypocalcaemia and tetany).

ii. Nezelof’s syndrome is due to failure of development of only the third pharyngeal pouch. As a result this syndrome is characterized by presence of superior parathyroid glands (normal function of parathyroid glands) but absence of inferior parathyroid glands and thymus (reduced cell-mediated immunity).
The thyroid gland is a highly vascular endocrine gland situated in the lower part of the front of the neck in close relation to larynx and trachea. The follicular cells of the thyroid gland secrete tri-iodo-thyronine (T3) and tetra-iodo-thyronine (T4) hormones, which raise the rate of metabolism. The hormones are stored in the follicles of the gland as thyroglobulin. The parafollicular cells secrete calcitonin, which is a hypocalcemic hormone.

**General Features (Fig. 43.1)**

i. The thyroid gland weighs approximately 25 gm in adult being slightly heavier in female.

ii. It consists of right and left lobes, which are connected by an isthmus.

iii. Each lobe is around 5 cm in length, 3 cm in breadth and 2 cm in thickness.

iv. The lobes extend from the oblique line of the thyroid cartilage to the level of fifth or sixth tracheal ring and correspond to C5-T1 vertebrae.

v. The isthmus lies against the second to fourth (or second to third) tracheal rings.

vi. A small pyramidal lobe usually extends from the upper margin of the isthmus on the left side. It may be attached to the hyoid bone by a slip of a muscle called levator glandulae thyroideae.

vii. The upward shift of an enlarged thyroid gland is arrested by the attachment of sternothyroid muscle to the oblique line of thyroid cartilage.

viii. The short neck and strong strap muscles are responsible for pushing the lower pole of a normally located but enlarged gland downward into the superior mediastinum (retrosternal goiter).

**Embryologic insight (Fig. 43.2) ...**

The thyroid gland develops from thyroglossal duct, which originates from the endoderm of the floor of the embryonic pharynx at the foramen cecum (which is a midline foramen at the junction of the anterior two-thirds and posterior one-third of

Contd...
the developing tongue). The thyroglossal duct has a peculiar course as follows. It passes from the foramen cecum via the substance of the tongue downwards in the midline anterior to the hyoid bone. The duct usually recurs posterior to the hyoid bone before proceeding down in front of thyroid and cricoid cartilages. The bilobed lower end of the thyroglossal duct gives origin to the follicular cells of the thyroid gland. The caudal pharyngeal complex (ultimobranchial body) joins each side of the lower end of thyroglossal duct to give origin to parafollicular cells. The thyroid gland starts functioning from the fourth month of intrauterine life.

**Remnants of Thyroglossal Duct**

i. The cranial end of the thyroglossal duct is indicated by the foramen cecum of the tongue.

ii. The caudal end of the duct may persist as pyramidal lobe extending from the isthmus and the occasional levator glandulae thyroideae (a fibromuscular slip attaching the pyramidal lobe to the hyoid bone).

iii. The rest of the thyroglossal duct obliterates.

**Congenital Anomalies (Fig. 43.3)**

i. If the thyroglossal duct fails to descend, the thyroid gland may remain in the oral cavity on the dorsum of the tongue. Such an anomaly is called lingual thyroid.

ii. Other ectopic sites of the thyroid gland are along the course of the thyroglossal duct, intralingual, suprathyroid, retrohyoid or infrahyoid.

iii. The thyroglossal duct may persist as thyroglossal cyst, which usually presents as midline swelling in the neck. Usually it is found in the vicinity of the hyoid bone. During surgical removal of the cyst the body of hyoid bone is also removed to prevent recurrence.

iv. A thyroglossal fistula is formed when the cyst breaks through the skin.

**Capsules of Thyroid Gland (Fig. 43.4)**

The thyroid gland has a true capsule (fibrous) and a false capsule (fascial).

i. The true capsule is the condensation of the connective tissue at the periphery of the gland. The venous plexus lies deep to the true capsule.

ii. The false capsule is derived from the pretracheal layer of deep cervical fascia. The pretracheal fascia is attached above to the oblique line of thyroid cartilage. On the posteromedial aspect of the lobe, the fascial capsule is thickened to form the suspensory ligament of Berry, which is attached to the arch of cricoid cartilage.
This ligament holds the gland firmly in contact with the larynx and thus prevent it from sliding down, when enlarged. During surgical removal of the gland, the ligament of Berry must be identified and cut. The attachments of the pretracheal fascia to the thyroid and cricoid cartilages and also to the hyoid bone are responsible for the movements of the thyroid during swallowing (deglutition) and speech.

**Relations of Lobes (Fig. 43.5)**

Each lobe of thyroid gland presents three surfaces and two borders.
1. Superficial (anterolateral) surface.
2. Medial surface.
3. Posterior (posterolateral) surface.
4. The anterior border separates the superficial and the medial surfaces.
5. The posterior border separates the medial surface from the posterolateral surface.

**Relations of Surfaces**

1. The superficial surface is related to sternothyroid, sternohyoid and superior belly of omohyoid muscles, which in turn, are laterally covered by the anterior margin of sternomastoid.
2. The relations of medial surface are as follows:
   i. The superior part of medial surface is related to the larynx and pharynx and to the inferior constrictor and cricothyroid muscles with external laryngeal nerve between the two.
   ii. The inferior part of medial surface is related to the trachea and esophagus. The recurrent laryngeal nerve passes upwards in the groove between the trachea and esophagus to lie immediately behind the cricothyroid joint and the ligament of Berry.
3. The posterolateral surface is related to the carotid sheath (with its contents), sympathetic chain behind the carotid sheath and to the prevertebral fascia and longus colli directly behind. On the left side, the lower pole may be closely related to the arch of the thoracic duct.
4. The anterior border is related to the anterior branch of superior thyroid artery.
5. The posterior border is related to the parathyroid glands and the anastomosis between the superior and inferior thyroid arteries.

**Relations of Isthmus**

i. Anteriorly, it is covered from within outwards by pretracheal fascia, strap muscles, investing layer of deep fascia, superficial fascia with anterior jugular veins and the skin.
ii. Posteriorly, it rests on second to third or second to fourth tracheal rings.
iii. Along its upper margin, the terminal parts of anterior branches of both superior thyroid arteries take part in a rich anastomosis, which supply twigs to the anterior surface of the isthmus also.
iv. Along the lower margin of the isthmus, the inferior thyroid veins emerge and the thyroidea ima (when present) enters. These vascular relations of the isthmus are to be kept in mind during tracheostomy.

**Arterial Supply (Figs 43.6 and 43.7)**

The superior and inferior thyroid arteries and an occasional arteria thyroidea ima (ima means single or unpaired) provide rich blood supply to the gland. The thyroid arteries are large-sized and show arterial loops in order to accommodate the upward and downward movements of the thyroid gland.

i. The superior thyroid artery is a branch of external carotid artery. It descends to the superior pole of the lateral lobe of the thyroid gland accompanying the external laryngeal nerve. The artery enters the gland at the upper pole but the nerve goes deep. Hence, the upper pole is the safest site for tying the superior thyroid artery during thyroidectomy.

ii. The inferior thyroid artery arises from the thyrocervical trunk of the first part of subclavian artery. It forms a loop with upward convexity to reach the level of sixth cervical vertebra and then descends to reach the base of the lateral lobe of the gland. It enters the lower pole of the gland, where it is very close to the recurrent laryngeal nerve. Hence, it is safer to tie the inferior thyroid artery as away from the lower pole of the gland as possible during thyroidectomy.
Chapter 43

Thyroid Gland and Parathyroid Glands

Fig. 43.6: Relations of thyroid arteries and accompanying nerves on left side.
(Note that black arrow indicates safe site to ligate superior thyroid artery and green arrow to ligate inferior thyroid artery)

iii. The thyroidea ima is a branch of arch of aorta or brachiocephalic trunk. It ascends in front of the trachea and enters the isthmus. It is not always present.

iv. The accessory thyroid arteries are the twigs from esophageal and tracheal branches of inferior thyroid arteries.

Venous Drainage (Fig. 43.8)
The thyroid veins do not accompany the thyroid arteries. The following three pairs of veins arise from venous plexus that lies deep to the true capsule.

i. The superior thyroid veins emerge from the upper pole on each side and terminate into the corresponding internal jugular veins.

ii. A very short middle thyroid vein emerges from the lobe and terminates into internal jugular vein of corresponding side.

iii. The inferior thyroid veins emerge from the lower margin of isthmus and descend on the anterior surface of trachea to open into the left brachiocephalic vein (though occasionally they open into respective brachiocephalic veins). The right and left inferior thyroid veins frequently communicate with each other in front of the trachea. Injury to these veins is a source of bleeding during tracheostomy.

iv. Occasionally, Kocher’s vein is present between the inferior and middle thyroid veins. It opens into the internal jugular vein.

Note: On the left side, there is a chance of injuring the arch of the thoracic duct during tying the artery.

The ascending branch of the inferior thyroid artery anastomoses with the descending branch of the superior thyroid artery along the posterior margin of the gland. While tying the branches of inferior thyroid artery, its ascending branch supplying the parathyroid glands is always preserved, since it is the main supply of the parathyroid glands.
Lymphatic Drainage (Fig. 43.9)

i. The lymph from the upper part of the thyroid gland reaches the upper deep cervical nodes (jugulodigastric) either directly or through the prelaryngeal nodes.

ii. The lymph from the lower part of the gland reaches the lower deep cervical group (jugulo-omohyoid) either directly or through the pretracheal (Delphic) and paratracheal nodes.

iii. A few lymph vessels may drain into brachiocephalic nodes in the superior mediastinum while others may directly reach the thoracic duct.

The lymphatic spread of papillary carcinoma of the thyroid gland manifests in an interesting way. The thyroid gland looks normal but the deep cervical lymph node of the jugular chain is enlarged and contains thyroid tissue.

Nuclear Scan of Thyroid Gland

It is a procedure to study functioning of thyroid gland by isotope scanning. The radioactive iodine ($^{131}$I) is given orally and then the photographs of thyroid gland are taken. Hyperactive area (hot spots) look darker than normal tissue and hypoactive areas look lighter or completely blank (cold spots). Thyroid scans are very useful in locating thyroid tissue outside the neck (lingual or retrosternal).

Thyroid Swellings (Fig. 43.10)

Enlargement of thyroid gland (goiter) is the common cause of a midline swelling in the neck. The thyroid swelling moves with deglutition. The goiter may present as a smooth swelling or a nodular swelling.

i. The smooth swelling may be visible during pregnancy.

ii. The endemic goiter presents as a large swelling due to deficiency of iodine in the diet or drinking water. Such goiters produce symptoms and signs of hypothyroidism.

iii. Toxic goiters (hyperthyroidism or thyrotoxicosis) manifest as symptoms related to the eye, cardiovascular system and nervous system. They are of diffuse or nodular variety.

iv. Thyroid cancer may present as enlargement of the gland.

Some types of thyroid cancer spread by lymph vessels while other types spread by blood to distant places like lungs, ends of long bones, skull and vertebrae.

Pressure Effects of Thyroid Swellings

The enlarged thyroid gland tends to compress the structures that are its anatomical relations. The pressure effects may be varied, depending on the structure or structures compressed as follows:

Clinical insight ...

Contd...
The parathyroid glands are small (6 × 3 × 2 mm) endocrine glands along the posterior margin of the lobe of thyroid gland. They are inside the fascial capsule of the thyroid gland. There are two pairs of parathyroid glands consisting of right and left superior and right and left inferior glands. The secretion of parathyroid glands is called parathyroid hormone or parathormone. It maintains the blood calcium level by mobilizing the stored calcium from the bones. Its action is opposite to that of thyrocalcitonin.

**Location**

The superior parathyroid gland of each side is usually on a level with the junction of upper and middle-thirds of lateral lobe of thyroid gland. The inferior gland lies behind the lower end of the thyroid gland on each side near the angle between the inferior thyroid artery and recurrent laryngeal nerve.

The parathyroid glands appear as small yellowish brown bodies. They are identified during surgery by isolating a small arterial branch that runs from the inferior thyroid artery to each parathyroid gland. Sometimes histological demonstration by taking frozen section is the only way to identify the gland during surgery.

### PARATHYROID GLANDS (FIG. 43.11)

<table>
<thead>
<tr>
<th>Structure</th>
<th>Effect of compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Trachea</td>
<td>Dyspnea or shortness of breath</td>
</tr>
<tr>
<td>2. Esophagus</td>
<td>Dysphagia or difficulty in swallowing</td>
</tr>
<tr>
<td>3. Recurrent laryngeal nerve</td>
<td>Hoarseness of voice</td>
</tr>
<tr>
<td>4. Carotid sheath</td>
<td>Posterior displacement</td>
</tr>
<tr>
<td>5. Sympathetic chain</td>
<td>Horner’s syndrome</td>
</tr>
</tbody>
</table>

**Operations on Thyroid Gland**

i. Thyroid lobectomy consists of removal of a lobe along with the isthmus.

ii. Near-total thyroidectomy consists of total thyroid lobectomy on the affected side with conservation of small thyroid tissue (between the esophagus and trachea) on the normal side.

iii. Total thyroidectomy includes removal of the entire gland.

**Complications of Thyroid Surgery**

i. Injury to the recurrent laryngeal nerve while tying the inferior thyroid artery or its branches is the most feared complication.

ii. In one percent of cases, the right recurrent laryngeal nerve may be nonrecurrent arising from the right vagus higher up in the neck. The reason for this anomaly is that the right subclavian artery is aberrant (Fig. 28.6). Therefore, if the surgeon does not locate the nerve in its normal position on the right side he or she must keep in mind the possibility of nonrecurrent right recurrent laryngeal nerve.

iii. Inadvertent removal of parathyroid glands along with thyroid gland results in parathyroid insufficiency (tetany). Tetany can also result due to injury to the artery supplying the parathyroid glands.

### Embryologic insight (Fig. 42.4)

The superior parathyroid glands develop from the endoderm of the fourth pharyngeal pouch on each side. The inferior parathyroid glands develop along with thymus from the endoderm of third pharyngeal pouch. Both descend to reach their definitive positions. At times the inferior parathyroid may ascend in superior mediastinum.

**Congenital Anomalies**

In DiGeorge syndrome both thymus and all four parathyroid glands are congenitally absent but in Nezelof’s syndrome, thymus and inferior parathyroid glands are absent but superior parathyroid glands are present.

**Blood Supply**

Both the superior and inferior parathyroid glands receive mainly small branches from the inferior thyroid arteries. The superior pair also receives branches from the anastomosis between the posterior branch of superior thyroid and ascending branch of inferior thyroid arteries. The tiny parathyroid arteries enter the hilum-like areas, which
distinguish the gland from the fat lobule. The inferior thyroid artery must be ligated distal to the origin of parathyroid artery during thyroidectomy. The veins and lymph vessels of the parathyroid glands follow the thyroid veins and lymph vessels.

**Clinical insight ...**

i. Parathyroidectomy means surgical removal of the parathyroid glands. Usually, three and half glands are removed leaving one half in the normal position.

Contd...

Alternatively, all the four glands are removed and a few pieces of one gland are implanted in the muscle of the forearm on one side, where they grow and produce required hormone.

ii. Parathyroid insufficiency results in tetany, which is characterized by low serum calcium, convulsions and carpopedal spasms due to increased neuromuscular excitability, and sensory symptoms like, numbness and tingling in hands and feet.

iii. Excess of parathormone leads to rise in blood calcium level due to excessive absorption from bones. This leads to fragility of bones and proneness to fractures.
The carotid arteries (common, internal and external) and the subclavian arteries pass through the neck. The external carotid and the subclavian arteries give branches in the neck. The jugular veins (anterior, external and internal) and the subclavian veins are the major venous channels of the neck.

**Common Carotid Arteries**

Due to the difference in the origin of the common carotid arteries (CCA), the left artery is longer than the right.

i. The left common carotid artery is a direct branch of the arch of aorta in the superior mediastinum.

ii. The right common carotid artery is one of the terminal branches of the brachiocephalic trunk behind the right sternoclavicular joint.

Each common carotid artery terminates by dividing into the external and internal carotid arteries at the level of upper margin of thyroid cartilage in the carotid triangle. The cervical course of the right and left arteries is similar.

**Surface Marking**

1. The left common carotid artery is marked by drawing two parallel lines about 8 to 10 mm apart joining the three points as follows:

   i. The lowest point lies just to the left of the center of manubrium sterni.

   ii. The second point corresponds to the left sternoclavicular joint.

   iii. The third point is marked on the anterior margin of the left sternomastoid at the level of upper margin of the thyroid cartilage.

2. The right common carotid artery is drawn similarly by joining the point on the right sternoclavicular joint and the point at the level of upper margin of thyroid cartilage on the anterior margin of the right sternomastoid.

**Cervical Course of Common Carotid Artery**

Each common carotid artery is enclosed in the carotid sheath along with the internal jugular vein and the vagus nerve. It runs up along the anterior margin of the sternomastoid but on a deeper plane.

i. It lies successively on the subclavian artery, vertebral artery and at the level of the carotid tubercle on the inferior thyroid artery. The thoracic duct crosses behind the lower part of the left artery and the right recurrent laryngeal nerve crosses behind the right artery.

ii. The common carotid artery is crossed by the superior belly of omohyoid at the level of cricoid cartilage. Below this level it is deeply placed because the sternomastoid...
and the infrahyoid muscles overlap it. But, above the level of omohyoid the artery is closer to the surface.

iii. Medially, the common carotid artery is related to larynx and pharynx up to the lower margin of cricoid cartilage, below which it is related to the trachea and esophagus. The thyroid gland, recurrent laryngeal nerve and inferior thyroid artery are its medial relations.

iv. The internal jugular vein is the immediate lateral relation inside the carotid sheath.

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**Clinical insight ...**

**Carotid Sinus and Body**

i. The carotid sinus is a slight dilatation at the bifurcation of common carotid artery and the commencement of internal carotid artery. It is a baroreceptor and hence richly innervated by carotid sinus branch of the glossopharyngeal nerve and branches of vagus and sympathetic chain. Carotid sinus hypersensitivity or digital pressure on one or both carotid sinuses may cause excessive slowing of heart rate, fall in BP and fainting (cardinal features of carotid sinus syndrome).

ii. The carotid body is a small reddish structure behind the bifurcation of common carotid artery. These bodies function as respiratory chemoreceptors to monitor oxygen and carbon dioxide levels in blood. The glomus cells and ganglion cells in carotid bodies receive nerve supply from the same sources as the carotid sinus.

The carotid bodies show enlargement in people, who live in high altitudes and in patients with hypoxia due to chronic lung diseases. The carotid body tumor or potato tumor of neck is a benign growth of carotid body usually adherent to all the three carotid arteries. It is a pulsatile swelling that moves transversely (vertical movement being prevented by the fork of the bifurcation of common carotid artery). When sufficiently enlarged it compresses the adjacent carotid sinus thereby precipitating an attack of carotid sinus syndrome.

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**Internal Carotid Artery**

The internal carotid artery (ICA) supplies the large part of the cerebral hemisphere, pituitary gland, eye and orbit, forehead and part of nasal cavity. It begins at the bifurcation of common carotid artery and ascends in the carotid sheath to reach the base of the skull. It enters the petrous part of the temporal bone by entering the carotid canal, in which it travels to reach the foramen lacerum, through the upper opening of which it enters the middle cranial fossa.

**Anterior Relation (Fig. 44.1)**

The anterior relations in the carotid triangle and above the triangle are different.

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**In Carotid Triangle**

The internal carotid artery is superficial in the carotid triangle. Its anterior relations are the skin, superficial fascia, deep fascia and anterior border of sternomastoid. It is crossed by occipital artery and hypoglossal nerve. The external carotid artery is anteromedial to the internal carotid artery.

**Above the Carotid Triangle**

The posterior belly of digastric and stylohyoid muscles cross it. The posterior auricular artery, styloid process and stylopharyngeus muscle, glossopharyngeal nerve and pharyngeal branch of vagus are the other structures that cross it. The parotid gland and its contents (external carotid artery and its bifurcation, facial nerve, retromandibular vein) lie in front of the artery.

**In Posterior Part of Digastric Triangle**

The external carotid artery lies superficial and lateral to the internal carotid artery. However, the styloid process, stylopharyngeus muscle, glossopharyngeal nerve, pharyngeal branch of vagus and the deep part of parotid gland separate the two arteries.

**Posterior Relation**

Behind the carotid sheath the internal carotid artery is related to the longus capitis muscle and the sympathetic chain. The superior laryngeal branch of the vagus passes posterior to the artery.
Lateral Relation
The internal jugular vein is on its lateral aspect and the vagus nerve is on the posterolateral aspect inside the carotid sheath.

External Carotid Artery
The external carotid artery (ECA) takes origin from the common carotid artery in the carotid triangle at the upper border of thyroid cartilage. It terminates in the substance of the parotid gland by dividing into superficial temporal and maxillary arteries at the back of the neck of mandible.

Relations in Carotid Triangle
i. The external carotid artery is anteromedial to the internal carotid artery in the carotid triangle.
ii. It gives rise to branches in the carotid triangle and lies closer to the surface, having the same superficial relations as the internal carotid artery.
iii. Medial relations of the artery in the triangle are the lateral pharyngeal wall, superior laryngeal nerve and ascending pharyngeal artery.
iv. The hypoglossal nerve, the lingual vein, common facial vein and superior thyroid vein cross the artery in the triangle.
v. As the artery leaves the carotid triangle, it is crossed by posterior belly of digastric and the stylohyoid muscles.

Relations in Posterior Part of Digastric Triangle
i. Here, the artery lies in the narrow gap between the parotid and the pharynx.
ii. It changes its relation to the internal carotid by coming in lateral relation from the anteromedial relation.

Branches in Carotid Triangle (Fig. 40.15)

i. Ascending pharyngeal artery is the first branch in the carotid triangle. It is a long slender branch that runs close to the pharyngeal wall. It is distributed to the pharynx, auditory tube, tonsil, palate, middle ear and meninges.
ii. Superior thyroid artery arises from anterior aspect. It runs downward and medially towards the superior pole of thyroid gland. Its named branches, from above downwards are, infrahyoid, superior laryngeal, sternomastoid, cricothyroid and glandular to thyroid and parathyroid glands. The superior thyroid artery is accompanied by external laryngeal nerve.
iii. Lingual artery is the chief supply of the tongue. It arises from the anterior aspect opposite the tip of the greater horn of hyoid. It is divided into three parts by the hyoglossus muscle. The first part of the lingual artery lies in the carotid triangle. It forms a characteristic upward loop, which is crossed by the hypoglossal nerve. The first part of the lingual artery is the preferred site for applying ligature. The second part passes deep to the hyoglossus muscle. The third part is known as arteria profunda linguae or deep lingual artery. It ascends along the anterior border of the hyoglossus. On reaching the undersurface of the tongue it runs forwards beneath the mucous membrane on the side of the frenulum linguae. It ends at the tip of the tongue by anastomosing with the artery of opposite side. It gives a few named branches (suprahyoid from the first part, dorsal lingual from the second part, and the sublingual from the third part).
iv. Facial artery is a big artery that has a cervical and facial course. Like the lingual artery it forms a loop in its cervical course. Its relation to the submandibular gland is very important. Details of the artery are given along with blood supply of face.
v. Occipital artery arises from the posterior aspect of the external carotid artery at the level of facial artery. It leaves the carotid triangle by following the lower margin of posterior belly of digastric muscle. At first it crosses the anterior aspect of the transverse process of atlas and then traverses the vascular groove on the medial aspect of mastoid process. Here, it lies deep to...
the digastric and other muscles attached to the mastoid process. In its further course the occipital artery enters the roof of the suboccipital triangle. It pierces the insertion of trapezius two to three centimeters from the midline to enter the superficial fascia of the posterior quadrant of the scalp in company with the greater occipital nerve. The occipital artery has a wide area of distribution. It gives two sternomastoid branches in the carotid triangle. In the suboccipital region, there are the muscular and the descending branches, which anastomose with the transverse cervical artery. The occipital artery may injure in the fracture of the base of skull near the mastoid process. This may result in bleeding and formation of a hematoma behind the ear, which may displace the pinna forwards (Battle’s sign).

**Branches Outside Carotid Triangle**

i. Posterior auricular artery arises just above the digastric and stylohyoid muscles. Its named branches are, stylomastoid (in one-third of subjects), auricular and occipital arteries.

ii. Superficial temporal artery is the smaller terminal branch of the external carotid artery given off in the substance of the parotid gland. This artery leaves the parotid gland through its base and crosses the root of the zygomatic arch to enter the anterior quadrant of the scalp. About five centimeters above the root of the zygomatic arch the superficial temporal artery divides into its anterior (frontal) and posterior (parietal) branches. Apart from branches to parotid gland the named branches of the artery are, transverse facial, anterior auricular, zygomatico-orbital, middle temporal (which perforates the temporal fascia and grooves the squamous temporal bone) and the terminal branches (Fig. 38.6). The arterial pulse can be felt at the root of the zygomatic arch in front of the auricle.

iii. Maxillary artery is the other terminal branch of the external carotid artery. It leaves the parotid gland to enter the infratemporal fossa. The details of the artery are dealt along with the infratemporal and pterygopalatine fossae.

**Subclavian Artery (Fig. 44.2)**

The subclavian arteries have a wide area of distribution as they supply the upper limb, part of neck and part of thoracic and abdominal walls, the contents of posterior cranial fossa and the spinal cord.

**Origin and Termination**

i. The right subclavian artery is a branch of brachiocephalic artery hence, it begins behind the right sternoclavicular joint.

**Surface Marking**

i. The left subclavian artery is marked by a 8 mm wide line, which starts at the left margin of the manubrium sterni at the level of the center of manubrium. This line is extended to the left sternoclavicular joint and then to the midclavicular point with upward convexity.

ii. The right subclavian artery is marked by a similar line, which starts at the right sternoclavicular joint and extends laterally to the midclavicular joint with an upward convexity.

**Parts of Subclavian Artery**

The scalenus anterior muscle crosses in front of the artery to reach the first rib for insertion. The muscle divides the subclavian artery in three parts. There are differences in the relations of the first part on the two sides but the second and third parts are identical on the two sides. The third part of the artery is the content of the posterior triangle.

First Part of Right Subclavian Artery

This part extends from the right sternoclavicular joint to the medial margin of right scalenus anterior. It ascends about two centimeters above the clavicle to take an arched course. The first part of the subclavian artery forms the base of the scalenovertebral triangle.

**Relations**

i. Anteriorly, the first part is covered by several structures hence it is deeply placed. The sternomastoid,
Chapter 44

Blood Vessels, Nerves and Lymph Nodes of Neck

sternohyoid and sternothyroid muscles cross in front of it. The union of right internal jugular and right subclavian veins to form right brachiocephalic vein takes place in front of the first part. The right vertebral vein crosses it. The nerves that cross the artery in front are, right vagus and its cervical cardiac branches, cervical cardiac branches of right sympathetic chain and ansa subclavia (a connection between the middle and inferior sympathetic ganglia).

ii. Two nerves loop round the inferior aspect (ansa subclavia and right recurrent laryngeal nerve).

iii. The posterior relations are the apex of the right lung, cervical pleura and suprapleural membrane. The same two nerves come in posterior relations after hooking round the inferior aspect.

First Part of Left Subclavian Artery

i. The thoracic part of the first part of the left subclavian artery is related to the structures in the superior mediastinum. Anteriorly, it is in relation to the left common carotid artery, left vagus, left phrenic nerve and left brachiocephalic vein. Its posterior relations are the left side of esophagus and thoracic duct. Medially, it is related to trachea, left recurrent laryngeal nerve, esophagus and thoracic duct and laterally, it is in contact with the mediastinal surface of the left lung and pleura.

ii. The relations of the cervical part of the first part of the left subclavian artery are similar to those on the right side except for the following. Anteriorly, it is crossed by the thoracic duct and the left phrenic nerve.

Second Part of Subclavian Arteries

Anteriorly, the artery is related to the scalenus anterior muscle and the subclavian vein in front of the muscle. Posteriorly there are lung and pleura, Sibson’s fascia and lower trunk of brachial plexus. Superiorly, it is related to the upper and middle trunks of brachial plexus.

Third Part of Subclavian Arteries

The third part extends from the lateral margin of the scalenus anterior to the outer margin of the first rib. It lies in the subclavian triangle of the neck.

Clinical insight ...

Approach to Subclavian Artery

This is the most superficial part of the subclavian artery and hence it can be approached just lateral to the posterior margin of the sternomastoid muscle and can be compressed against the first rib with shoulder depressed and the pressure being directed in downward, backward and medial direction.

Relations of Third Part

The third part is related anteriorly to the external jugular vein and its tributaries and nerve to subclavious. The clavicle lies in front of it. The subclavian vein is present anteroinferiorly while the lower trunk of brachial plexus lies posteroinferiorly. The left lung and pleura form the posterior relations. The middle and superior trunks of the brachial plexus lie superiorly. The artery is in direct contact with the superior surface of first rib inferiorly. The subclavian artery and the lower trunk of the brachial plexus lie in a narrow scalene triangle bounded by the superior surface of the first rib and the scalenus anterior and medius muscles. The cervical rib may further narrow the triangle producing symptoms of arterial and neural compression giving rise to the cervical rib syndrome (Fig. 24.2).

Branches of First Part (Fig. 44.2)

There are three branches from the first part, vertebral, thyrocervical, and the internal mammary arteries. The costocervical trunk is the branch of the first part on the left side only.

1. For vertebral artery (refer to the suboccipital triangle in chapter 53).

2. Thyrocervical trunk at once breaks up into three branches, inferior thyroid, suprascapular and transverse cervical.

i. The inferior thyroid artery forms a loop to reach the inferior pole of the thyroid gland. First it runs up along the medial margin of scalenus anterior then turns medially just below the transverse process of the sixth cervical vertebra and finally it descends on the longus colli to reach the inferior pole of the thyroid gland. As the inferior thyroid artery nears the thyroid gland it is closely related to the recurrent laryngeal nerve. The branches of the inferior thyroid artery are, ascending cervical, inferior laryngeal, pharyngeal, tracheal, esophageal and glandular to thyroid and parathyroid glands. The inferior thyroid artery may be injured in surgery on thyroid gland.

ii. The suprascapular artery turns laterally across the scalenus anterior muscle to reach the posterior triangle. Here, it crosses anterior to the third part of the subclavian artery and the brachial plexus. The suprascapular artery and the nerve leave the posterior triangle along with the inferior belly of omohyoid and reach the scapular region. Further course of the artery is described along with muscles of the back.

iii. The transverse cervical artery divides in superficial and deep branches in the posterior triangle.
Frequently, the deep branch takes origin directly from the third part of the subclavian artery. In that case it is called the dorsal scapular artery, which accompanies the dorsal scapular nerve to the back. In such cases the superficial branch represents the transverse cervical artery and travels along the accessory nerve to the deep surface of the trapezius muscle.

3. The internal mammary artery (internal thoracic) takes origin from the inferior aspect of the subclavian artery. Its further course is described in chapter 24 on blood vessels of the thoracic wall.

Branches of Second Part
The costocervical trunk takes origin from the posterior aspect of the second part of the subclavian artery on the right side and from the first part of the subclavian artery on the left side. Sometimes it takes origin from the first part on both sides. It divides in the superior or highest intercostal and deep cervical branches at the neck of the first rib. The superior intercostal artery descends in front of the neck of the first rib and gives posterior intercostal arteries to the first two intercostal spaces. The deep cervical artery passes to the back of the neck, where it ascends in the deep muscles and anastomoses with the descending branches of the occipital artery.

Branches of Third Part
Usually there are no branches but in a percentage of subjects the dorsal scapular artery takes origin from the third part and takes the place of the deep branch of the transverse cervical artery.

**VEINS OF NECK**

The veins of the neck are the anterior jugular, external jugular, internal jugular and the subclavian veins. The anterior jugular veins are described with midline region of the front of the neck and the external jugular veins are described with the posterior triangle of neck. These two are the superficial veins of the neck.

**Internal Jugular Vein (Fig. 44.3)**
The internal jugular vein (IJV) is the major deep vein of the neck. It lies inside the carotid sheath. It begins as a continuation of the sigmoid sinus at the posterior part of the jugular foramen at the base of the cranium. At its origin it exhibits superior bulb, which is closely related to the floor of middle ear. The vein travels in the carotid sheath to the root of the neck, where it joins the subclavian vein to form the brachiocephalic vein medial to the medial border of the scalenus anterior and behind the medial end of the clavicle. At its termination it lies in the lesser supraclavicular triangle between the sternal and clavicular heads of the sternomastoid, where it can be easily approached. It presents the inferior bulb at its termination. The cervical lymph nodes belonging to the deep group lie in intimate relation of the internal jugular vein. The IJV may be injured during removal of the tuberculous or neoplastic (nodes involved in malignancy) lymph nodes.

**Surface Marking**
A broad band from the lobule of the ear to the medial end of the clavicle represents the IJV. Its inferior bulb is located in the depression between the sternal and clavicular heads of the sternomastoid muscle.

**Tributaries**
Inferior petrosal sinus is the first tributary and opens in the superior bulb of the internal jugular vein. The other tributaries are, pharyngeal veins, common facial vein, lingual veins (deep lingual and dorsal lingual), superior thyroid and middle thyroid veins and occasionally the occipital vein.

**Subclavian Vein**
Each subclavian vein begins as the continuation of axillary vein at the outer border of first rib. It has two parts corresponding to the third and second parts of the subclavian artery. In the posterior triangle it lies anterior and inferior to the subclavian artery. This part of the vein lies in
the anterior vascular groove on the superior surface of the first rib. The second part of the subclavian artery is separated from the vein by the scalenus anterior muscle. The subclavian vein ends by joining the internal jugular vein to form the brachiocephalic vein at the medial margin of the scalenus anterior muscle behind the medial end of the clavicle. External jugular vein is its main tributary in the posterior triangle.

### Clinical insight ...

The internal jugular and the subclavian veins are usually used in clinical practice for central venous access. This venous route is used for measuring the pulmonary artery pressure and intracardiac pressure, for prolonged intravenous feeding and for introduction of cardiac pace makers.

i. The internal jugular vein is the most commonly used vein for central venous access. In one approach the needle is introduced through the apex of lesser supraclavicular triangle between the two heads of sternomastoid muscle.

ii. The right internal jugular vein is an ideal venous manometer as it is in direct line with the right brachiocephalic vein, superior vena cava and the right atrium. There are no intervening valves in these veins. Therefore pressure in the IJV is the reliable indicator of the right atrial pressure. Normally when the subject is standing or sitting upright the internal jugular vein is collapsed. When the subject is lying flat the vein is completely filled. When the subject lies supine at 45° the point at which jugular pulsation becomes visible is usually above the clavicle. A quick rule of thumb is, if jugular venous pulsation is visible above the clavicle with the subject bolt upright then the jugular venous pressure (JVP) must be raised. The common cause of raised jugular pressure is congestive cardiac failure.

iii. The subclavian vein is the commonly used vein for central venous access for which infraclavicular approach is considered safer. The needle is inserted below the clavicle at the junction of its medial and middle-thirds and then directed towards the posterior aspect of suprasternal notch to reach the vein.

### Formation (Fig. 44.4)

There are three loops in the cervical plexus. Each ramus except the first divides into ascending and descending parts, which unite in communicating loops. The first loop is between C2 and C3, the second between C3 and C4 and the third between C4 and C5 rami. The lowest loop connects the cervical and brachial plexuses. The C1 communicates with C2 but all C1 fibers leave this connection to join the hypoglossal nerve. The C1 ventral ramus has no cutaneous supply.

### Deep or Muscular Branches

<table>
<thead>
<tr>
<th>Medial</th>
<th>Rectus capitis lateralis and anterior</th>
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<tbody>
<tr>
<td></td>
<td>Longus capitis and longus colli</td>
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<td></td>
<td>Descendens cervicals (C2, C3)</td>
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<tr>
<td></td>
<td>Phrenic nerve (C3, C4, C5)</td>
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<tr>
<th>Lateral</th>
<th>Scalene muscles</th>
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<tr>
<td></td>
<td>Levator scapulae</td>
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<td></td>
<td>Proprioceptive supply to trapezius</td>
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<td>and sternomastoid</td>
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### Superficial Branches (Fig. 40.7)

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<tr>
<th>Ascending</th>
<th>Lesser occipital (C2) nerve</th>
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<tr>
<td></td>
<td>Great auricular (C2, C3) nerve</td>
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<td></td>
<td>Transverse cutaneous nerve of neck (C2, C3)</td>
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<table>
<thead>
<tr>
<th>Descending</th>
<th>Medial, intermediate and lateral</th>
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<tr>
<td></td>
<td>supraclavicular (C3, C4) nerves</td>
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### CERVICAL PLEXUS

The cervical plexus is located in the upper part of the neck behind the prevertebral fascia and in front of the origin of the scalenus medius and levator scapulae muscles. It is formed by the ventral rami of upper four cervical spinal nerves (C1 to C4). Its most important branch is the phrenic nerve, which supplies the muscle of inspiration (diaphragm). Each ventral ramus of cervical plexus receives grey ramus from the superior cervical sympathetic ganglion.
These six cutaneous branches pierce the prevertebral fascia and appear in the posterior triangle of neck at the nerve point of the posterior triangle along with the spinal accessory nerve (refer to posterior triangle of neck in Chapter 40).

**Communicating Branches**

i. The superior cervical sympathetic ganglion gives postganglionic fibers to all four cervical rami via grey rami communicantes.

ii. The first loop of the plexus sends a communicating branch carrying C1 fibers to the hypoglossal nerve.

**Ansa Cervicalis (Fig. 40.13)**

The C1 ventral ramus joins the hypoglossal nerve. A few of the C1 fibers leave the hypoglossal nerve as the superior root of ansa cervicalis. The fibers of C2 and C3 form the inferior root of the ansa. The superior and inferior roots unite with each other to form a nerve loop, which is embedded in the anterior wall of the carotid sheath. The remaining C1 fibers leave the hypoglossal nerve as the superior root of ansa cervicalis. The fibers of C2 and C3 form the inferior root of the ansa. The superior and inferior roots unite with each other to form a nerve loop, which is embedded in the anterior wall of the carotid sheath. The remaining C1 fibers in the hypoglossal nerve, supply to the geniohyoid muscle by a branch of the hypoglossal nerve. The branches to the inferior belly of omohyoid, sternohyoid and sternothyroid arise from the loop. The superior limb supplies the superior belly of omohyoid muscle and thyrohyoid muscle (by a nerve called thyrohyoid branch).

**Phrenic Nerve**

The phrenic nerve (Fig. 26.9) is described in Chapter 26.

**Cervical Sympathetic Chain**

The cervical part of the sympathetic chain extends from the base of the cranium to the neck of the first rib, where it continues as its thoracic part. The cranial continuation of the sympathetic chain is called internal carotid nerve, which forms a plexus along the internal carotid artery. The sympathetic chain has a straight course in the neck lying behind the carotid sheath and in front of the prevertebral fascia.

**Sympathetic Ganglia**

The cervical sympathetic chain is characterized by three ganglia, superior, middle and cervicothoracic or stellate (which is formed by the fusion of inferior cervical and first thoracic ganglia).

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![Fig. 44.5: Cervical sympathetic chain and its branches.](Image)

(Note that vascular branches of superior ganglion to extracranial arteries and those of other ganglia are not shown)

**Superior Cervical Ganglion (Fig. 44.5)**

The superior ganglion is the largest and is formed by fusion of upper four cervical ganglia. It lies in front of the transverse processes of second and third cervical vertebrae. It receives long preganglionic fibers from T1 to T4 segments of spinal cord, as these fibers pass uninterrupted through the corresponding thoracic and the inferior and middle cervical ganglia.

**Branches**

i. Gray rami to first to fourth cervical spinal nerves.

ii. Laryngotraheal branches.

iii. Superior cervical cardiac branch on the left side takes part in the superficial cardiac plexus and on the right side in the deep cardiac plexus.

iv. Communicating branches to the cranial nerves at the base of skull.

v. Branches to common and external carotid arteries form plexuses around these arteries. These plexuses are distributed around branches of external carotid artery. The plexus around the facial artery supplies the sweat glands and blood vessels of the face. The plexus around the middle meningeal artery sends a branch to the otic ganglion and another branch called external petrosal nerve to the geniculate ganglion of the facial nerve.
vi. Internal carotid nerve from the upper pole of the superior ganglion forms a plexus around the internal carotid artery. The plexus provides sympathetic supply to the dilator pupillae through the plexus around the ophthalmic artery or through the communicating branches to the nasociliary nerve. It is noteworthy that the course of the preganglionic as well as postganglionic sympathetic fibers for dilator pupillae muscle is very long.

Cervicothoracic Ganglion

This ganglion is irregular in shape hence the name stellate ganglion. It is formed by the fusion of seventh and eighth cervical ganglia (inferior cervical) and first thoracic ganglion. It is located in the scaleno-vertebral triangle, where it lies behind the first part of the vertebral artery. Here, the ganglion is related to the front of the neck of the first rib.

Branches

i. Gray rami to cervical seventh and eighth nerves and first thoracic nerve for distribution to the upper limb.
ii. Inferior cervical cardiac branch to the deep cardiac plexus.
iii. Branches that form plexus around the subclavian artery, which extends along the axillary artery.
iv. Ansa subclavia connects it to the middle ganglion
v. Branches, which form plexus around the vertebral artery.

Clinical insight ...

Horner’s Syndrome

Lesion of cervical sympathetic chain below the superior cervical ganglion disrupt preganglionic fibers and at or above the ganglion disrupt postganglionic fibers for eye (Fig. 12.3). Interruption of the fibers anywhere along this long route results in constriction of pupil, partial ptosis, loss of sweating and flushing on the same side of face (Horner’s syndrome).

Middle Cervical Ganglion

This small ganglion lies in front of the transverse process of the sixth cervical vertebra. It is formed by fusion of fifth and sixth cervical ganglia. It lies on the inferior thyroid artery.

Branches

i. Gray rami to fifth and sixth cervical spinal nerves.
ii. Middle cervical cardiac branch of each side joins the deep cardiac plexus.
iii. Branches to thyroid and parathyroid glands through a plexus around the inferior thyroid artery.

Clinical insight ...

Stellate Ganglion Block

For stellate ganglion block anesthetic solution is injected into the ganglion.

1. In one method the needle is introduced at a point, which is 2 cm above the sternoclavicular joint and passed in a perpendicularly backward direction until it hits the transverse process of seventh cervical vertebra. This depth is usually 2.5 to 3 cm from the surface.
2. The other method of stellate ganglion block is as follows:
   i. First the carotid tubercle (a large tubercle on the transverse process of the sixth cervical vertebra) is palpated. It lies about a fingerbreadth lateral to the cricoid cartilage.
   ii. The carotid sheath and sternomastoid are pushed laterally. The needle is inserted at the skin over the carotid tubercle. The anesthetic is then injected in the lower direction.

CERVICAL LYMPH NODES

Of the total of nearly 800 lymph nodes in the body about 300 are located in the neck. Inflammation of the cervical lymph nodes is very common, especially due to tuberculosis. The secondary deposit in the lymph nodes from the primary cancer in the area of drainage of the nodes is another cause of lymph node enlargement. The cervical lymph nodes can be broadly divided into superficial and deep groups.
Superficial Lymph Nodes (Fig. 44.7)

i. The occipital nodes are located at the apex of the posterior triangle. They drain the back of scalp. The efferent vessels drain into the deep cervical nodes. The occipital nodes are enlarged in German measles.

ii. The posterior auricular or retroauricular nodes are located on the mastoid process. They drain the back of scalp and posterior wall of external acoustic meatus. Their efferent vessels drain into the deep cervical nodes.

iii. The superficial parotid nodes are located on the surface of parotid gland. Their area of drainage consists of upper part of face, anterior part of scalp, auricle and external acoustic meatus. These nodes drain into the superficial cervical nodes along the external jugular vein.

iv. The deep parotid nodes are located in the substance of the parotid gland. The area of drainage is the temporal and infratemporal fossa, middle ear, auditory tube, upper molar teeth and gums. Their efferent vessels drain in the deep cervical nodes.

v. The submandibular nodes are embedded on the surface of the submandibular salivary gland. They drain the part of face below the line joining the medial angle of eye and the angle of mandible, submandibular and sublingual salivary glands, side of tongue and floor of mouth, teeth and gums, palate and part of nasal cavity. The buccal lymph nodes on the buccinator muscle also drain into these nodes. Their efferent vessels drain into the deep cervical nodes.

vi. The submental nodes are present in the submental triangle. Their area of drainage includes the tip of tongue, floor of mouth below the tip of tongue, incisor teeth and associated gums and central part of lower lip. Their efferent vessels drain into the deep cervical nodes.

vii. The superficial cervical nodes are located along the course of anterior jugular and external jugular veins. The nodes along the external jugular vein receive the lymph vessels from the parotid and the superficial tissues of the lower face and ear. The nodes along the anterior jugular vein receive lymph from the skin and muscles of the front of the neck.

Deep Lymph Nodes (Fig. 44.8)

i. The anterior cervical nodes include the prelaryngeal, pretracheal, paratracheal lymph nodes and the nodes in the suprasternal space of burns. These nodes drain larynx, trachea and thyroid gland and their efferent vessels empty in the lower deep cervical nodes.

ii. The retropharyngeal nodes are present in the space between the pharyngeal wall and prevertebral fascia. They receive lymph from the oropharynx, nasopharynx, palate, auditory tube, nasal cavity, paranasal sinuses and cervical vertebral column. These nodes are infected in tuberculosis of the cervical spine and form retropharyngeal abscess. Their efferents drain into the deep cervical nodes.
iii. The upper and lower deep cervical lymph nodes form a long chain on the carotid sheath (almost embedded in the tunica adventitia of the internal jugular vein). Two nodes in this group are large compared to others.

The upper is called the jugulodigastric (located in a triangle formed by posterior belly of digastric, common facial vein and internal jugular vein). It lies just below and behind the angle of the mandible. It receives lymph from the tonsil and the tongue.

The jugulo-omohyoid node is located in relation to the intermediate tendon of the omohyoid. It receives lymph mainly from the tongue.

iv. The supraclavicular nodes are located in the lower part of the posterior triangle in relation to the subclavian vessels and are palpated in the subclavian triangle (Fig. 40.10). Retrograde spread through the thoracic duct on the left side may be cause of their enlargement especially in cancer from the stomach, colon and both the testis, which spreads to the nodes of left side and not of the right side. The left supraclavicular lymph nodes are called Virchow’s nodes.

The deep cervical lymph nodes receive lymph from the entire head and neck. The efferents from the deep group form the jugular lymph trunk on each side, which terminates on the right side in the right lymphatic duct or at the junction of right subclavian and right internal jugular veins. The left jugular trunk usually joins the thoracic duct or may join either the internal jugular or the subclavian vein.

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**Clinical insight ...**

**Palpation of Cervical Lymph Nodes**

The palpation of the cervical lymph nodes is part of the clinical examination of the patient. All the nodes are palpated starting at one point and proceeding in a sequential order. If any node is enlarged its area of drainage is examined for inflammatory conditions or malignancy. Figure 44.9 shows grossly enlarged cervical lymph nodes in cancer of cheek. The cervical lymph nodes may be involved in diseases of the lymphatic system like Hodgkin’s disease or inflammatory disease like tuberculosis or AIDS. Sometimes for confirmation of the clinical diagnosis cervical node biopsy is performed.

**Block Dissection of Neck**

The block dissection of the neck is a procedure in which all the lymph nodes of the neck along with the other structures like; sternomastoid muscle, internal and external jugular veins, submandibular salivary gland and accessory nerve are removed. The block dissection is usually required if cancer of tongue spreads to lymph nodes of the neck.

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**Paravertebral Muscles of Neck**

The paravertebral muscles include the scalenus anterior, scalenus medius, scalenus posterior and scalenus minimus muscles.

**Scalenus Anterior (Fig. 24.1)**

This muscle is the key muscle of the root of the neck. It takes origin from the anterior tubercles of the transverse processes of the third to sixth cervical vertebrae and is inserted into the scalene tubercle on the inner margin of the first rib and into the ridge on the superior surface of the first rib.

**Relations of Anterior Surface**

i. The phrenic nerve is plastered to the anterior surface of the muscle by the prevertebral fascia.

ii. The lateral part of the carotid sheath is related to the anterior surface.

iii. The transverse cervical and suprascapular arteries cross in front of the muscle.

iv. The subclavian vein crosses in front of the lower part of the muscle.

**Relation of Medial Margin**

The lower part of the medial margin of the scalenus anterior muscle forms the lateral margin of the scalene-vertebral triangle or triangle of vertebral artery (Fig. 44.10).
Boundaries of Scalenovertebral Triangle

i. Medially, by the lateral margin of longus colli muscle.
ii. Laterally, by medial margin of scalenus anterior muscle.
iii. Inferiorly, by the first part of subclavian artery.

Contents of Triangle

i. It contains first part of vertebral artery, thyrocervical trunk and the sympathetic chain.
ii. The subclavian vein and the internal jugular vein unite to form the brachiocephalic vein medial to the medial margin of the scalenus anterior muscle behind the medial end if the clavicle.
iii. On the left side the thoracic duct is related to the medial margin as it arches down to open at the point of union of the left subclavian and left internal jugular veins.

Relations of Posterior Surface

The contents of the scalene triangle (second part of subclavian artery and lower trunk of branchial plexus) are related posteriorly near the insertion of scalenus anterior. This triangle is bounded by posterior aspect of scalenus anterior, superior surface of the first rib and anterior aspect of scalenus medius (Fig. 24.1).

Nerve Supply

The scalenus anterior receives direct branches from the anterior primary rami of the fourth, fifth and sixth cervical nerves.

Actions

i. Acting bilaterally, the muscles fix the first rib during quiet inspiration.
ii. Acting bilaterally, the muscles lift the first ribs during forced inspiration.
iii. Acting unilaterally, the muscle bends the neck forwards and laterally thereby turning the face to the opposite side.

Scalenus Anterior Syndrome

Hypertrophy or spasm of the muscle may compress the contents of the scalene triangle. The symptoms are similar to those produced by the cervical rib. Division of the muscle (scalenotomy) is performed to relieve the symptoms.

Scalenus Medius

This muscle takes origin from the posterior tubercles of the second to seventh cervical vertebrae and is inserted into the upper surface of the first rib posterior to the groove for subclavian artery. The dorsal scapular nerve and the C5 and C6 roots of the long thoracic nerve pierce the muscle in the floor of the posterior triangle of neck.

Nerve Supply

Direct branches of the third to eighth cervical anterior primary rami supply the scalenus medius muscle.
Action  
The muscle bends the neck to its own side. It raises the first rib during forced inspiration.

**Scalenus Posterior**  
It takes origin from the posterior tubercles of the transverse processes of the fourth, fifth and sixth cervical vertebrae and is inserted in the outer surface of the second rib.

**Nerve Supply**  
The direct branches of primary rami of the lower three cervical nerves supply the muscle.

**Action**  
It bends the neck to its own side and elevates the second rib during forced inspiration.

**Scalenus Minimus**  
This muscle is also known a scalenus pleuralis. It takes origin from the transverse process of the seventh cervical vertebra and is inserted into the inner margin of the first rib. Some of its fibers are continuous with the suprapleural membrane (Sibson’s fascia) and the cervical pleura.

**Prevertebral Muscles of Neck**  
These muscles are located in front of the cervical vertebral column and are covered with prevertebral layer of deep cervical fascia. These muscles consist of longus colli, longus capitis, rectus capitis anterior and rectus capitis lateralis muscles.

**Longus Colli**  
This muscle consists of three parts, upper oblique part, middle vertical part and lower oblique part. The upper oblique part extends between the anterior arch of atlas to the transverse processes of the third, fourth and fifth cervical vertebrae. The vertical part arises from the bodies of the lower three cervical and the upper three thoracic vertebrae and is inserted into the bodies of the second, third and fourth cervical vertebrae. The lower oblique part takes origin from the bodies of the upper three thoracic vertebrae and is inserted into the anterior tubercles of the transverse processes of the fifth and sixth cervical vertebrae. This part forms the medial margin of the scalenovertebral triangle.

**Nerve Supply**  
The muscle receives direct branches from the ventral rami of second to sixth cervical spinal nerves.

**Action**  
The longus colli flexes the cervical vertebral column.

**Longus Capitis**  
This muscle takes origin from the anterior tubercles of the transverse processes of the third to sixth cervical vertebrae and is inserted into the base of the cranial on either side and behind the pharyngeal tubercle.

**Nerve Supply**  
The muscle receives branches from the ventral rami of the first, second and third cervical ventral rami.

**Rectus Capitis Anterior**  
It arises from the lateral mass of atlas vertebra and is inserted into the basilar part of the occipital bone.

**Rectus Capitis Lateralis**  
It takes origin from the transverse process of atlas and is inserted into the jugular process of the occipital bone.

**Nerve Supply**  
Both the recti muscles are innervated by the loop of communication between the first and second cervical ventral rami.
**INFRATEMPORAL FOSSA**

The infratemporal fossa is an irregular space below the temporal fossa.

**Bony Boundaries (Fig. 45.1)**

The infratemporal fossa has roof, medial wall and anterior wall. It is open inferiorly.

i. The roof is formed medially by the infratemporal surface of the greater wing of sphenoid. The roof separates the fossa from the middle cranial fossa. The features of the roof are spine of sphenoid, foramen spinosum, foramen ovale and infratemporal crest.

ii. Medially, the fossa is bounded by lateral pterygoid plate of the sphenoid and pyramidal process of the palatine bone.

iii. Anteriorly, the fossa is limited by the posterior surface of the body of maxilla (bearing maxillary tuberosity).

iv. Its medial and anterior walls meet below but are separated above by pterygomaxillary fissure. The upper end of the pterygomaxillary fissure is continuous with the inferior orbital fissure. Medially, the fossa communicates with pterygopalatine fossa through the pterygomaxillary fissure and with the orbit through the inferior orbital fissure.

v. Posteriorly the temporomandibular joint, tympanic plate and the styloid process are seen.

**Contents**

The main contents are the mandibular nerve and its branches, otic ganglion, chorda tympani nerve, first and second parts of maxillary artery and their branches, pterygoid plexus of vein and maxillary vein, sphenomandibular ligament, tendon of insertion of temporalis and medial and lateral pterygoid muscles.

**Mandibular Nerve**

This nerve is the largest of the three divisions of the trigeminal nerve. It has a large sensory root and a small motor root. The sensory root arises from the posterior end of the lateral surface of trigeminal ganglion in the middle...
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cranial fossa. The motor root arises from the pons. It passes under the trigeminal ganglion (lying outside it). The two roots unite with each other in the foramen ovale or just outside the foramen and the trunk, thus formed enters the infratemporal fossa.

Extracranial Course (Fig. 45.2)

In the infratemporal fossa, the short trunk of the mandibular nerve passes between the lateral pterygoid and tensor palati muscles and soon divides into anterior and posterior divisions.

Branches of Trunk
i. The meningeal branch (nervus spinosus) enters the middle cranial fossa through foramen spinosum to supply the dura mater of middle cranial fossa.
ii. The nerve to medial pterygoid muscle supplies the medial pterygoid and also the tensor palati and tensor tympani muscles (via its connection to the otic ganglion).

Branches of Anterior Division
i. The buccal branch is the only sensory branch of anterior division. It passes anteriorly between the two heads of the lateral pterygoid muscle to supply the skin of the cheek and the buccal mucosa lining the buccinator muscle.
ii. The nerve to lateral pterygoid enters the deep surface of the muscle.
iii. The deep temporal nerves (an anterior and a posterior) pass superiorly into the temporal fossa where they enter the deep surface of the temporalis muscle.

Branches of Posterior Division
i. The auriculotemporal nerve arises by two sensory roots, which encircle the middle meningeal artery and unite behind it to form a single nerve. The auriculotemporal nerve receives postganglionic parasympathetic fibers from the otic ganglion for the secretomotor supply of the parotid gland. It leaves the fossa by passing posteriorly in relation to the lateral aspect of the spine of the sphenoid. It hooks round the back of the neck of the mandible and enters the parotid gland to supply the secretomotor fibers. Then it leaves the parotid gland at its upper end (lying behind the superficial temporal vessels) to enter the temporal region (anterior quadrant of scalp). It supplies the tragus, upper part of lateral surface of the pinna, external auditory meatus, tympanic membrane and the skin of the temple.
ii. The inferior alveolar nerve passes vertically downward between the lateral and medial pterygoid muscles. After giving off the nerve to mylohyoid, it enters the mandibular foramen to travel in the bony canal inside the mandible. Here, it supplies the mandibular teeth and gums. Its branch called the mental nerve leaves the mandible through the mental foramen to supply the skin of the chin and the lower lip. The inferior alveolar nerve block is used in dental practice. For this the anesthetic is injected anterior to the lower end of sphenomandibular ligament, which is felt through the opened mouth of the patient.
iii. The lingual nerve is located anterior to the inferior alveolar nerve. It is joined by the chorda tympani (a branch of facial nerve) at an acute angle. In this way the lingual nerve carries the chorda tympani (containing sensory fibers for taste sensations from the anterior two thirds of tongue and preganglionic parasympathetic fibers for relay in the submandibular ganglion). The lingual nerve leaves the infratemporal fossa by passing in close contact with the mandible just inferior to the last molar tooth. Then it travels in the submandibular region on the surface of the hyoglossus muscle. Here the submandibular ganglion is suspended from the lingual nerve. Through these connections the lingual nerve distributes preganglionic parasympathetic fibers (belonging to chorda tympani) to the ganglion and receives postganglionic parasympathetic fibers for the sublingual salivary gland. Finally the lingual nerve enters the oral cavity, where it supplies general sensory fibers and distributes taste fibers (belonging to chorda tympani) to the anterior two-thirds of the tongue.
For further details of chorda tympani nerve refer to submandibular salivary gland (chapter 41), nerve supply of tongue (chapter 47) and facial nerve (chapter 71).

**Otic Ganglion**

This is a parasympathetic ganglion, which is a relay station on the secretomotor pathway of the parotid gland. Though the otic ganglion is located close to the mandibular nerve it is functionally related to the glossopharyngeal nerve.

**Location**

It is located deep in the infratemporal fossa just below the foramen ovale. The ganglion lies between the trunk of mandibular nerve on lateral side and the tensor palati muscle on the medial side.

**Connections of Otic Ganglion (Fig. 45.3)**

i. The parasympathetic root is formed by the lesser petrosal nerve, which is an indirect branch of glossopharyngeal nerve. (This nerve takes origin from the tympanic plexus in the middle ear (tympanic plexus is formed by tympanic branch of the glossopharyngeal nerve). It enters the middle cranial fossa through the roof of middle ear. Then it enters the infratemporal fossa via the foramen ovale or foramen innominatum. Thus, it is the fibers of the glossopharyngeal nerve that are relayed in the otic ganglion).

ii. The postganglionic secretomotor fibers join the auriculotemporal nerve, which carries them to the parotid gland.

iii. The motor root is the communication from the nerve to medial pterygoid, which passes through the ganglion to supply tensor palati and tensor tympani.

iv. The postganglionic sympathetic fibers reach the ganglion from the sympathetic plexus around the middle meningeal artery. These fibers pass through the ganglion uninterrupted and join the auriculotemporal nerve for the vasomotor supply to the parotid gland.

### Pterygopalatine Fossa

The pterygopalatine or sphenopalatine fossa is a small pyramidal space below the apex of the orbit. The root of the lateral pterygoid plate of the sphenoid and the adjoining part of the greater wing of the sphenoid limit the fossa posteriorly. The perpendicular plate of the palatine bone forms the medial boundary. The maxilla bounds the fossa anteriorly and laterally, there is a pterygopalatine (pterygomaxillary) fissure.

**Communications**

The pterygopalatine fossa has a number of communications through which nerves and vessels leave or enter the fossa.

i. The foramen rotundum transmits the maxillary nerve from the middle cranial fossa.

ii. The nerve of the pterygoid canal travels inside the pterygoid canal, which connects the fossa to the foramen lacerum.

iii. The third part of maxillary artery enters via the pterygopalatine fissure from the infratemporal fossa.

iv. The nasopalatine nerves and vessels leave through the nasopalatine or sphenopalatine foramen to enter the nasal cavity.

v. The palatinovaginal canal connects it to the nasopharynx and transmits the pharyngeal branch of the maxillary nerve.

vi. The greater palatine canal transmits the palatine nerves and vessels to the oral cavity.

vii. The inferior orbital fissure leads to the orbital floor and here the maxillary nerve continues as the infraorbital nerve.

### Maxillary Nerve (Fig. 45.4)

The maxillary nerve is one of the three divisions of the trigeminal nerve. It is entirely sensory. It leaves the trigeminal ganglion between the opthalmic and mandibular nerves in the middle cranial fossa and passes forwards in the lower part of the lateral wall of the cavernous sinus to reach the foramen rotundum, through which it enters the pterygopalatine fossa.
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In the cranial cavity it gives meningeal branch to the dura mater of middle cranial fossa.

The pterygopalatine ganglion is suspended from the maxillary nerve by its two ganglionic branches in the pterygopalatine fossa. From the posterior wall of the fossa, the maxillary nerve courses forwards in the upper part of the fossa and gives its ganglionic branches. It turns sharply in the lateral direction in the inferior orbital fissure. About halfway between the orbital apex and the orbital rim the nerve turns medially to enter the infraorbital groove and canal (in the floor of the orbit) to continue as the infraorbital nerve, which emerges on the face through the infraorbital foramen.

Branches of Trunk in the Fossa

i. The ganglionic branches to the pterygopalatine ganglion pass through the ganglion and supply the mucous membrane of the palate, nasopharynx and nasal cavity (see below).

ii. The zygomatic nerve leaves the fossa through the inferior orbital fissure to enter the orbit. It travels forwards along the lateral wall of the orbit, where it divides into zygomaticotemporal and zygomaticofacial nerves. The zygomatic nerve usually carries the postganglionic parasympathetic fibers from the sphenopalatine ganglion to the lacrimal gland.

iii. The posterior superior alveolar nerve supplies the upper molar teeth of its side.

Branches of Infraorbital Nerve

i. In the infraorbital canal, the infraorbital nerve gives rise to the middle superior alveolar and the anterior superior alveolar nerves.

ii. After emerging on the face, the infraorbital nerve gives palpbral branches to lower eyelid, nasal branches to the side of the nose and the labial branches to the upper lip.

Superior Alveolar (Dental) Nerves

There are three superior alveolar nerves, posterior superior, middle superior and anterior superior alveolar nerves, which supply the upper gums and teeth.

i. The posterior superior alveolar nerve pierces the posterior surface of the maxilla and then descends under the mucosa of the maxillary sinus. It supplies the mucosa of the sinus and the molar teeth.

ii. The middle superior alveolar nerve arises from the infraorbital nerve in the infraorbital canal. It passes downward and anteriorly in the lateral wall of the maxillary sinus. It supplies upper premolar teeth.

iii. The anterior superior alveolar nerve arises from the infraorbital nerve in the infraorbital canal. It traverses downwards and medially in the anterior wall of the maxillary sinus. It supplies the upper canine and incisor teeth.

The infraorbital nerve and the superior alveolar nerves are in intimate relation to the maxillary sinus. The infraorbital nerve is in the roof, the posterior superior alveolar is in the posterior wall, the middle superior alveolar nerve is in the lateral wall and the anterior superior alveolar nerve is in the anterior wall. Due to this close proximity the inflammation in the maxillary sinus causes irritation of these nerves leading to pain in the maxillary teeth.

Pterygopalatine (Sphenopalatine) Ganglion

This ganglion is the largest of the peripheral parasympathetic ganglia. Though topographically it is related to the maxillary nerve functionally it is related to the facial nerve.

Fig. 45.4: Direct branches of maxillary nerve in middle cranial fossa and ganglionic branches in pterygopalatine fossa.

Fig. 45.5: Connections of pterygopalatine ganglion. (Note that the sensory branches of ganglion are the indirect branches of maxillary nerve.)
Connections of Ganglion (Fig. 45.5)

i. The parasympathetic root is derived from the nerve of the pterygoid canal (Vidian nerve), which is formed by the union of the deep petrosal nerve and the greater petrosal nerve in the foramen lacerum. The greater petrosal nerve (a branch of facial nerve) carries preganglionic parasympathetic fibers for relay in the ganglion. The postganglionic fibers either join the zygomatic nerve or pass through the orbital branches of the ganglion to supply secretomotor fibers to the lacrimal gland. In addition, the nasal and palatine glands also receive secretomotor fibers through nasal and palatine nerves.

ii. The sympathetic root is derived from the deep petrosal component of the nerve of pterygoid canal. The deep petrosal nerve arises from the sympathetic plexus around the internal carotid artery. This nerve brings postganglionic sympathetic fibers to the ganglion where they do not synapse. They leave through its orbital branches for the orbitalis muscle in the orbit and are vasomotor to nasal cavity and palate.

iii. The sensory root is derived from the ganglionic branches of the maxillary nerve. These fibers of the maxillary nerve just pass through the ganglion and leave it through its following branches.

Sensory Branches

i. The branches to the palate include the greater and lesser palatine nerves, which enter the greater palatine canal and reach the oral cavity through the greater and lesser palatine foramina. They supply the mucous membrane and glands of the inferior surface of the palate.

ii. The branches to the nasal cavity include, a few posterior inferior nasal branches from greater palatine nerve to supply the mucosa covering the inferior nasal concha, inferior meatus and middle meatus in posteroinferior part of the lateral nasal wall.

iii. The nasal branches arise directly from the ganglion. They pass through the sphenopalatine foramen to enter the nasal cavity. These are called posterior superior nasal nerves. They are divided in two sets. The nerves of the lateral set supply the nasal mucosa of the posterosuperior part of the lateral wall. The nerves of the medial set supply the roof and the posterior part of the nasal septum. One of the nerves of the medial set is long and is called the nasopalatine (sphenopalatine) nerve. It runs anteroinferiorly on the nasal septum lying in a groove and leaves the nasal cavity through the incisive foramen to enter the oral cavity, where it supplies the mucosa covering the anterior part of the hard palate.

iv. The orbital branches enter the orbit through the inferior orbital fissure to supply the orbital peristeme.

v. The pharyngeal branch enters the palatinovaginal canal to enter the nasopharynx for the supply of the mucous membrane behind the opening of the auditory tube and the mucosa of the auditory tube.

Maxillary Artery

The maxillary artery is the larger of the two terminal branches of the external carotid artery. It begins behind the neck of the mandible in the substance of the parotid gland. It is divided into three parts. The first and second parts are located in the infratemporal fossa. The third part is located in the pterygopalatine fossa. The maxillary artery supplies a wide area through its many branches.

Subdivisions (Fig. 45.13)

1. The first part (mandibular part) extends from the mandibular neck to the sphenomandibular ligament. It runs along the lower margin of the lateral pterygoid muscle. The first part alone is accompanied by maxillary vein. It gives off five branches.

2. The second part (pterygoid part) ascends obliquely forwards and upwards between the lower head of lateral pterygoid and the temporalis muscles. It then passes superficial or deep to the lower head of the lateral pterygoid. The pterygoid venous plexus surrounds this part. This part of the artery gives off four branches.

3. The third part (pterygopalatine part) passes between the two heads of the lateral pterygoid muscle and enters the pterygomaxillary fissure to reach the pterygopalatine fossa. Six branches arise from this part.

Branches in Infratemporal Fossa (Fig.45.6)

The branches from the first part are as follows:

i. The deep auricular artery ascends in the substance of the parotid gland and pierces the bony or cartilaginous part of the external acoustic meatus to supply the TMJ and external auditory meatus.

ii. The anterior tympanic artery enters the tympanic cavity (middle ear) through the petrotympanic fissure.
iii. The accessory meningeal artery enters the cranium through the foramen ovale and supplies the dura mater.

iv. The inferior alveolar artery enters the mandibular foramen to travel in the mandibular canal located inside the body of the mandible. It gives lingual and mylohyoid arteries before entry into the mandibular foramen. The lingual artery supplies the tongue and the mylohyoid artery accompanies the mylohyoid nerve in the mylohyoid groove. In the mandibular canal, the inferior alveolar artery gives branches to the lower teeth. Its named branch called mental artery comes out on the face through the mental foramen along with mental nerve.

v. The middle meningeal artery is a very important branch. It is described in detail in chapter 56.

The branches from the second part are as follows:

i. The deep temporal branches (anterior and posterior) enter the temporal fossa to supply the temporalis muscle.

ii. Separate pterygoid branches for lateral and medial pterygoid muscles arise from this part.

iii. The masseteric artery passes through the mandibular notch along with masseteric nerve to reach the deep surface of the muscle.

iv. The buccal branch runs forward along with the buccal branch of mandibular nerve and supplies the external surface of the buccinator. It also provides blood to the buccal mucosa.

Branches in Pterygopalatine Fossa (Fig.45.6)

The third part of the maxillary artery gives off following branches:

i. The posterior superior alveolar artery arises just as the maxillary artery enters the pterygomaxillary fissure and is spent in supplying the upper molar teeth.

ii. The infraorbital artery may arise in common with posterior superior alveolar artery. It enters the orbit through the inferior orbital fissure and courses forwards in the infraorbital groove and canal in the floor of orbit. Along with the infraorbital nerve the artery appears on the face through the infraorbital foramen. In the infraorbital canal, it gives rise to orbital branches for orbital contents and anterior superior and middle superior alveolar branches for the upper teeth.

iii. The greater or descending palatine artery descends in the greater palatine canal and enters the oral cavity through the greater palatine foramen. It travels anteriorly on the surface of the hard palate to reach the incisive foramen through which some terminal branches enter the nasal cavity. The lesser palatine artery is a branch of the greater palatine artery as it lies in the palatine canal. These small arteries emerge through the lesser palatine foramina into the oral cavity.

iv. The pharyngeal artery leaves through the palatovaginal canal and supplies the nasopharynx, auditory tube and sphenoid sinus.

v. The artery of the pterygoid canal leaves through the pterygoid canal and supplies the nasopharynx, auditory tube and tympanic cavity.

vi. The sphenopalatine artery is the continuation of the maxillary artery. It leaves through the sphenopalatine foramen to enter the nasal cavity.

Clinical insight...

Pterygoid Venous Plexus
The pterygoid venous plexus lies in the muscles of the infratemporal fossa. It continues as the maxillary vein, which accompanies only the first part of the maxillary artery. The pterygoid plexus receives the following veins, sphenopalatine, deep temporal, pterygoid and masseteric, buccal, alveolar (both superior and inferior), greater palatine, middle meningeal and a branch of inferior ophthalmic vein. The communications of the plexus are important in the spread of infection to the cavernous sinus. The deep facial vein connects the pterygoid plexus to the facial vein and the emissary vein connects it to the cavernous sinus. The dangerous area of face is thus brought in communication with the cavernous sinus. Any infection of this area of face may cause cavernous sinus thrombosis.

Temporomandibular Joint
The Temporomandibular Joint (TMJ) is the articulation between the cranium and the mandible. The right and left joints help in mastication and in opening and closing the mouth.

Special Features
The unique feature of this articulation is that a single bone (mandible) articulates bilaterally with right and
left mandibular fossae of temporal bone. Moreover, its cranial components are immobile while the lower component (mandible) alone is mobile. The right and left joints, though anatomically distinct, act as a single unit functionally. Each joint is completely divided in upper and lower compartments by an articular disc.

**Type of joint**
Temporomandibular Joint (TMJ) is a bicondylar variety of synovial joint.

**Articular Bones (Fig. 45.7)**
The condyle or the head of the mandible forms a convex articular surface inferiorly. The mandibular fossa on inferior surface of squamous temporal bone and the adjacent articular tubercle at the root of zygoma form a concavoconvex articular surface superiorly. The articular surfaces are covered with fibrocartilage.

**Fibrous Capsule**
The upper attachment of the capsule is to the articular tubercle, periphery of the articular fossa and the squamo-motympanic fissure. The lower attachment is to the neck of the mandible just below the condyle. The fibrous capsule is loose above the articular disc but closely fitting below it.

**Ligaments**
i. The lateral or temporomandibular ligament extends from the tubercle of the root of the zygoma backward and downward to the posterior margin of the neck of the mandible. It is the thickening of the fibrous capsule. It is the strongest ligament of the joint that prevents posterior dislocation of the joint.

ii. The sphenomandibular ligament is an accessory ligament of TMJ. It is situated on the medial aspect of the joint in the infratemporal fossa and extends from the spine of the sphenoid to the lingula of the mandible.

iii. The stylomandibular ligament is an accessory ligament of TMJ. It extends from the styloid process of temporal bone to the angle of the mandible. It is the thickened part of cervical fascia.

iv. The articular disc of the TMJ is a fibrocartilage. It is congruous with both the articular surfaces. Thus, its upper surface is concavoconvex and lower surface is concave. It divides the joint in upper meniscotemporal and lower meniscocondibular compartments. It is firmly attached to the fibrous capsule at its periphery. Anteriorly it blends with the lateral pterygoid muscle at its insertion (the disc is regarded, morphologically a part of lateral pterygoid). It is firmly attached to the back of the neck of the mandible to ensure the movements of the mandibular head and the disc together in the upper compartment. The disc shows five different regions, as follows, the anterior extension, anterior thick band, intermediate zone, posterior thick band and bilaminar zone. The upper fibroelastic lamina of the bilaminar zone is attached to the mandibular fossa while the lower nonelastic lamina is attached to the back of the neck of the mandible. A venous plexus lies between the two laminae. When the articular disc is detached from the fibrous capsule is known as derangement of the joint. It causes painful movements and clicking sound while opening and closing the mouth.

**Synovial Membrane**
The synovial membrane lines the fibrous capsule above and below the disc but does not line the disc. It also lines the nonarticular surfaces of the both the compartments.

**Relations**
i. Anteriorly, it is related to the insertion of lateral pterygoid muscle. The massesteric nerve and vessels are related as they pass through the mandibular notch.

ii. Laterally, the temporomandibular ligament is covered with parotid gland but the rest of the lateral aspect is subcutaneous being covered with fascia and skin. Therefore, it is possible to feel the head of the mandible by a finger placed in front of the tragus.

iii. Posteriorly, it is related to the glenoidea process of the parotid, which separates it from the bony part of external acoustic meatus ( tympanic plate).

iv. Medially, it is related to the maxillary artery, maxillary vein and the auriculotemporal nerve (structures in the infratemporal fossa).
Nerve Supply
The auriculotemporal nerve and the nerve to masseter, both branches of the mandibular nerve, supply the joint.

Movements (Fig. 45.8)
i. The depression or the downward movement of the mandible is responsible for opening the mouth.
ii. The elevation or the upward movement of the depressed mandible brings about closure of the mouth.
iii. The protraction (protrusion) means forward movement of the mandible.
iv. The retraction means backward movement of the protracted mandible.
 v. Side-to-side or grinding movements in right and left joints alternately are responsible for mastication.

The movements of elevation and depression take place around a mobile (dynamic) transverse axis in both the compartments of the joint. The protraction and retraction take place in the upper compartment around a transverse axis. The rotation of mandibular condyle takes place around a vertical axis in both the compartments in side-to-side movements.

Depression Movement
The depression of mandible results in opening of the mouth. This movement takes place in three stages. At first, there is a forward rotation of the mandibular condyle in the lower compartment so that the condyle comes in contact with the intermediate area of the disc. The axis of this movement passes through the condyles of both mandibles. In the second stage, there is a forward movement of both the disc and the condyle in the upper compartment around a transverse axis. The rotation of mandibular condyle takes place around a vertical axis in both the compartments in side-to-side movements.

Elevation Movement
In this movement, first the stages in the rotation of condyle alone and condyle with disc as seen in depression are reversed. The masseter, temporalis and the medial pterygoid muscles of both sides contract to produce elevation.

Protraction or Protrusion Movement
In this movement, the mandible is pulled forwards with the closed mouth. The condyle and the disc together slide forwards on the mandibular fossa of both sides in the upper compartment. The lateral pterygoid and the medial pterygoid muscles bring about protraction.

Retraction Movement
In this movement, the mandible is returned to the position of rest by backward sliding of the condyle and the disc together. The posterior fibers of temporalis have the primary role in retraction.

Side-to-Side (Grinding or Chewing) Movements
These movements are also called rotatory movements of mastication. One condyle with its disc rotates forward around a vertical axis passing through the posterior aspect of opposite condyle. It then glides backwards. During the backward movement, the condyle and the disc of the opposite side move forward. This alteration swings the mandible from side to side. The medial and lateral pterygoids of the two sides act alternately in grinding movements. Masseter and temporalis assist the pterygoid muscles.

Clinical insight ...
Dislocation of TMJ (Fig. 45.9)
The anterior dislocation of the head of the mandible in the infratemporal fossa after opening the mouth widely may occur due to sudden blow on the chin or due to spasm of lateral
Muscles of Mastication

There are four muscles of mastication (jaw muscles). Masseter lies external to the ramus of the mandible and is the most superficial of the four muscles. The temporalis lies partly in the temporal fossa and partly in infratemporal fossa. The lateral and medial pterygoid muscles lie in the infratemporal fossa. All the four muscles take origin from the cranium and insert in mandible, which they move at the TMJ. All the four muscles of mastication develop from the mesoderm of the first pharyngeal arch and hence are supplied by the nerve of the first arch (mandibular nerve). The buccinator is regarded as the accessory muscle of mastication.

Masseter (Fig. 45.10)

It is quadrilateral shape. It can be palpated in the living on clenching the teeth. At its anteroinferior angle pulsations of the facial artery are felt.

Attachment

The masseter takes origin from the lower margin and deep aspect of the zygomatic arch and is inserted in the lateral aspect of ramus and coronoid process of mandible.

Relation

The parotid duct and branches of facial nerve cross the muscle superficially. The posterior part of its superficial surface is in contact with anteromedial surface of parotid gland. The buccal pad of fat separates its anterior border from the buccinator muscle. It is covered with parotidomasseteric fascia, which is the extension of deep fascia of the neck in the face.

Nerve Supply

The anterior division of mandibular nerve supplies it.

Action

The masseter elevates the mandible. Its superficial fibers help in protraction of mandible.

Temporalis (Fig. 45.10)

It is a fan-shaped muscle. It is covered with stiff temporal fascia, which is attached to the superior temporal line of parietal bone and to the medial and lateral margins of the zygomatic arch by two layers.

Attachment

The temporalis takes origin from the medial wall of temporal fossa and the temporal fascia and is inserted in the anterior margin of coronoid process and anterior margin of the ramus of mandible. The anterior fibers are vertical in direction while the middle fibers are obliquely placed and the posterior fibers are horizontally disposed.

Action

The anterior vertical fibers cause elevation. The posterior horizontal fibers are responsible for retraction. It also assists in side-to-side movements.
Nerve Supply
It is supplied by the deep temporal branches of the mandibular nerve.

Lateral Pterygoid (Fig. 45.11)
It is roughly triangular with base (origin) directed anteriorly and apex (insertion) posteriorly. It is a short muscle with two heads (upper and lower).

Attachment
i. The upper head arises from the infratemporal surface and infratemporal ridge of the greater wing of sphenoid.
ii. The lower head arises from the lateral surface of the lateral pterygoid plate.
iii. The insertion of the muscle is in the pterygoid fovea on the anterior aspect of the neck of the mandible and in the articular disc and fibrous capsule of the TMJ. It receives branches from the mandibular nerve.

Important Relations (Fig. 45.12)
Superficially, it is related to the mandibular ramus, tendon of temporalis, masseter and the second part of maxillary artery (if it passes superficial to it). The medial pterygoid muscle, middle meningeal artery, second part of maxillary artery (if it passes deep to the lateral pterygoid), sphenomandibular ligament and the mandibular nerve are related to its deep aspect. Its upper border is related to the deep temporal nerves and masseteric nerve with accompanying vessels and its lower border is related to the lingual and inferior alveolar nerves, inferior alveolar vessels and the first part of maxillary artery (with its meningeal branches namely middle meningeal and accessory meningeal).

In between the two heads of the muscle, the buccal nerve emerges and maxillary artery enters to become the third part. The maxillary vein and pterygoid plexus of veins are intimately related to the lateral pterygoid muscle. The contraction of the lateral pterygoid helps in propulsion of the blood in the pterygoid venous plexus in to the maxillary vein.

Action
The most important action of the lateral pterygoid muscles of the two sides is the depression of mandible (opening the mouth). The lateral pterygoid of one side pushes the mandible to the opposite side. The combined action of the two muscles keeps the chin in the midline. The protrusion is by simultaneous actions of lateral and medial pterygoid of both sides. Acting with medial pterygoid of the same side it causes lateral movement of mandible to the opposite side. When the same movement is followed in the opposite side, grinding or chewing of the food occurs.

Nerve Supply
A branch from anterior division of mandibular nerve supplies lateral pterygoid.

Medial Pterygoid
This muscle is of quadrilateral shape. It has larger deep and smaller superficial heads, which embrace the lower head of the lateral pterygoid muscle.

Attachments (Figs 45.11 and 45.13)
i. The deep head arises from the medial surface of lateral pterygoid plate.
ii. The superficial head arises from the lateral surface of pyramidal process of palatine bone and from the maxillary tuberosity.

iii. The two heads unite below the lower head of the lateral pterygoid muscle and are inserted on a roughened area on the medial surface of the ramus of mandible below the mylohyoid line.

**Actions**
The medial pterygoid muscles of both sides act to elevate the mandible (closure of mouth). The medial and lateral pterygoids of both sides act to protract the mandible. The medial and lateral pterygoid of one side act together to move the mandible in grinding movements and this is followed by similar movements in the opposite side.

**Nerve Supply**
The nerve to medial pterygoid arises from the trunk of mandibular nerve. For unusual features of the nerve to medial pterygoid refer otic ganglion.

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**Clinical insight ...**

1. In tetanus, there is contraction of both masseter muscles (trismus), which causes locked jaw.
2. Paralysis and wasting of temporalis produce hollowing in the temple. Paralysis of masseter causes flattening of the angle of jaw and clenching of the teeth is not possible. Paralysis of the lateral pterygoid muscles causes the jaw to deviate towards the paralysed side on opening the mouth because of action of normal muscle (Fig. 45.14).

**Testing the Function of Muscles of Mastication**
The muscles of mastication are routinely tested in clinical assessment of trigeminal nerve.

1. A subject is asked to clench the teeth to test masseter and temporal muscles, which stand out in prominence equally on each side. This is checked by inspection and palpation of the muscles of both sides. There will be absence of contraction in a patient with unilateral paralysis of these muscles.

2. To test lateral pterygoid muscle a subject is asked to open the mouth widely but slowly against resistance. The chin moves down in the midline in a normal case. Deviation of chin (lower jaw) to one side indicates paralysis of the lateral pterygoid of the side to which the chin deviates.

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**Fig. 45.13:** Origin of medial pterygoid muscle

**Fig. 45.14:** Jaw deviation to the left (indicated by arrow) due to paralysis of left lateral pterygoid muscle
The orbit is a pyramidal-shaped bony cavity on the norma frontalis. It protects the delicate eyeball and other structures associated with it in the orbit.

Bony Boundaries (Fig. 46.1)
The bony orbit presents apex, base, roof, floor, lateral wall and medial wall. The medial walls of the right and left orbits are parallel to each other while the two lateral walls meet at an angle of 90 degrees.

i. The bony orbit has an apex situated posteriorly at the medial end of the superior orbital fissure.
ii. The base is directed anteriorly and is formed by the orbital margin.
iii. The roof is formed mainly by the orbital plate of the frontal bone with a small contribution posteriorly by lesser wing of sphenoid. The roof separates the orbital cavity from the anterior cranial fossa.
iv. The floor is formed by the orbital plate of the maxilla, orbital surface of zygomatic bone anterolaterally and a small contribution from palatine bone posteriorly. The floor separates the orbit from the maxillary air sinus. The floor is marked by infraorbital groove that lodges the infraorbital nerve.
v. The lateral wall is thickest. It consists of orbital surface of frontal process of zygomatic bone in front and the anterior surface of greater wing of sphenoid behind. Whitnall’s tubercle is an elevation on the zygomatic bone closer to the orbital margin. At the junction of lateral wall and roof, there is a fossa for lacrimal gland.
vi. The medial wall is thinnest. It consists of four bones. From before backward, the bones are frontal process of maxilla, lacrimal bone, orbital plate of ethmoid and body of sphenoid. The orbital plate of ethmoid (lamina papyracea) separates the orbit from the middle and posterior ethmoidal sinuses. A deep lacrimal groove is present at the junction of maxilla and lacrimal bone for the lacrimal sac.

Periorbita
The periorbita or orbital fascia is the periosteum that lines the orbit. It can be easily stripped off from the bones. At the orbital margins the periorbita projects inside the eyelids as orbital septa, which are attached to the tarsal plates in the eyelids.

Communications
i. The supraorbital notch (foramen) located in the medial part of superior orbital margin transmits the supraorbital nerve and vessels from the orbit to the anterior quadrant of scalp.
ii. The infraorbital groove and canal located in the orbital floor carries the infraorbital nerve to the infraorbital foramen through which it appears on the face.

iii. The nasolacrimal canal connects the lacrimal groove to the inferior meatus of nasal cavity. It lodges the nasolacrimal duct.

iv. The inferior orbital fissure is located posteriorly between the maxilla and the greater wing of sphenoid. It communicates the orbit to the pterygopalatine fossa and transmits the maxillary nerve, its zygomatic branch and inferior ophthalmic vein.

v. The superior orbital fissure is located posteriorly between the greater and lesser wings of sphenoid. It communicates with the middle cranial fossa and transmits a number of structures (Fig. 46.2), which are, the lacrimal, frontal and nasociliary (branches of ophthalmic nerve), the oculomotor, trochlear and abducent nerves in addition to superior ophthalmic vein.

vi. The optic canal is located at the apex of the orbit, bounded by the lesser wing and the body of the sphenoid. It transmits the optic nerve and ophthalmic artery.

vii. The anterior and posterior ethmoidal foramina are present on the medial wall for the passage of anterior and posterior ethmoidal nerves and vessels.

viii. On the lateral wall, there are two foramina for the passage of zygomaticotemporal and zygomaticofacial nerves.

**Fig. 46.1:** Bones forming the walls of the orbit

**Fig. 46.2:** Optic canal, superior orbital fissure and common tendinous ring at the apex of orbit

**Contents**

1. The eyeball is the most important content. It lies in the anterior part of the orbit
2. The retrobulbar space (space of orbit behind the globe of eyeball) contains the following:
   i. The cranial nerves are the optic, oculomotor, trochlear and abducent. In addition, the lacrimal, frontal and nasociliary branches of the ophthalmic division of the trigeminal nerve course through this space.
   ii. The ciliary ganglion (a peripheral parasympathetic ganglion) is suspended from the nasociliary nerve.
iii. The blood vessels are the opthalmic artery with its branches and the superior and inferior opthalmic veins.

iv. A group of six extraocular muscles are inserted into the sclera of the eyeball and the levator palpebrae superioris passes closer to the roof of the orbit for insertion into the upper eyelid.

All the above mentioned contents are enveloped in fascial sheath of the eyeball (fascia bulbi) and are supported by orbital fat.

The cone of extraocular muscles contains optic nerve (and accompanying blood vessels), oculomotor nerve, abducens nerve and nasociliary nerve (with ciliary ganglion). The trochlear nerve and frontal and lacrimal branches of opthalmic nerve are outside the cone of muscles.

(Note: The lacrimal gland and the lacrimal sac are present in the anterior part of the orbit).

### Extraocular Muscles

The extraocular muscles are so called because they are located outside the eyeball. However, they are inside the orbit hence called intraorbital muscles. A group of six muscles is concerned with the movements of the eyeball and one is concerned with the elevation of the upper eyelid. These muscles are divisible into two groups, voluntary and involuntary.

#### Voluntary Muscles

The voluntary muscles are named as, levator palpebrae superioris, superior and inferior recti, lateral and medial recti and superior and inferior oblique. Of the seven voluntary muscles, the levator palpebrae elevates the upper eyelid while the four recti and two oblique muscles are responsible for the movements of the eyeball.

#### Involuntary Muscles

There are three involuntary or smooth muscles, the superior tarsal or Müller’s muscle, inferior tarsal and orbitalis.

### Special Features of Voluntary Extraocular Muscles

i. The extraocular muscles have the smallest motor units among the skeletal muscles. The ratio of nerve fiber to muscle fiber is 1: 2 or 3 or 4 in extraocular muscles while it is 1: 125 in other skeletal muscles. The small motor units signify fine movements of eyeball by muscle contractions.

ii. These muscles are described as ‘yoke muscles’ because simultaneous contraction of the muscles in the two eyes is necessary for conjugate movements of the eyes, e.g. simultaneous contraction of right medial rectus and left lateral rectus muscles causes lateral conjugate movement of the eyes to the left.

#### Levator Palpebrae Superioris

This muscle has voluntary and involuntary parts. The involuntary part is known as Müller’s muscle or superior tarsal muscle. It is the highest muscle in the orbit lying very close to the orbital roof.

**Origin**

The levator palpebrae superioris takes origin by a tendon from the inferior surface of the lesser wing of sphenoid at the apex of the orbit. The muscle broadens as it passes forwards above the superior rectus and enters the upper lid as a wide aponeurosis, which splits in three laminae.

**Insertion**

The upper lamina is inserted in the anterior surface of superior tarsus and in the skin of upper eyelid. The middle lamina containing smooth muscle fibers of Müller’s muscle is attached to the superior margin of superior tarsus and the lower lamina gains attachment to the superior conjunctival fornix.

**Nerve Supply**

i. The voluntary part receives nerve supply from the superior division of oculomotor nerve.

ii. The involuntary part receives supply from the postganglionic sympathetic fibers from the superior cervical sympathetic ganglion (Fig. 12.3).

**Action**

The levator palpebrae superioris elevates the upper eyelid. So, it is antagonistic to orbicularis oculi.

### Clinical insight ...

#### Ptosis

Ptosis means drooping of the upper eyelid.

i. The paralysis of levator palpebrae superioris due to injury to oculomotor nerve results in complete ptosis.

ii. The paralysis of Müller’s muscle due to disruption of sympathetic nerve supply results in partial ptosis (as seen in Horner’s syndrome).

#### Recti Muscles

The four recti muscles take origin from a common fibrous ring (tendon of Zinn), which encircles the optic foramen and adjacent part of the superior orbital fissure. The superior, inferior, medial and lateral recti arise from the corresponding parts of the fibrous ring. The recti muscles run forward encircling the optic nerve first and then the eyeball inside a muscular cone.
The recti are inserted into the sclera in front of the equator of the eyeball. The average distance of insertion of the recti behind the sclerocorneal junction is as follows, superior rectus - 7.7 mm, lateral rectus - 6.9 mm, inferior rectus - 6.5 mm and medial rectus - 5.5 mm.

Oblique Muscles (Figs 46.3A and B)

i. The superior oblique muscle is the longest of the intraorbital muscles. It arises from the body of sphenoid just above and medial to the optic canal. It passes forward along the superomedial part of the orbit and ends in a tendon, which turns sharply in posterolateral direction by passing through the fibrocartilaginous trochlea on the frontal bone (trochlea is regarded as the functional origin of the muscle). The tendon passes inferior to the superior rectus muscle and is inserted in the posterosuperior quadrant of the sclera behind the equator of the eyeball.

ii. The inferior oblique muscle is entirely separate from the other five muscles as far as its origin is concerned. It arises from the anteromedial part of the floor of the orbit, from the maxilla just lateral to the nasolacrimal groove. At first, it passes in posterolateral direction under the eyeball below the inferior rectus muscle. Then it turns upward for insertion in the sclera close to that of superior oblique behind the equator of the eyeball.

Nerve Supply of Extraocular Muscles

i. The lateral rectus muscle is supplied by abducent nerve.

ii. The superior oblique is supplied by trochlear nerve.

iii. The superior division of oculomotor nerve supplies superior rectus and medial rectus.

The inferior division of oculomotor nerve supplies inferior rectus and inferior oblique muscles.

Actions

The medial rotation (adduction) and lateral rotation (abduction) of the eyeball take place around a vertical axis passing through the equator. The elevation and depression take place around a transverse axis passing through the equator. Intorsion and extorsion (moving 12 o’ clock position of cornea medially and laterally respectively) take place around the anteroposterior or visual axis.

Understanding the relationship of the visual axis and the line of the muscle pull is the basis of understanding the actions of the extraocular muscles (Fig. 46.4) and of testing the integrity of the nerves supplying the muscles.

The visual axis is the line that passes through the anterior and posterior poles of the eyeball.

i. The superior and inferior recti are disposed at an angle of about 25 degree lateral to the visual axis in the primary position of the eyeball. Therefore, only

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**Fig. 46.4:** Action of an isolated muscle as elevator and depressor of eyeball according to change in position of Visual axis (VA), Transverse axis (TA), Inferior oblique (IO), Superior oblique (SO), Superior rectus (SR), Inferior rectus (IR)
in the abducted position of the eyeball, the visual axis coincides with the axis of superior and inferior recti.

ii. The superior and inferior oblique muscles are disposed at an angle of about 51 degree medial to the visual axis in the primary position of the eyeball. Therefore, only in the abducted position of the eyeball, the visual axis coincides with the axis of oblique muscles.

**Actions of Individual Muscles (Fig. 46.5)**

i. The medial rectus causes adduction only.

ii. The lateral rectus causes abduction only.

iii. The superior rectus causes elevation, adduction and intorsion in primary position of eyeball. It causes elevation only in the abducted position of the eyeball.

iv. The inferior rectus causes depression, adduction and extorsion in the primary position while it causes depression only in the abducted position of the eyeball.

v. The superior oblique causes depression, abduction and intorsion in the primary position while it causes depression only in the adducted position of the eyeball.

vi. The inferior oblique causes elevation, abduction and extorsion in the primary position while it causes elevation only in the adducted position of the eyeball.

**Combined Actions of Muscles**

i. Adduction is the combined action of medial, superior and inferior recti.

ii. Abduction is the combined action of lateral rectus and superior and inferior oblique muscles.

iii. Pure elevation in the primary position is the combined action of superior rectus and inferior oblique muscles.

iv. Pure depression in the primary position is the combined action of inferior rectus and superior oblique muscles.

v. Intorsion is the combined action of superior rectus and superior oblique muscles.

vi. Extorsion is the combined action of inferior rectus and inferior oblique muscles.

**Clinical Testing**

i. For testing medial rectus, the subject is asked to move the eye medially.

ii. For lateral rectus, to move the eye laterally.

iii. For testing the superior oblique muscle, the subject is asked to look at his or her tip of the nose because in the adducted position of eye the superior oblique is the only depressor.

iv. For testing the inferior oblique muscle, the subject is asked to adduct the eye and look upward because in the adducted position of the eye, inferior oblique is the only elevator.

v. For testing the superior rectus muscle, the subject is asked to abduct the eye and then look upward because in the abducted position of the eye superior rectus alone is the elevator.

vi. For testing the inferior rectus muscle, the subject is asked to abduct the eye and look downward because in the abducted position of the eye inferior rectus alone is the depressor.

**Conjugate Movements**

The conjugate movements occur when both eyes move in the same direction. For looking toward the left side, the left lateral rectus and right medial rectus muscles contract simultaneously.

**Clinical insight ...**

i. Unilateral paralysis of a single muscle produces strabismus or squint (deviation of the eye to the opposite side). This results in diplopia or double vision on looking towards the side of muscle action.

ii. The paralysis of lateral rectus produces internal squint and diplopia on turning the eye laterally. The paralysis of medial rectus causes external squint and diplopia on turning the eye medially.

iii. The paralysis of superior rectus produces diplopia on looking up. The paralysis of inferior rectus produces diplopia on looking down.

iv. In paralysis of superior oblique, there is no obvious squint but patient experiences diplopia on looking down, e.g. while coming down the staircase.

v. The paralysis of inferior oblique produces diplopia on looking up.

vi. In cavernous sinus thrombosis, there may be ophthalmoplegia (paralysis of all extraocular muscles).
Ophthalmic Nerve (Fig. 46.6A)
The ophthalmic nerve is one of the three divisions of the trigeminal nerve. It takes origin from the trigeminal ganglion and enters the lateral wall of the cavernous sinus. Here the nerve divides into three branches, lacrimal, frontal and nasociliary. These branches enter the orbit through the superior orbital fissure.

Lacrimal Nerve
It enters through the lateral part of the superior orbital fissure outside the tendinous ring. The lacrimal nerve passes forward along the upper border of lateral rectus muscle and receives a twig from the zygomaticotemporal nerve. This communication brings postganglionic parasympathetic fibers for the lacrimal gland from the pterygopalatine ganglion. The lacrimal nerve supplies the skin of the lateral part of the upper eyelid and conjunctiva.

Frontal Nerve
This nerve enters the orbit through the lateral part of the superior orbital fissure medial to the lacrimal nerve. After entering the orbit, the frontal nerve passes between the orbital roof and the levator palpebrae superioris. About halfway between the apex and the base of the orbit, the frontal nerve divides in supraorbital and supratrochlear nerves. The distribution of these nerves is mentioned in chapter based on the scalp.

Nasociliary Nerve
This nerve enters the orbit through the common tendinous ring lying between the superior and inferior divisions of oculomotor nerve. Inside the orbit, the nasociliary nerve passes from lateral to medial side by crossing above the optic nerve. It continues as the anterior ethmoidal nerve after reaching the anterior ethmoidal foramen on the medial wall of the orbit.

Intraorbital Branches
i. A communicating branch is given to the ciliary ganglion.
ii. Two to three long ciliary nerves pierce the sclera around the attachment of optic nerve to the eyeball. They run forward in the space between the sclera and choroid and supply ciliary body, iris and cornea.
iii. Infratrochlear nerve emerges below the pulley of the superior oblique tendon. It supplies skin of both eyelids, adjoining part of the side of the nose, conjunctiva and lacrimal sac.
iv. Anterior ethmoidal nerve is the continuation of nasociliary nerve. It has a very complex course. It leaves the orbit through the anterior ethmoidal foramen and canal to enter the anterior cranial fossa, where it lies on the cribriform plate of ethmoid bone. The nerve enters the slit by the side of the crista galli to enter the nasal cavity, where it divides in lateral and medial internal nasal branches. The lateral branch of the internal nasal nerve emerges from the nose as the external nasal nerve to supply the skin of ala, vestibule and tip of the nose.
v. Posterior ethmoidal nerve is a slender branch that passes through the posterior ethmoidal foramen and supplies the ethmoidal and sphenoidal sinuses.

Ciliary Ganglion
This is a peripheral parasympathetic ganglion located in the posterior part of the orbit hung from the nasociliary nerve. It lies between the optic nerve and the origin of the lateral rectus muscle, the optic nerve being medial to it.

Connections
i. Motor or parasympathetic root is a branch from the nerve to inferior oblique. The motor root conveys the preganglionic fibers, which make synaptic contact with the ganglionic cells.
ii. Sensory root is provided by connections to nasociliary nerve. This root contains sensory fibers from the eyeball and these fibers pass through the ganglion without relay.
iii. Sympathetic root is derived from the plexus around the ophthalmic artery, carrying the postganglionic sympathetic fibers from the superior cervical ganglion. These fibers pass through the ganglion without relay and supply the dilator pupillae muscle.

**Clinical insight ...**

**Retrobulbar Anesthesia (Fig. 46.6B)**

This anesthesia is given in cataract surgery (which is the most common surgery of eye) to achieve akinesia (immobility) of eyeball by paralyzing the muscles and anesthesia by numbing the sensory nerves inside the orbit. The anesthetic is introduced inside the cone of muscles in the retrobulbar space. Since the trochlear nerve is outside the muscular cone, the akinesia of superior oblique muscle is late compared to other extraocular muscles.

**Fig. 46.6B:** Site of insertion of needle (arrow) to give retrobulbar (behind the eyeball) anesthesia to numb sensory nerves and motor nerves before eye surgery

**Fig. 46.7:** Distribution of right ophthalmic artery

**Branches**

About eight to ten short ciliary nerves arise from the ganglion. These branches run anteriorly to pierce the sclera around the attachment of the optic nerve. The short ciliary nerves carry postganglionic parasympathetic fibers to the sphincter pupillae and ciliaris muscles.

**Ophthalmic Artery (Fig. 46.7)**

The ophthalmic artery is the sole supply of the contents of orbit including the eyeball. It arises from internal carotid artery after the latter’s emergence from the roof of the cavernous sinus. The ophthalmic artery enters the orbit through the optic canal, where it lies below and lateral to the optic nerve. Inside the orbit, the ophthalmic artery runs forward lying lateral to the optic nerve and then crosses obliquely above the optic nerve to reach the medial wall of the orbit. The relations of the three structures crossing the optic nerve are the superior ophthalmic vein, the ophthalmic artery and the nasociliary nerve (VAN from before backward). At the medial end of the upper eyelid, it divides in supratrochlear and dorsal nasal branches.

**Branches**

The ophthalmic artery gives rise to as many as ten branches.

i. Central artery of retina is the first branch, which enters the substance of the optic nerve.

ii. Lacrimal artery supplies the lacrimal gland and ends by giving lateral palpebral branches to both the lids. A recurrent meningeal branch passes back via the lateral part of superior orbital fissure to anastomose with an anastomotic branch of the middle meningeal artery.
artery. Sometimes this anastomosis may replace the lacrimal artery.

iii. Muscular branches (lateral and medial) are given to intraorbital muscles. These muscular branches give rise to anterior ciliary arteries, which travel with four recti to provide blood to the anterior segment of the eyeball.

iv. Long and short posterior ciliary arteries pierce the sclera to enter the eyeball.

v. Supraorbital artery arises, where the ophthalmic artery crosses the optic nerve.

vi. Posterior ethmoidal artery enters the posterior ethmoidal canal and supplies the posterior ethmoidal cells. It enters the anterior cranial fossa to supply the dura mater there. Its nasal branches descend in the nasal cavity via a slit in the cribriform plate to anastomose with sphenopalatine branches.

vii. Anterior ethmoidal artery enters the anterior ethmoidal canal and supplies the anterior and middle group of ethmoidal and frontal air sinuses. It enters the anterior cranial fossa to supply the dura mater there and send nasal branches to the nasal cavity.

viii. Medial palpebral arteries descend behind the lacrimal sac to enter the lids.

ix. Supratrochlear artery is the terminal branch, which leaves the orbit superomedially.

x. Dorsal nasal artery is the other terminal branch. It emerges from the orbit and divides in two branches. One of the branches joins the terminal part of facial artery while the other runs along the dorsum of the nose joining the artery of the opposite side.

**Ophthalmic Veins (Fig. 46.8)**

i. The superior ophthalmic vein is formed postero medial to the upper eyelid by the union of its two tributaries, which communicate with the facial and supraorbital veins. It travels backwards in the orbit along with the ophthalmic artery and leaves the orbit through the superior orbital fissure to terminate in the cavernous sinus. It receives venae vorticosae and the anterior ciliary veins from the eyeball.

ii. The inferior ophthalmic vein begins near the anterior part of orbital floor in a network of veins and usually terminates in superior ophthalmic vein or may reach the cavernous sinus. It communicates with pterygoid venous plexus by way of small veins that pass through the inferior orbital fissure.

The ophthalmic veins are potentially emissary veins since they connect the cavernous sinus to the veins in the face and thus become the route for the spread of infection from the face to the cavernous sinus.

**Fascia Bulbi (Tenon’s Capsule)**

The fascia bulbi is the fascial covering of the eyeball. It extends anteriorly up to the sclerocorneal junction and posteriorly up to the point of commencement of the optic nerve from the eyeball. At these limits the fascia bulbi is attached to the sclera. The facial sheath separates the eyeball from the orbital fat and forms a socket for it to move freely. Ciliary nerves and vessels and the tendons of the six extraocular muscles pierce the fascial sheath. It forms a tubular sheath for each muscle belly. From the sheath around the lateral rectus an extension towards the lateral wall on Whitnall's tubercle of zygomatic bone is called lateral check ligament. A similar extension from the sheath around the medial rectus to the posterior lacrimal crest on the medial wall is called medial check ligament. The two check ligaments are connected below the eyeball by a fascial hammock called suspensory ligament of Lockwood. This ligament envelops the inferior rectus and inferior oblique muscles. So this fascial hammock provides stability to the eyeball.

**EYEBALL**

The eyeball is the peripheral organ of vision. It contains the refractive media, intraocular muscles and the photosensitive retina. The extraocular muscles are inserted in the sclera of the eyeball to give it mobility so that the visual axis remains under the neuromuscular control. This is essential in determining the spatial relationship of the two eyeballs to each other, which is needed for binocular vision and conjugate eye movements.

The eyeball is located in the anterior part of the orbital cavity embedded in the orbital fat and separated from it by a membranous envelope called fascia bulbi or Tenon’s capsule. The eyeball is made up of the segments of two spheres of different sizes placed one in front of the other.
The anterior segment is the transparent cornea and forms one-sixth of the eyeball. Its radius of curvature is about eight millimeter. The posterior segment is the opaque sclera and forms five-sixth of the eyeball. Its radius of curvature is about twelve millimeter.

Embryologic insight (Fig. 46.9)...

The eyeball develops from neuroectoderm, surface ectoderm and the mesenchyme. During the fourth week of intrauterine life bilateral optic vesicles project from the diencephalon and proceed laterally towards the surface ectoderm. The optic vesicle consists of the optic cup and the optic stalk. Under the inductive influence of the optic vesicle the overlying surface ectoderm becomes thickened to form the lens placode. The lens placode sinks below the surface ectoderm to become the lens vesicle by sixth week. The optic vesicle is invaginated to form the double-layered optic cup. The space between the inner and outer layers of the cup is called the intraretinal space, which is gradually obliterated. The choroid fissure is the deficiency on the lower edge of the optic vesicle and of the optic stalk. Its function is to carry the hyaloid artery to the developing lens. By seventh week the choroidal fissure closes forming a narrow optic canal inside the optic stalk. Failure of the fissure to close completely results in coloboma formation. The pigment layer of retina develops from outer thinner layer of optic cup and its neural layer develops from the posterior four-fifths of the inner layer of optic cup. The retinal detachment takes place through the embryonic intraretinal space. The optic stalk and the contained axons of the ganglion cells form the optic nerve. The myelination of the nerve fibers in optic nerve takes place after birth by oligodendroglia. The hyaloid vessels convert into central artery and vein of retina.

Crystalline Lens

The lens develops from the lens placode, which is a thickening of surface ectoderm formed under the inductive influence of the optic vesicle (in the absence of the inductive influence the lens fails to develop). The critical period in the development of the lens is fourth to the sixth weeks. Hence, if the mother is exposed to rubella virus (German measles) before seventh week of gestation the child may be born with congenital cataract. The lens placode invaginates to form the lens vesicle, which consists of anterior and posterior epithelial walls enclosing a cavity. The cells of the posterior wall rapidly elongate and are filled with crystallins, which make them transparent. These are known as primary lens fibers, which gradually obliterate the lens cavity. The mitotic division of the anterior epithelial cells at the equator forms the new lens fibers (secondary lens fibers) throughout life. The mesenchyme on the anterior surface of the developing lens condenses to form the pupillary membrane. The pupillary membrane begins to degenerate around eighth month of intrauterine life. The developing lens is richly supplied through the vascular capsule fed by the hyaloid artery and the anterior choroidal artery. However, the vascular capsule of the lens disappears before birth.

Choroid, Ciliary Body and Iris (uveal tract)

i. The choroid and ciliary body develop from the condensation of mesenchyme surrounding the optic vesicle.
ii. The iris develops from both neuroectoderm and mesenchyme. The sphincter and dilator muscles of the iris are derived from the neuroectoderm while the ciliaris is mesodermal.

Cornea and Sclera

i. The corneal epithelium is derived from the surface ectoderm and the rest of the cornea from the mesenchyme.
ii. The sclera develops from condensation of the mesenchyme outside the optic cup.

Vitreous Body

The primary vitreous is derived from ectodermal cells of the developing lens and the neuroectoderm of the retinal layer of optic cup. The mesenchyme that enters the cup through the choroidal fissure also joins the primary vitreous. The branches of the hyaloid artery supply blood to the primary vitreous. The secondary vitreous develops from the retina and it pushes the primary vitreous behind the lens. The secondary vitreous is basically an extracellular matrix. When the hyaloid artery atrophies it leaves behind a hyaloid canal in the vitreous (Fig. 46.10).
The anterior pole of the eyeball is the center of curvature of cornea and the posterior pole is the center of posterior curvature of the eyeball, which is located slightly lateral to the attachment of optic nerve. The geometric or optic axis is the line joining the two poles. The equator of the eyeball lies midway between the two poles. The visual axis is the line passing through the fovea centralis of retina. The visual axis lies lateral to the optic axis.

**Coats of Eyeball (Fig. 46.10)**

The eyeball consists of three layers, which from without inwards are, the fibrous layer, the vascular and pigmented layer (uveal tract) and the neural layer.

**Fibrous layer**

i. The anterior one-sixth is formed by cornea, which is colorless and transparent.

ii. The posterior five-sixth is formed by sclera, which is white and opaque.

**Sclera**

The sclera is a thick non-distensible membrane that maintains the shape of the eyeball. It helps in maintaining the normal intraocular pressure of about 15 to 20 mm of mercury. The external surface of the sclera is white and the internal surface is brown. The anterior part of sclera (known as the white of the eye) is covered with transparent conjunctiva. The rest of the sclera is covered with fascia bulbi and gives insertion to six extraocular muscles. The sclera is continuous with the cornea at the limbus anteriorly. A circular channel called sinus venosus sclerae or canal of Schlemm is located in the sclera just behind the limbus. A triangular projection of sclera in the cornea medial to the canal of Schlemm is called the scleral spur. The sclera is continuous with the dural sheath of optic nerve posteriorly. The weakest part of the sclera is called lamina cribrosa, where the axons of optic nerve pierce the sclera to leave the eyeball. The point of emergence of the optic nerve is located 3 mm medial to the posterior pole of the eyeball.

**Structures Piercing the Sclera**

i. The optic nerve pierces the sclera along with central vessels of retina at the lamina cribrosa.

ii. The short ciliary nerves and vessels pierce around the entry of the optic nerve.

iii. The long ciliary nerves and vessels pierce the sclera in front of the short ciliary nerves and vessels.

iv. The venae vorticosae pierce just behind the equator of the eyeball.

v. The anterior ciliary arteries from the muscular branches of recti enter at various points.

vi. The aqueous veins, which drain the aqueous humor from the sinus venosus sclerae into the anterior ciliary veins pierce near the limbus.

**Nerve Supply and Blood Supply of Sclera**

i. The sclera is richly supplied through the long and short ciliary nerves.

ii. The sclera receives blood through the anterior ciliary arteries (twigs from muscular branches of ophthalmic artery) and also from the long and short posterior ciliary arteries.

**Cornea**

The cornea is transparent and avascular part of the fibrous layer. As the cornea is more convex than the sclera the...
sclerocorneal junction is indicated by a groove called the sulcus sclerae. The thickness of cornea is 1 mm at the periphery and 0.5 mm at the center. The cornea is an important refractive medium of eye as the maximum refraction of light takes place from it.

**Structure of Cornea**
The cornea consists of five layers.

i. The outer layer (corneal epithelium) is a stratified squamous non-keratinized type of epithelium.

ii. Inner to the corneal epithelium is the anterior elastic lamina or Bowman’s membrane.

iii. The third layer called substantia propria contains lamellae of collagen fibers. The transparency of cornea is due to the parallel arrangement of collagen fibers and the chemical nature of the ground substance in this layer.

iv. The fourth layer is the posterior elastic lamina or Descemet’s membrane.

v. The innermost or endothelial layer consists of a single row of flat polygonal cells.

**Nourishment**
The cornea is avascular and devoid of lymphatic vessels. Therefore, it is nourished by diffusion from capillaries at its edge and from aqueous humor at its internal surface. In addition to this, the central part of the cornea receives atmospheric oxygen dissolved in tear film. The avascularity of the cornea is of advantage in placing surgical incisions on it to approach the lens or the iris.

**Nerve Supply**
The cornea is richly innervated through the long ciliary branches of the nasociliary nerve.

**Sclerocorneal Junction (Fig. 46.11)**
The sclerocorneal junction (SCJ) or the limbus is the site where cornea and sclera merge with each other. This is the region of the iridocorneal angle. At the SCJ, a circular venous sinus (canal of Schlemm) traverses the sclera. The pectinate ligaments of the iris or the fibrils of the Descemet’s membrane of the cornea pass through the iridocorneal angle to get attached to the iris and give rise to the trabecular tissue in the angle. The trabecular tissue encloses endothelium-lined spaces called spaces of Fontana, which communicate medially with anterior chamber and laterally with sinus venosus sclerae. The aqueous humor filters through the spaces of Fontana at the iridocorneal angle (filtration angle) and drains in the canal of Schlemm. Blockage of the filtration angle results in rise in intraocular pressure (glaucoma).

**Uveal Tract**
It is a vascular and pigmented layer consisting of from behind forwards, the choroid, the ciliary body and the iris. These parts are functionally different but form a continuous layer. Inflammation of the iris is called iritis and that of ciliary body, cyclitis. The combined inflammation of the iris and the ciliary body is called iridocyclitis.

**Choroid**
The choroid is a brown coat situated inner to the sclera. It extends from the optic nerve posteriorly to the ciliary

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**Clinical insight ...**

i. Inflammation of cornea is called keratitis, which may lead to the formation of corneal ulcers.

ii. Injuries to cornea can lead to corneal opacities resulting in blindness.

iii. The corneal transplants are very readily accepted because the cornea is immunologically inert.

**Corneal Reflex (Blink Reflex)**
On touching the cornea with a wisp of cotton there is bilateral reflex closure of eyes.

i. The afferent limb is the ophthalmic division of the trigeminal nerve (refer to nerve supply of cornea). It carries impulses to the sensory nucleus, which is connected to motor nucleus of facial nerve in the pons on both sides.

ii. The center of reflex is the motor nucleus of facial nerve.

iii. The efferent limb is the facial nerve, which supplies orbicularis oculi (refer to action of this muscle). The reason for bilateral closure is understood from the bilateral connection of the sensory nucleus of trigeminal nerve to facial nucleus.

In injury to facial nerve (afferent limb) the closure of contralateral eye is seen on touching the cornea of affected side.

In injury to ophthalmic division of trigeminal nerve (afferent limb) on touching the cornea on affected side there is no response but on touching the cornea on normal side there is bilateral response.

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**Fig. 46.11: Sclerocorneal junction (arrow indication direction of flow of aqueous humor)**
(Note that the aqueous humor secreted by ciliary processes flows from the posterior to anterior chamber and onwards to spaces of Fontana, canal of Schlemm and aqueous veins to drain into anterior ciliary veins)
body anteriorly. Its inner surface is firmly attached to the pigment layer of retina. Its rough outer surface is separated from the sclera by a potential space called the perichoroidal space through which long posterior ciliary arteries and ciliary nerves (long and short) traverse.

Structure of Choroid
The choroid is divided in four layers. The outer layer (in contact with sclera) is the suprachoroidal lamina, inner to which is the vascular layer of large and medium sized blood vessels with scattered melanocytes. Inner to this is the layer of choriocapillaries. Bruch’s membrane, which is avascular, is believed to play a role in the passage of tissue fluid from the choriocapillaries to the retina. The choroid receives rich blood supply from the posterior ciliary arteries, which are the branches of the ophthalmic artery. The venous blood is drained by four or five vortico-cose veins, which pierce the sclera to join the ophthalmic veins. The choroid provides nutrition to outer layers of retina. The pigment cells in the choroid absorb excess light thus preventing reflection.

Ciliary Body
The ciliary body is located between the iris in front and the choroid behind. It is a highly vascular part of the uveal tract. Its shape is like a complete ring that runs around the periphery of the iris. On cross section the ciliary body is triangular in shape. The base or anterior surface is very narrow and faces the iridocorneal angle. The apex is continuous posteriorly with the choroid. The outer surface is in contact with the sclera. The inner surface is curved since it faces the lens and the vitreous body and is covered with ciliary epithelium. It is this surface that sends ciliary processes to surround the iris. The pigment cells in the choroid absorb excess light thus preventing reflection.

i. The ciliary epithelium is bilaminar. Its deeper or inner layer is nonpigmented and secretory in function. The deep layer covering the pars plicata is responsible for the secretion of the aqueous humor. Similar cells lining the pars plana facing the vitreous humor are believed to secrete the vitreous body. The cells of the superficial layer of the ciliary epithelium are pigmented in nature. Both the layers are continuous with the retina at the ora serrata. They represent the pars ciliaris retinae and are continuous with the pars ciliaris iridis anteriorly.

ii. The ciliary stroma consists of loose collagen fibers and supports the ciliaris muscle, long posterior ciliary arteries, anterior ciliary arteries, posterior short ciliary arteries and long and short ciliary nerves.

iii. The ciliary muscle or ciliaris is the muscle of accommodation. The contraction of circular and meridional fibers relaxes the suspensory ligament of the lens thereby increasing the convexity of the lens. This in turn reduces the focal length of the lens, which helps the lens in near vision (accommodation). The muscle receives parasympathetic nerve supply via the short ciliary nerves (Fig. 46.12), which pierce the sclera and reach the ciliary muscle along the perichoroidal space.

Iris
Iris means rainbow. The color of the iris varies from light blue to dark brown. The iris forms the circular diaphragm that is positioned between the lens behind and the cornea in front. It presents in its center an aperture called the pupil, through which the anterior and the posterior chambers of the eyeball communicate with each other. The main function of the iris is to regulate the amount of light that reaches the lens by regulating the size of the pupil.

Structure of Iris
The iris consists of the pigmented stroma containing the muscles of the iris, blood vessels and nerves. The stroma is lined posteriorly by a double-layered epithelium (the pars iridis retinae), which is deeply pigmented. The anterior surface of the iris is covered with epithelium of pupillary membrane in fetal life but by eighth month of intra-uterine life the membrane degenerates.

Muscles of Iris
1. The sphincter pupillae is a smooth muscle that encircles the pupil. When the muscle contracts the pupil is narrowed (miosis). The muscle receives nerve supply from the postganglionic parasympathetic fibers (Fig. 46.12). Parasympatholytic drugs like atropine relax the sphincter muscle thereby causing dilatation of the pupil.

2. The dilator pupillae is a thin smooth muscle. Its radially arranged fibers merge with those of the sphincter pupillae near the pupil. On contraction, the muscle
produces dilatation of the pupil (mydriasis). It receives sympathetic nerve supply as follows:

i. The long preganglionic fibers arise in intermediolateral horn of the T1-T2 segments of the spinal cord (ciliospinal centre) and course upwards through the cervical sympathetic trunk to relay in the superior cervical ganglion.

ii. The postganglionic fibers pass through the sympathetic plexus around the internal carotid artery to reach the dilator pupillae via the nerve plexus around the ophthalmic artery or via a communication with the nasociliary nerve. Injury to the sympathetic fibers in any location along this long course will give rise to Horner’s syndrome in which the pupil is constricted.

Arterial Supply of Iris
The major or greater arterial circle is present at the junction of the ciliary body and the iris. It is formed by the anastomosis between the long posterior ciliary arteries and the anterior ciliary arteries. Branches arise from this anastomosis and enter the iris to travel towards the pupil. These branches in turn anastomose close to the pupillary margin to form a minor or lesser arterial circle. Branches from both the circles supply the iris.

Sensory Nerve Supply of Iris
The sensory nerves are derived from the long ciliary branches of ophthalmic nerve.

Retina
The retina is the photosensitive layer that is located innermost. The photoreceptors in the retina convert the light energy into electrical impulses, which are processed in the retina and carried in the axons of ganglion cells contained in the optic nerve. The retina lies between the choroid externally and the hyaloid membrane of the vitreous body internally. Anteriorly, it terminates at the ora serrata, where the non-nervous part of retina in the form of a bilaminar epithelium extends to line the deep surfaces of the ciliary body and the iris.

Parts of Retina (Fig. 46.13)
On ophthalmoscopic examination the retina shows some distinguishing features:

i. The macula lutea is the yellowish area near the center of the retina. It has a central depression called the fovea centralis, where the retina is thinnest. Because of high concentration of cone cells the visual acuity is greatest at fovea.

ii. The optic disc lies 3 mm nasal or medial to the macula lutea. At this point, the optic nerve emerges from the retina. The central artery of the retina pierces the disc in the center. The disc is also called the blind spot because it is devoid of photoreceptors (rods and cones). Swelling of the disc (papilledema) occurs in optic neuritis and raised intracranial tension. Depression or cupping of the optic disc occurs in atrophy of the optic nerve and glaucoma.

Layers of Retina (Fig. 46.14)
There are ten layers of retina, which are numbered from outer to inner side. The first layer is adjacent to the choroid and the tenth layer is adjacent to the vitreous body.

i. Retinal pigment cells form a single layer of cubical cells. They contain melanin in their cytoplasm. The pigment cells absorb the excess light rays and prevent bouncing of light back into the retina. Their defense role consists of phagocytosis of parts of rods and cones.
that are discarded. They also form an effective blood-
retinal barrier between the retina and blood vessels of
choroid.

i. The layer of rods and cones contains the outer
segments of rod and cone cells, which are elongated
photoreceptors. The rods are cylindrical in shape.
They are larger in numbers compared to cones in
the peripheral part of retina. They are absent at
the fovea centralis. Their outer segments contain
rhodopsin (visual purple), which senses low level of
illumination and black and white colors. The cones
are flask shaped. Visual acuity is highest. Their outer
segments contain iodopsin, which senses bright light
and colors.

iii. External limiting layer is the junction between the
retinoglial cells (Müller's cells) and the inner segments
of the photoreceptors.

iv. Outer nuclear layer consists of cell bodies of rods and
cones and their nuclei.

v. Outer plexiform layer is made of synapses between the
processes of rods and cones cells and the dendrites of
bipolar cells and horizontal cells.

vi. Inner nuclear layer is composed of cell bodies and
nuclei of bipolar cells, amacrine cells, horizontal cells
and the Müller's cells (retinal gliocytes). The bipolar
cells are the first order neurons in the visual pathway.
The amacrine and horizontal cells are the association
neurons.

vii. Inner plexiform layer is formed of numerous synapses
between the axons of bipolar cells and amacrine cells
and the dendrites of ganglion cells.

viii. Ganglion cell layer contains the multipolar neurons,
which are the second order neurons of the visual pathway.

ix. Nerve fiber layer contains the unmyelinated axons of
the ganglion cells. These axons aggregate at the optic
disc to form the optic nerve.

x. Internal limiting lamina is composed of the processes
of retinal gliocytes. This layer separates the retina from
the vitreous body.

Arterial Supply of Retina

i. The outer layers of retina are nourished by diffusion
from the choriocapillaries.

ii. The central artery of retina supplies the inner layers of
the retina. This artery (a branch of ophthalmic artery)
runs in the substance of optic nerve and enters the
eyeball at the optic disc, where it divides into a supe-
rior and an inferior branch. Both branches further
divide into nasal and temporal branches. The superior
nasal branch supplies the superior nasal quadrant
and the superior temporal branch supplies the supe-
rior temporal quadrant of retina. Likewise the inferior
quadrants receive blood from the respective inferior
branches. Beyond the optic disc the central artery of
retina is an end artery. Therefore, when this artery is
blocked there is instant and total loss of vision.

Clinical insight...

The retina is the only place in the body, where the arteries
can be examined directly with the help of the ophthalmoscope
to note pathological changes in diseases like diabetes and
hypertension.
Venous Drainage of Retina

The veins follow the arteries. The arteries are placed superficial to the veins. The veins converge to form the central retinal vein, which opens into the cavernous sinus. The central vein is compressed as it passes through the subarachnoid space around the optic nerve in raised intracranial pressure. This results in papilledema and gradual loss of vision.

Refractive Media

The eyeball consists of four transparent media, the cornea, aqueous humor, crystalline lens and the vitreous body.

i. Cornea is exposed to the air hence maximum refraction of light takes place from its epithelium.

ii. The aqueous humor is a thin watery fluid that fills the spaces in front of and behind the iris, namely anterior and posterior chambers of the eyeball. It is secreted by the epithelium of ciliary processes in the posterior chamber from where it reaches the anterior chamber through the pupil. It is absorbed in the sinus venosus sclerae at the iridocorneal angle (filtration angle). The aqueous fluid from this canal is drained into the anterior ciliary veins via the aqueous veins in the sclera. The aqueous humor provides nourishment to the lens and cornea and maintains the intraocular pressure. It helps in refraction of the light. Blockage in the circulation of aqueous humor due to disease of the angle of filtration or due to blockage of the pupil (as a result of fusion of iris with the anterior surface of lens or posterior surface of cornea) results in rise of intraocular pressure. This is called glaucoma, which may lead to degeneration of retina and blindness.

iii. The lens is avascular, transparent and biconvex in shape and is covered by a glassy elastic capsule. It is suspended from the ciliary body by the suspensory ligament. The lens is placed between the posterior chamber and the vitreous chamber. The equator separates the anterior and posterior surfaces. The curvature of its anterior surface can be adjusted by the action of the ciliaris muscle. This is useful for accommodation in near vision. The aqueous humor and vitreous body nourish the avascular lens.

iv. The vitreous body occupies a large vitreous chamber, which is located behind the lens and the ciliary body and in front of the retina. The vitreous body is a jelly like material composed of water, hyaluronic acid and a meshwork of loose collagen fibrils. It is enveloped by hyaloid membrane, which separates it from the retina, ciliary body and lens. The posterior surface of the lens causes a depression in the hyaloid membrane called hyaloid fossa. A small passage called the hyaloid canal extending from the optic disc to the center of the posterior surface of the lens traverses the vitreous body. In fetal life the canal contains the hyaloid artery, which later degenerates.
ORAL CAVITY

The oral cavity is divided into two parts. The vestibule is the anterior slit like space bounded by the teeth and gums internally and the lips and cheeks externally. The parotid duct opens into the vestibule opposite to the crown of second upper molar tooth (Fig. 47.1). The oral cavity proper lies behind the teeth. The palate forms its roof. The anterior two-thirds of the tongue occupies its floor except in the anteriormost part. The oral cavity communicates with the oropharynx through oropharyngeal isthmus.

Teeth or Dentition

There are two sets of teeth. The temporary (or milk or deciduous) teeth are twenty in number. Each jaw contains ten teeth of which five are present in each half of the jaw (two incisors, one canine and two molars). The milk teeth erupt in the following sequence, incisors (6–10 months), first molars (10–16 months), canines (16–20 months) and second molars (20–30 months). The permanent teeth are thirty two in numbers. Each jaw has sixteen teeth of which eight are present in each half of the jaw (two incisors, one canine, two premolars and three molars). The permanent teeth erupt in the following sequence, first molars (6 years), incisors (7–9 years), premolars (10–12 years), canines (11–12 years), second molars (13–14 years) and third molars (17–22 years).

Embryologic insight ...

Development of Tooth

The enamel of the tooth develops from the ectoderm. It is the toughest tissue in the body. The pulp, dentine and cementum of the tooth develop from the mesoderm.
Floor of the Mouth (Fig. 47.2)
The frenulum linguae is a fold of mucous membrane connecting the undersurface of the anterior part of the tongue to the most anterior part of the floor of the mouth. The sublingual papillae are present on either side of the frenulum. On the summit of each papilla the submandibular duct opens. Numerous small ducts of sublingual salivary glands open on the sublingual fold on each side.

TONGUE
The tongue is a mobile muscular organ located partly in the oral cavity and partly in the oropharynx. It is attached to the hyoid bone below, to the palate above, to the mandible in front and to the styloid process behind by means of muscles. It is a highly mobile organ. The tongue is the peculiar organ, where stratified squamous non-keratinized mucosa closely covers a mass of striated muscle fibers disposed in vertical, transverse and longitudinal directions. The substance of tongue is divided into two halves by a median fibrous septum. The functions of the tongue include, tasting, masticating and swallowing the food besides its role in speech.

Parts of the Tongue
The tongue consists of a tip, a root, inferior surface and a curved dorsal surface.

i. The tip of the tongue is directed forwards and it remains in contact with the incisor teeth when the mouth is closed.
ii. The root of the tongue lies in the floor of the mouth and is composed of genioglossus and hyoglossus muscles.

Thus, the tongue is attached to the mandible and hyoid bones by its root.

iii. The inferior surface is covered with mucous membrane, which is continuous with the mucous membrane of the floor of the mouth. A midline mucosal fold called frenulum linguae connects the inferior surface to the floor of the mouth. The deep lingual vein is located on either side of the frenulum linguae. On both sides of the posterior end of frenulum, there is a sublingual fold and papilla. The submandibular duct opens in the summit of this papilla.

iv. The curved dorsal surface or the dorsum of the tongue is its most important surface.

Gross Appearance of Dorsum (Fig. 47.3)
The dorsum presents a V-shaped sulcus terminalis. The apex of the V is directed posteriorly and the limbs are directed forwards and laterally from the apex, which coincides with foramen cecum. The foramen cecum is a pit indicating the site of origin of embryonic thyroglossal duct, which develops into thyroid gland. The sulcus terminalis divides the dorsum of the tongue into two parts, namely, anterior two-thirds (presulcal or oral) and posterior one-third (postsulcal or pharyngeal). The mucous membrane covering the two parts differs in gross features, sensory innervation and development.

Anterior Two-third
The mucous membrane on this part of the tongue is characterized by the presence of lingual papillae, which are the projections of the mucosa. These papillae are responsible for the rough appearance to the dorsum. There are four
types of papillae—filiform, fungiform, foliate and vallate or circumvallate.

i. The filiform papillae are conical in shape and cover most of the anterior two-thirds of dorsum. They are arranged in rows parallel to the sulcus terminalis on either side of the midline. The stratified squamous epithelium covering these papillae are keratinized, hence the papillae appear whitish in color. The function of these papillae is to facilitate the friction between the tongue and the food. They are devoid of taste buds.

ii. The fungiform papillae are found mainly on the margins of the tongue but a few are scattered on the dorsum. They are deep red in color due to absence of keratinized epithelium covering them. Each papilla usually bears taste bud at its apex.

iii. The foliate papillae are present on the lateral margins of the tongue near the sulcus terminalis. They are red in color and appear as leaf-like mucosal ridges. They bear taste buds.

iv. The vallate papillae are largest in size (number being 10–12). These papillae are located just in front of the sulcus terminalis. The shape of the vallate papilla is like that of an inverted cone with a narrow base and broad apex. Each papilla is 1 to 2 mm in diameter and lies in a well-marked depression or trench in the mucosa. Numerous taste buds are present on the walls of the papilla and the walls of the surrounding trench.

Posterior One-third

This part is located in the floor of oropharynx. The palatoglossal folds connect it to the palate. A median and two lateral glossoepiglottic folds attach the base of tongue to the epiglottis.

i. The mucosa on the dorsum of this part is devoid of papillae.

ii. Its surface has characteristic cobblestone appearance due to presence of lingual tonsils, which are submucosal lymphatic nodules belonging to Waldeyer’s lymphatic ring.

Muscles of Tongue

Each half of the tongue contains extrinsic and intrinsic muscles. The four pairs of extrinsic muscles alter the position and size of the tongue as they attach the tongue to neighboring bones on each side. The four pairs of intrinsic muscles located wholly within the tongue alter the shape of the tongue.

Extrinsic Muscles (Fig. 47.4)

1. The genioglossus muscle has a narrow tendinous origin from the upper genial tubercle of the mandible. It has a wide insertion into entire aspect (tip and side) of tongue. Its lowest fibers are attached to body of hyoid bone.

   i. Acting together the genioglossi pull the tongue forward to protrude the tip out of the mouth. The origin of the muscle is anterior in location compared to its insertion. On contraction each muscle draws the posterior part of tongue forwards and medially. Because the medial pull of each muscle cancels out, protrusion of the tongue in the midline is the net result.

   ii. Unilateral action of the muscle pushes the tongue to the opposite side.

Clinical insight ...

Importance of Lingual Tonsils

The lingual tonsils are most often overlooked in the head and neck examination of the patient (because they cannot be inspected directly due to their anatomic location on the base of the tongue). Moreover, their inflammation and enlargement (lingual tonsillitis) produce symptoms like odynophagia (pain during swallowing), dysphagia (difficulty in swallowing), otalgia (pain in ear), halitosis (bad odor in mouth), chronic cough and dyspnea (difficulty in breathing).
2. The palatoglossus muscle is a common muscle of the tongue and palate. It takes origin from the palatine aponeurosis and is inserted into the side of the tongue. The muscle and the covering mucosa form the palatoglossal arch. The right and left muscles act together in bringing the two palatoglossal arches together thereby shutting the oral cavity from the oropharynx.

3. The styloglossus muscle arises from the anterolateral aspect of styloid process near its apex. It passes downwards and forwards to reach the tongue for insertion. It draws the tongue upwards and backwards.

4. The hyoglossus muscle is quadrilateral in shape. It has very important relations (Fig. 47.4) hence it is regarded as the key muscle of the submandibular region.
   i. It arises from the greater cornu and the body of hyoid bone. The fibers pass upwards to insert into the side of the tongue.
   ii. The hyoglossus of each side depresses the side of the tongue so as to make its dorsal surface more convex.
   iii. The relations of the hyoglossus are as follows. Superficially, it is related from above downwards to, styloglossus, lingual nerve, submandibular ganglion, submandibular duct and the deep part of the submandibular gland. The lowest structure on this surface is the hypoglossal nerve. There are three structures that pass deep to the posterior margin of the muscle, glossohyoideus nerve, stylohyoid ligament and lingual artery from above downwards. Anterior to the hyoglossus are placed the sublingual gland and geniohyoid muscle. Deep to the hyoglossus are found the same three structures that pass deep to its posterior margin and two muscles, namely, genioglossus and middle constrictor.

Intrinsic Muscles

i. The right and left superior longitudinal muscles arise from the posterior part of the median fibrous septum of the tongue and are inserted into the respective sides of the tongue. On contraction, they make the dorsal surface concave from side to side.

ii. The right and left inferior longitudinal muscles arise from the sides of the tongue and converge to the anterior part of the median septum for insertion. On contraction, they make the dorsal surface more convex.

iii. The vertical muscles originate from the dorsum and descend through the fibers of genioglossus for insertion in the sides of the tongue. On contraction, they increase the width of the tongue.

iv. The transverse muscles originate in the septum and proceed transversely through the fibers of genioglossus, hyoglossus and vertical muscles to the margin of the tongue. On contraction, the two muscles make narrow the tongue.

Nerve Supply

Motor Nerve Supply

All the muscles of the tongue except the palatoglossus are supplied by the hypoglossal nerve. The palatoglossus is the only one supplied by vago-accessory complex through pharyngeal plexus.

Sensory Nerve Supply

The sensory nerves of the tongue are divided into two groups:

i. Nerves carrying general sensations like pain, touch and temperature.

ii. Nerves carrying special sensation of taste.

Anterior Two-third

The lingual nerve carries the general sensations and the chorda tympani nerve carries the taste sensation from all taste buds except those on vallate papillae.

Posterior One-third

The glossopharyngeal nerve carries the general sensations as well as the taste sensation from the vallate papillae.

The internal laryngeal nerve (a branch of vagus) supplies a small area adjacent to the epiglottis.

Arterial Supply (Fig.47.7)

i. The lingual artery, a branch of external carotid artery, is the main arterial supply to the tongue through its dorsal and deep branches.
The lingual branches of inferior alveolar artery also supply the tongue. The details of the lingual artery are described with branches of external carotid artery in chapter 44.

**Venous Drainage (Fig. 47.8)**

The dorsal lingual veins drain the dorsum and sides of the tongue. They unite with the venae comitantes of the trunk of the lingual artery to form a lingual vein, which opens in the facial or internal jugular vein. The deep vein begins near the tip and travels on the inferior surface of the tongue. It joins the sublingual vein from the salivary glands to form the veins accompanying the hypoglossal nerve. This vein may drain into the lingual or the facial or the internal jugular vein. The inferior surface of tongue is suitable for rapid absorption of medicines due to presence of deep lingual veins. The coronary vasodilators like nitroglycerine or sorbitrate are kept sublingually to relieve pain of angina pectoris.

**Lymphatic Drainage (Fig. 47.8)**

The lymphatic drainage of the tongue is of clinical importance because the cancer spreads via the lymphatics to the regional lymph nodes. The cancer of the tongue (Fig. 47.9) is very common in people habituated to tobacco chewing. The enlarged lymph nodes in this cancer are removed by

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**Embryologic insight...**

**Correlation of Nerve Supply and Development (Fig. 47.6)**

i. The muscles of the tongue and its mucosa develop from different sources. All the muscles of the tongue except the palatoglossus develop from occipital myotomes, hence they are supplied by hypoglossal nerve. The palatoglossus develops from fourth arch mesoderm along with muscles of the palate, hence it is supplied by the vagoglossissory complex.

ii. The mucosa of the anterior two-thirds develops from the fusion of three endodermal swellings in the floor of the pharynx associated with the first arches (bilateral lingual swellings and the midline tuberculum impar). This explains its general sensory innervation from the mandibular nerve (nerve of first arch) through its lingual branch. The myelomeric nerve of the first arch is the chorda tympani branch of facial nerve (nerve of second arch). Thus, the sensory supply to the taste buds of anterior two-thirds of the tongue by chorda tympani is justified.

iii. The mucosa of the posterior one-third of the tongue develops from the cranial part of hypobranchial eminence, which is derived from the endoderm of third arches. Hence, the general and special sensory nerve of the posterior one-third is the glossopharyngeal nerve (the nerve of third arch). This nerve supplies the vallate papillae also because these papillae develop from hypobranchial eminence.

iv. The mucosa of the vallecula develops from the fourth arch endoderm, hence it is supplied by the internal laryngeal nerve (a branch of superior laryngeal nerve).
block dissection of the neck along with total glossectomy or hemiglossectomy.

i. Abundant lymph vessels from the tip of tongue drain bilaterally in submental nodes. A few reach directly to jugulodigastric nodes. Thus, cancer of the tip of the tongue spreads to almost all cervical nodes.

ii. The central lymph vessels from either side of the midline pass vertically downward through the substance and end bilaterally in the jugulodigastric nodes.

iii. The lymphatics from the lateral part of the anterior two-thirds reach unilaterally to the submandibular nodes.

iv. The lymphatics from the posterior one-third pass bilaterally to the jugulodigastric and juguloomohyoid nodes.

**Gustatory or Taste Pathways**

The taste pathways for the anterior two-thirds and the circumvallate papillae are different.

i. The taste sensations from the anterior two-thirds (fungiform and filiform papillae are carried in the chorda tympani nerve, which lies inside the lingual nerve up to the infratemporal fossa. The chorda tympani comes out of the lingual nerve in the infratemporal fossa and enters the petrotympanic fissure to join the facial nerve 6 mm above the stylomastoid foramen. The taste fibers carried in the facial nerve terminate on the cells of the geniculate ganglion (first order neurons). The central processes of the ganglion cells join the nervus intermedius through which the taste sensations reach the nucleus of tractus solitarius (second order neuron) in the medulla oblongata. The solitariothalamic pathway further carries the taste to the nucleus VPM of thalamus (third order neuron), which projects via the superior thalamic radiation to the anteroinferior part of the postcentral gyrus (parietal operculum) and parainsular cortex.

ii. The taste sensation from the circumvallate papillae is carried by the glossopharyngeal nerve to its inferior sensory ganglion (first order neurons). The central processes of the ganglion cells enter the medulla oblongata along with the glossopharyngeal nerve to end in the nucleus of tractus solitarius (second order neurons). The rest of the path is similar to the path for taste sensations from anterior two-thirds.
The palate is composed of two parts. The hard palate forms the larger anterior part and the soft palate forms the posterior smaller part of the palate. The hard palate separates the oral cavity from the nasal cavity. The soft palate is a movable muscular curtain between the nasopharynx and the oropharynx.

Components of Hard Palate (Fig. 47.10)
The palatine processes of the maxillae and the horizontal plates of palatine bones unite by a cruciform suture to form the hard palate. A vascular groove extends from the greater palatine foramen along the lateral side of the inferior surface of the hard palate. It contains the greater palatine vessels. The epithelium lining the inferior or oral surface of hard palate is known as mucoperiosteum because it is fused with the periosteum of the hard palate. The palatine mucous glands are abundant on this surface.

Foramina in Hard Palate
i. Greater palatine foramen is located near the lateral palatal border behind the palatomaxillary suture.
ii. Lesser palatine foramen is seen behind the greater foramen
iii. Incisive fossa is situated anteriorly. It shows the openings of lateral incisive foramina.

Soft Palate
The soft palate is a muscular curtain that hangs from the posterior margin of the hard palate in a slightly downward and backward direction. Its free margin presents uvula in the midline. The soft palate is connected to the tongue by means of palatoglossal arches and to the pharyngeal wall by palatopharyngeal arches. Structurally, the soft palate is a fold of mucous membrane containing palatine aponeurosis, muscles, glands, blood vessels and nerves.

In the stretched position, the palate has an upper or nasopharyngeal surface and a lower or oropharyngeal surface. In the relaxed position, the upper surface becomes posterior and the lower surface becomes anterior.

Layers of Soft Palate
In relaxed position (from posterior to anterior) the layers of the soft palate are as follows:
i. Pseudostratified ciliated columnar epithelium
ii. Layer of palatine glands and lymphoid tissue
iii. Palatine aponeurosis
iv. Layer of palatine glands
v. Stratified squamous nonkeratinized epithelium on which taste buds are present.

Palatine Aponeurosis
The palatine aponeurosis strengthens the soft palate. It is attached to the posterior border of hard palate. It is the expanded tendon of tensor veli palatini muscles of both sides and it encloses the musculus uvulae near the midline. It provides attachment to other palatine muscles.

Muscles of Soft Palate (Fig. 47.11)
There are five pairs of palatine muscles, tensor palati, levator palati, palatoglossus, palatopharyngeus and musculus uvulae.

Tensor Palati or Tensor Veli Palatini
This muscle takes origin from the scaphoid fossa at the base of medial pterygoid plate, lateral (membranous) wall of auditory tube and the spine of sphenoid (deep in the infra-temporal fossa). It ends in a tendon, which winds round the pterygoid hamulus to turn medially towards the pharynx.
It spreads out in the soft palate to become the palatine aponeurosis.

**Actions**

i. The tensor palati is the tensor of the soft palate.

ii. It opens the auditory tube during deglutition and yawning to equalize the air pressure between the middle ear and the nasopharynx. Because of this action, the fibers of tensor palati that take origin from the lateral wall of the tube are known as dilator tubae.

**Levator Palati or Levator Veli Palatini**

This muscle takes origin from the medial (cartilaginous) wall of the auditory tube and the part of petrous temporal bone in front of the lower opening of carotid canal. The levator palati follows the auditory tube over the free upper margin of superior constrictor muscle and enters the pharynx by piercing the pharyngobasilar fascia. It is inserted in the upper surface of palatine aponeurosis between the two strands of palatopharyngeus muscle.

**Actions**

The contraction of muscles both sides raises the soft palate towards the posterior wall of the oropharynx. This action helps in closure of nasopharyngeal isthmus during swallowing.

**Palatoglossus**

This muscle takes origin from the oral surface of the palatine aponeurosis and extends forwards, downwards and laterally in front of the palatine tonsil to reach the side of the tongue. It is covered with mucosa of oropharynx and thus, forms the palatoglossal arch (anterior pillar of tonsillar fossa).

**Actions**

The contraction of the muscles of both sides elevates the base of the tongue and brings the two palatoglossal arches in approximation in order to close the oropharyngeal isthmus.

**Palatopharyngeus**

This muscle takes origin from the palate by two slips, the larger anterior slip from the posterior margin and adjacent upper surface of hard palate and the posterior slip from the posterior part of the upper surface of the palatine aponeurosis. The two slips are separated at origin by the insertion of levator palati. Both slips join to form a single muscle, which passes posterolaterally under cover of palatopharyngeal arch (posterior pillar of tonsillar fossa). The muscle travels through the pharyngeal wall for gaining attachment to the posterior border of the lamina of thyroid cartilage.

**Actions**

i. The muscle depresses the soft palate on the dorsum of the pharyngeal part of tongue. This prevents the soft palate from being forced into the nasopharynx during blowing through the mouth against resistance.

ii. The fibers of palatopharyngeus that arise from the hard palate pass horizontally backwards with the superior constrictor and meet each other to form a circular muscular ridge called Passavant’s ridge. This muscular ridge is responsible for closure of the nasopharyngeal isthmus by approximating the pharyngeal wall to the raised soft palate.

**Musculus Uvulae**

These are the paired intrinsic muscles. Each takes origin from the posterior nasal spine of the hard palate and is inserted in the mucosa of the uvula. The palatine aponeurosis splits to enclose the musculus uvulae near the midline. The action of these muscles is to shorten and tense the uvula.

**Motor Nerve Supply**

The muscles of the soft palate are supplied by vago-accessory complex through the pharyngeal plexus except the tensor palati, which is supplied by mandibular nerve through its branch to medial pterygoid via otic ganglion. Paralysis of muscles of the soft palate may occur in injury to the vagus nerve or due to lesion of nucleus ambiguus in the medulla oblongata (lateral medullary syndrome). This results in nasal regurgitation of food and nasal voice.

**Secretomotor Nerve Supply**

The secretomotor supply to the palatine glands is by the postganglionic fibers of the sphenopalatine ganglion via the palatine nerves. The preganglionic fibers arise in the superior salivatory nucleus, travel in nervus intermedius,
facial nerve, greater petrosal nerve and nerve of pterygoid canal to reach the sphenopalatine ganglion.

**Sensory Nerve Supply**

i. The general sensations like touch, pain and temperature are carried through the palatine nerves, nasopalatine nerve and glossohypoglossal nerve.

ii. Taste sensation from the palate is carried in the lesser palatine nerves. After reaching the sphenopalatine ganglion, the further course of the taste sensation is via the greater petrosal nerve, facial nerve, geniculate ganglion and nervus intermedius to end on nucleus of tractus solitarius. Some taste fibers reach the nucleus of tractus solitarius via the glossohypoglossal nerve.

**Blood Supply**

The greater palatine branch of maxillary artery supplies the palate. The ascending palatine branch of facial artery takes an unusual course. It first ascends to the upper limit of pharynx and then descends along the levator palati to reach the palate. The palatine branch of the ascending pharyngeal branch of external carotid artery also supplies the palate. The veins drain in the pterygoid and tonsillar venous plexuses.

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**Embryologic insight (Fig. 47.12) ...**

i. The part of the palate in front of the incisive fossa carrying the four incisor teeth develops from the frontonasal process (inter-maxillary segment or premaxilla).

ii. The rest of the palate develops from right and left palatal processes arising from the maxillary processes of respective side.

**Contd...**

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**Fig. 47.12: Developmental sources of palate**

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**Contd...**

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**Fig. 47.13: Different types of developmental defects in palate (cleft palate)**

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**Congenital Anomalies (Fig. 47.13)**

The cleft palate may be isolated or associated with cleft upper lip. Different degrees of cleft palate occur depending on the complete or partial and unilateral or bilateral failure of fusion of the three embryonic elements forming the palate. The child with cleft palate experiences difficulty in speech and swallowing unless surgical correction is carried out.

i. A serious anomaly comprises of the bilateral complete cleft palate due to complete failure of fusion of the Y-shaped suture. This is associated with bilateral cleft upper lip.

ii. Unilateral complete cleft palate is due to nonunion of palatine processes with each other and non-union of palatine process and premaxilla on one side. This is associated with unilateral cleft upper lip.

iii. A midline cleft in both soft and hard palate is due to failure of fusion of the two palatine processes either fully or partially.

iv. Cleft or bifid uvula occurs when there is failure of fusion in the posterior end of the two palatine processes.
The nasal cavity is located between the two orbits and below the middle part of anterior cranial fossa. It is divided into right and left halves by a midline nasal septum. If the septum is deviated to one side the right and left halves are of unequal size. The nasal cavity opens on the face by two nostrils or anterior nasal apertures and it opens in the nasopharynx by two choanae or posterior nasal apertures (for boundaries of the choanae refer to pharynx in chapter 49).

Each half of the cavity has four walls, floor and roof, lateral wall and medial wall. The vertical medial wall (septal wall) is common for the two halves.

Subdivisions
Each half of the nasal cavity is divided into nasal vestibule and nasal cavity proper.

Nasal Vestibule
The vestibule forms the beginning of the nasal cavity hence, it is located anteriorly. It is bounded laterally by the major alar cartilage and medially by the septal process of major alar cartilage. It is limited above and behind by limen nasi, which is a curved ridge, where the skin of vestibule is continuous with nasal mucosa of lateral wall. The vestibule is lined with skin and hence has sweat and sebaceous glands and coarse hairs called vibrissae.

Nasal Cavity Proper
The nasal cavity proper is subdivided into two functionally different areas, respiratory and olfactory (chemosensory).

The respiratory area is large and covered by pseudostratified columnar ciliated epithelium supported by subjacent lamina propria containing numerous nasal glands (serous and mucous) and cavernous vascular plexuses. This mucosa covers major part of the lateral wall, septum, roof and floor. The olfactory area is limited to upper one-third of nasal cavity. It is covered by olfactory epithelium.

Functions of Nasal Cavity

i. The vibrissae in the vestibule trap the foreign bodies in the inspired air.

ii. The respiratory mucosa is thick and spongy due to the presence of rich vascular plexuses. This helps in warming and humidification of the inspired air. The mucus secretion of nasal glands traps the dust particles. Rhinitis is the inflammation of nasal mucosa, usually seen in common cold and hay fever. In rhinitis, the nasal mucosa becomes swollen due to rich vascularity and there is increased secretion of the mucous glands resulting in choked nose. In common cold or allergic rhinitis, there is increased secretion of serous glands causing watery discharge from nasal cavity.

iii. The olfactory mucosa is considerably thicker than respiratory mucosa. It occupies an area covering the postero-superior part of the lateral nasal wall (including the back of superior concha and the sphenoethmoidal recess), upper part of the nasal septum and the arching roof between the septum and the lateral wall. It is yellowish brown in color. It is characterized by bipolar olfactory receptor cells, which are the first order neurons in the olfactory path. The axons
of the receptor cells gather to form bundles of olfactory nerve. These bundles pierce the cribriform plate of ethmoid in the roof of nasal cavity.

**Communications of Nasal Cavity**

The nasal cavity communicates with the paranasal air sinuses. In addition, it shows following communications.

i. It communicates with anterior cranial fossa via cribriform plate of ethmoid bone. The cribriform plate carries the olfactory nerves inside the cranium.

ii. Close to the cribriform plate, there is canal for anterior ethmoidal nerve and vessels.

iii. Occasionally, there is foramen cecum between crista galli and frontal bone. This foramen gives passage to the emissary vein connecting nasal veins with superior sagittal sinus.

iv. The sphenopalatine foramen in the lateral wall connects nasal cavity with pterygopalatine fossa. The structures passing through this foramen are sphenopalatine artery, nasopalatine nerve and superior nasal branches of sphenopalatine ganglion.

v. Incisive canals in the incisive fossa in the hard palate communicate the nasal cavity to the oral cavity. The nasal branches of greater palatine artery and palatine branches of nasopalatine nerve pass through these canals.

vi. The nasolacrimal duct communicates the nasal cavity with the lacrimal sac and through it with the conjunctival sac.

**Boundaries of Nasal Cavity Proper (Fig. 48.1)**

The nasal cavity proper presents floor, roof, lateral wall and medial wall or nasal septum.

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**Floor**

The floor is formed by the mucosa covering the superior surface of the hard palate (composed of palatine process of maxilla and horizontal process of palatine bone).

**Formation of Roof**

The roof is the narrowest wall of nasal cavity. It lies at the junction of lateral and medial walls. It has anterior sloping part, middle horizontal part and posterior sloping part.

i. The anterior sloping part is formed by the nasal cartilages, nasal bones and nasal part of frontal bone.

ii. The middle horizontal part is formed by cribriform plate of ethmoid.

iii. The posterior sloping part is formed by lower surface of body of sphenoid.

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**Clinical insight ...**

**CSF Rhinorrhea**

It is important to note that the middle part of the roof separates the nasal cavity from the anterior cranial fossa. Therefore, in fracture of the cribriform plate of ethmoid, the cerebrospinal fluid may leak in to the nasal cavity resulting in CSF rhinorrhea (dribbling of clear fluid from the nose on bending or straining). The roof provides a route for spread of infection from the nasal cavity into the cranial cavity.

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**Lateral Wall**

The lateral wall of the nasal cavity is highly irregular. It is characterized by conchae or turbinates and meatuses. The conchae are the bony shelf-like elevations and the meatuses are the spaces between the conchae. They increase the surface area of the nasal cavity.

**Nasal Conchae**

The conchae (turbinates) are the inferomedial bony projections from the lateral wall of nasal cavity. There are three conchae.

i. The superior concha is the smallest and is located in the posterior part of nasal cavity. It is a projection from the ethmoid bone.

ii. The middle concha is projection from ethmoid bone.

iii. The inferior concha is an independent bone.

**Nasal Meatuses**

The meatuses are the spaces enclosed by the conchae. There are three meatuses (superior, middle and inferior). In addition to the above three spaces, the lateral wall is characterized by a fourth space called sphenethmoidal recess above the superior concha.
**Nasal Cavity and Paranasal Air Sinuses**

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**Inferior Meatus**
The inferior meatus lies between the nasal floor and the inferior concha. It runs along the entire length of the lateral wall. It receives the opening of the nasolacrimal duct in its anterior part. The mucous membrane at this orifice is usually raised to form a lacrimal fold, which acts as valve (of Hasner) preventing air and nasal secretions being blown up into the duct. The inferior meatus provides an approach for draining out the pus from the maxillary sinus.

**Middle Meatus**
The middle meatus is the space between the middle and inferior conchae. It receives openings of four paranasal sinuses (middle ethmoidal, anterior ethmoidal, frontal and maxillary). It continues anteriorly into a space called atrium of the middle meatus, which is limited above by agger nasi (an insignificant mucosal ridge shown in Figure 48.2).

**Main Features of Middle Meatus (Fig. 48.2)**

i. The bulla ethmoidalis is a rounded bulge produced by the middle ethmoidal sinus, which opens on or above it.

ii. The hiatus semilunaris is a curved cleft below and in front of the bulla ethmoidalis.

iii. The infundibulum is a duct like passage beginning at the anterior end of the hiatus. The anterior ethmoidal sinus opens into it.

iv. The frontal sinus opens into the infundibulum by frontonasal duct.

v. The opening of the maxillary air sinus lies below the bulla ethmoidalis.

(Note: This opening is reduced in size by four bones seen in the lateral wall namely, descending process of lacrimal bone in front, uncinate process of ethmoid bone above, inferior nasal concha below and perpendicular plate of palatine bone behind).

The position of the opening of frontal sinus is at a much higher level compared to that of the maxillary sinus. This favors the flow of fluid from the frontal to the maxillary opening. Thus, maxillary sinus is filled in frontal sinusitis.

**Superior Meatus**
This space is present between the superior and middle conchae. It is limited to only the posterior third of the lateral wall. The posterior ethmoidal sinus opens into it.

**Sphenoethmoidal Recess**
This space lies above and behind the superior concha. It is very narrow and receives the opening of sphenoidal sinus.

**Nasal Septum**
The nasal septum is partly bony and partly cartilaginous (Fig. 48.3). The perpendicular plate of ethmoid bone forms the posterosuperior part of the septum and the vomer forms the posteroinferior part. The septal cartilage bridges the gap anteriorly. The other bones which make minor contributions to the periphery of the septum are shown in Fig 48.3. The posterior free margin of the septum is formed by the free margin of the vomer, which separates the two posterior nasal apertures or choanae. The free margin of the septum can be inspected through the nasopharynx by a procedure called posterior rhinoscopy (refer to “inspection of nasopharynx” in chapter 49).

The skeletal nasal septum is covered with mucoperichondrium and mucoperiosteum except where it forms the medial wall of the vestibule (this part is covered by skin). This part of the septum is mobile and is called the columnella.

![Fig. 48.2: Openings in lateral wall of nasal cavity](image1)

![Fig. 48.3: Skeletal components of nasal septum (Note the minor contributions around the edges)](image2)
Arterial Supply of Nasal Cavity (Fig. 48.4)

The nasal cavity receives rich arterial supply.

**Arterial Supply of Nasal Septum**

The following arteries supply the septum.

i. The anterior and posterior ethmoidal arteries (branches of ophthalmic branch of internal carotid artery).

ii. The septal branches of superior labial branch of facial artery (branch of external carotid artery).

iii. The septal branches of sphenopalatine and greater palatine branches of maxillary artery (branch of external artery).

**Arterial Supply of Lateral wall**

The lateral wall also receives blood from the same sources like that of the nasal septum except that instead of the septal branches of the superior labial branch of facial artery, the alar twigs from lateral nasal branch of facial artery supply the lateral wall.

**Venous Drainage of Nasal Cavity**

The veins accompany the arteries and drain into the superior ophthalmic veins, pterygoid venous plexus and facial veins.

**Nerve Supply of Nasal Cavity (Fig. 48.5)**

i. The receptor cells in the olfactory zone are supplied by 10 to 20 bundles of olfactory nerves.

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**Clinical insight ...**

**Deviated Nasal Septum**

Deviated nasal septum (DNS) (Fig. 48.8) is a common cause of nasal obstruction. The septum is deviated due to trauma or error in development or unequal growth in the base of skull and palate. The deviated septum causes symptoms due in nasal block, sinusitis, epistaxis and anosmia.

**Little’s Area and Kiesselbach’s Plexus**

This is a vascular area in the anteroinferior part of the nasal septum (Fig. 48.4). The septal branches of the anterior ethmoidal, sphenopalatine, greater palatine and superior labial arteries and their corresponding veins form an anastomotic plexus (Kiesselbach’s plexus) in this area. Injury to this plexus is the commonest cause of epistaxis or nasal bleeding (this area of septum is exposed to finger-nail trauma).

**Fig. 48.4:** Arterial supply of nasal septum (Note the vascular plexus of Kiesselbach at Little’s area)

**Fig. 48.5:** Nerve supply of lateral wall and medial wall (septum) of nasal cavity
ii. The nerves carrying general sensations from the respiratory zone are described below.

**From Nasal Septum**

i. The posterior three-fourth of the septum is supplied by branches of nasopalatine (sphenopalatine) nerve and medial group of superior nasal branches of sphenopalatine ganglion. The nasopalatine nerve produces a groove on the septum as it travels downwards and forwards giving branches to the septum. It leaves the nasal cavity through the incisive canal to enter the oral cavity.

ii. The branches of anterior ethmoidal nerve supply the upper and anterior part.

iii. The nasal branches of anterior superior alveolar nerve supply the skin of the vestibule and the anteroinferior part of the septum.

**From Lateral Wall**

i. The lateral group of posterior superior nasal branches from the sphenopalatine ganglion.

ii. The nasal branches of greater palatine nerve.

iii. The anterior ethmoidal nerve.

**General Characteristics**

Developmentally, the sinuses are the extensions of the nasal cavity. Hence, they are lined with thin pseudostratified ciliated columnar epithelium with goblet cells. The secretions of the goblet cells are drained through the openings of the sinuses into the nasal cavity. The main function of the paranasal sinuses is to warm and humidify the inspired air. They add to the resonance of voice and reduce the weight of skull. The sinuses are filled during expiration. The warmed and humidified air is released in the nasal cavity during inspiration.

**Embryologic insight ...**

The paranasal sinuses develop as evagination or outpouching of the nasal epithelium into the bones surrounding the nasal cavity during the third to fourth month of intrauterine life. Therefore, the lining of the paranasal sinuses is ectodermal. The sinuses are not fully developed at the time of birth. The ethmoidal sinuses begin to develop before birth and a few cells are present at birth. The frontal sinuses are usually absent at birth. The maxillary sinuses are the first to develop. They appear as shallow grooves on the medial surface of each maxilla around third month of intrauterine life. At birth the size of the maxillary sinus is around 7x4x4 mm. The first spurt in the growth of the maxillary sinuses is during 6 to 7 years. They achieve adult size after the eruption of permanent teeth. The sphenoidal sinuses begin to develop before birth. At the time of birth, they appear as extension of nasal cavity in the sphenoidal concha. During the second and third years, they extend in the body and during adolescence adult size is achieved.

**Frontal Sinus (Figs 48.1 and 48.2)**

Each frontal sinus is situated between the inner and outer tables of frontal bone above and deep to supraorbital margin. The right and left sinuses are often asymmetrical as the septum between them is obliquely placed. The anterior wall of the sinus is thick and is related to the skin of the forehead. The posterior wall is thin and related to the meninges and frontal lobe of brain. Its inferior wall forms the roof of the orbit. The frontonasal duct begins in the opening of the sinus, which is located in the floor of the sinus. Usually, the frontal sinus opens by this duct in the anterior end of the infundibulum of the middle meatus. The supraorbital nerve, a branch of frontal nerve, supplies the mucous membrane of the sinus.

The frontal sinus is marked on the surface by drawing a triangle joining the nasion, a point 3 cm above nasion and a point at the junction of medial-third and lateral two-thirds of the supraorbital margin.
**Ethmoidal Sinuses (Fig. 48.6)**

These sinuses are thin-walled air cells in the labyrinth of the ethmoid bone. They are located between the upper part of lateral nasal wall and the medial wall of orbit. The roof is related to the meninges of the anterior cranial fossa. The lateral wall is formed by paper-like lamina of bone called lamina papyracea. This wall is extremely fragile hence slightest injury to it can lead to spread of ethmoidal infection to the orbit. There are three groups of ethmoidal sinuses. The anterior group opens in the anterior part of infundibulum of middle meatus. The middle group project in the middle meatus producing ethmoidal bulla. The middle group opens at the summit of the bulla. The posterior group opens in the superior meatus. The ethmoidal nerves (branches of nasociliary) and orbital branch of maxillary nerve supply the mucous membrane of the sinuses.

**Sphenoidal Sinus (Fig. 48.2)**

These sinuses occupy the body of the sphenoid bone. The right and left sinuses are separated from each other by a deflected bony septum. The two sinuses are therefore asymmetrical in size. Each sinus opens in the sphenethmoidal recess of the lateral wall of the nasal cavity by an opening situated in the upper part of its anterior wall. Relations of the sinus are surgically important especially during trans-sphenoidal hypophysectomy. The anterior part of the roof is related to the optic chiasma while the posterior part of the roof is related to the pituitary gland. Each lateral wall is related to the cavernous sinus, internal carotid artery and oculomotor, trochlear, abducent and the three divisions of trigeminal nerve. The posterior ethmoidal nerves and orbital branches of maxillary nerve supply the mucous membrane of the sinuses.

**Maxillary Sinus (Fig. 48.6)**

The maxillary sinus (antrum of Highmore) is the largest paranasal air sinus. It has the capacity of 15 ml in the adult. Each sinus occupies the body of the maxilla of its side. It is pyramid-shaped with base (its medial wall) directed towards the lateral wall of nasal cavity and apex pointing laterally towards the zygomatic bone.

**Clinical insight ...**

**Surgical Approach to Hypophysis**

Due to the anatomical proximity of the sphenoidal sinus and the pituitary gland, the sinus is used as a route to approach the gland in a procedure called transnasal trans-sphenoidal hypophysectomy. The mucoperiosteum of the nasal septum is elevated on both sides to reach the sphenoid bone via the roof of nasal cavity.

**Relations of Walls of Sinus**

i. The anterior wall is formed by the anterior surface of the maxilla covered by cheek.
ii. The roof forms the floor of the orbit, through which travels the infraorbital nerve.
iii. The floor is formed by the alveolar and palatine processes of the maxilla. It is located about 1 cm below the floor of nasal cavity (hard palate). The roots of the upper molar and premolar teeth almost project in the floor of the sinus since the bone is very thin here. Extraction of upper molar or premolar teeth may lead to a communication between the sinus and oral cavity. For the same reason infection from caries teeth is a common cause of maxillary sinusitis.
iv. The medial wall is related to the lateral wall of the nasal cavity. The superior part of the medial wall bears the opening of the sinus in the middle meatus. The high position of the opening hinders the natural drainage of the sinus. This opening (maxillary hiatus) is reduced in size in the living state by following bony parts, the uncinate process of ethmoid from above, the descending process of lacrimal bone in front, perpendicular plate of palatine bone behind and the inferior nasal concha below (Fig. 48.1). The pus of frontal sinusitis may run via the hiatus semilunaris to the maxillary sinus because the location of the openings of these sinuses favors the passage of pus from the frontal to the maxillary sinus.
v. The posterior wall is related to contents of infratemporal and pterygopalatine fossae.
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Nerves Related to Maxillary Sinus

Refer to Figure 45.4.

Radiology of PNS

Figure 48.7 is a Water’s view radiograph to show all paranasal sinuses.

Clinical insight ...

Clinical Conditions of Maxillary Sinus

i. This sinus is more prone to infections in chronic smokers because epithelium loses cilia, which hampers the drainage of sinus. The maxillary sinus is very often filled with pus due to poor natural drainage and due to its position favoring collection of pus in frontal sinusitis. Figure 48.8 shows a CT view of pus filled left maxillary sinus and DNS.

ii. There are two surgical approaches to maxillary sinus. In intranasal antrostomy (antral puncture), an artificial opening is made in the lateral wall of inferior meatus of nasal cavity (Fig. 48.9). This opening is closer to the floor of the sinus and hence facilitates drainage. In Caldwell-Luc operation, the upper lip is retracted upwards and the angle of mouth is retracted laterally. An incision is placed in the mucous membrane and the periosteum covering the canine fossa. This exposes the anterior wall of the sinus closer to the floor. An artificial opening is created here to drain the pus.

iii. Maxillary sinus is the common site of malignancy in paranasal sinuses. The cancer of maxillary sinus initially may present as symptoms of sinusitis. However, it easily spreads the neighboring regions because the walls of the sinus are very thin. The symptoms and signs depend on which anatomical structure in the vicinity of the sinus is involved. Invasion of the medial wall of the sinus causes obstruction to the nasal cavity and epistaxis. Involvement of the anterior wall gives rise to swelling of the cheek. The spread through floor results in dental pain, loosening of teeth, ulceration of gums and swelling of hard palate. Superior spread invades the orbit causing proptosis, ocular pain and epiphora (overflow of tears). Posterior spread in the sphenopalatine fossa may cause pain in the area of distribution of maxillary nerve. Spread into infratemporal fossa may lead to trismus.
ANATOMY OF PHARYNX

The pharynx is the fibro-muscular tube forming the upper part of the air and food passages.

Shape
Conical

Length
It is 12 to 14 cm long.

Width
It is 3.5 cm wide at its roof and 1.5 cm wide at its lower end.

Extent
The pharynx extends from the base of skull to the lower border of cricoid cartilage (vertebral level C6), where it becomes continuous with esophagus.

Deficiencies in Anterior Wall
The anterior wall of pharynx has three deficiencies through which it opens into the nasal cavity, oral cavity and larynx, from the above downwards.

Subdivisions (Fig. 49.1)

i. The nasopharynx or epipharynx performs respiratory function and communicates with nasal cavity.

ii. The oropharynx is common to both respiratory and digestive tracts, which cross each other here.

iii. The laryngopharynx or hypopharynx acts as a conduit of food from oropharynx to the esophagus. It also conducts air in the larynx via the laryngeal inlet.

Layers of Pharyngeal Wall
The wall of the pharynx consists of five layers from within outward as follows:

i. Mucous membrane

ii. Submucosa

iii. Pharyngeal aponeurosis or pharyngobasilar fascia

iv. Muscular coat

v. Buccopharyngeal fascia.

Mucous Membrane

i. The mucous membrane lining the nasopharynx is continuous with that of pharyngotympanic tubes and nasal cavity. The nasopharynx is lined with respiratory epithelium (pseudostratified ciliated columnar in type).

ii. The mucous membrane of oropharynx is stratified squamous non-keratinizing and is continuous with that of oral cavity.

iii. The mucous membrane of laryngopharynx is stratified squamous non-keratinizing and is continuous with mucosa of larynx and that of esophagus.

Submucosa
The submucosa of the nasopharynx and oropharynx contains lymphatic aggregations, which are the constituent of a lymphatic ring called Waldeyer’s ring.
Chapter 49: Pharynx

Pharyngeal Aponeurosis (Pharyngobasilar Fascia)

This fascial layer lies outer to submucosa but inner to the muscular coat. The thick part of this fascia fills the gap (sinus of Morgagni) between the upper margin of superior constrictor and base of the cranium. Here, it is pierced by auditory tube, ascending palatine branch of facial artery, ascending pharyngeal artery and levator palati muscle (Fig. 49.2).

Pharyngeal Muscles

The pharyngeal muscles consist of two groups, circularly disposed and longitudinally disposed muscles.

Constrictor Muscles

i. Superior constrictor
ii. Middle constrictor
iii. Inferior constrictor

Longitudinal Muscles

i. Salpingopharyngeus
ii. Palatopharyngeus
iii. Stylopharyngeus

The longitudinal muscles are located inner to the constrictors.

Constrictor Muscles (Fig. 49.2)

The constrictor muscles are located in the posterior wall and sides of the pharynx. They overlap each other from below upwards in such a way that inferior constrictor lies outer to the lower part of middle constrictor and the middle constrictor lies outer to the lower part of superior constrictor.

The constrictor muscles are inserted into the median fibrous raphe in the midline posteriorly extending from the pharyngeal tubercle on the basilar part of occipital bone to the upper end of esophagus.

Superior Constrictor

This is a thin sheet of muscle lying in the wall of nasopharynx and oropharynx. It has a wide origin and according to the origin it divided into four parts.

1. Pterygopharyngeal part originates from the posterior border of medial pterygoid lamina and pterygoid hamulus.
2. Buccopharyngeal part originates from the pterygomandibular raphe.
3. Mylopharyngeal part takes origin from posterior end of the mylohyoid line of mandible.
4. Glossopharyngeal part arises from the mucous membrane of the side of tongue.

From this wide origin, the superior constrictor is inserted into the pharyngeal tubercle and the upper part of median fibrous raphe.

**Structures Piercing Superior Constrictor**

This muscle forms the tonsillar bed in the lateral wall of oropharynx. A number of blood vessels and lymphatic vessels of the tonsil pierce the muscle in this location (tonsillar branch of facial artery, ascending palatine artery, of ascending pharyngeal artery and paratonsillar or external palatine vein).

**Passavant’s Ridge or Palatopharyngeal Sphincter**

Near its superior margin, a few fibers of superior constrictor blend with a band of muscle fibers belonging to palatopharyngeus muscle. These fused fibers form a ring or a band around the posterior wall and sidewalls of nasopharyngeal isthmus. When the soft palate is elevated, this muscle band appears as a ridge known as Passavant’s ridge. During the act of swallowing, the Passavant’s ridge and the soft palate are approximated by contraction of this sphincter and the levator palatii. In this way, nasopharynx is shut off from oropharynx to prevent regurgitation of food in the nasopharynx and nasal cavity. The Passavant’s ridge is hypertrophied in cases of complete cleft palate.

**Middle Constrictor**

This is a fan-shaped muscle with narrow origin and broad insertion. It takes origin from the lower part of stylohyoid ligament, lesser cornu and upper border of greater cornu of hyoid bone. The fibers fan out and are inserted into the median fibrous raphe. The middle constrictor forms part of the floor of carotid triangle.

**Inferior Constrictor**

This is the thickest of the three constrictors. The inferior constrictor is related to the medial surface of the lateral lobe of thyroid gland and is part of the floor of the carotid triangle of neck.

**Subdivisions**

According to the origin, the inferior constrictor is divisible into two parts.
1. Thyropharyngeus
2. Cricopharyngeus

i. The thyropharyngeus arises from oblique line of thyroid cartilage, the tendinous band stretching across the cricothyroid muscle and from the inferior cornu of thyroid cartilage. Its fibers are obliquely disposed as they curve to reach the median fibrous raphe for insertion. Like the other constrictors, this muscle contracts during swallowing to propel food downward and relaxes in between the acts of swallowing.

ii. The cricopharyngeus arises from the side of cricoid cartilage and its fibers are transversely disposed. Inferiorly, the cricopharyngeus is continuous with circular muscle coat of esophagus. The muscles of the two sides form an upper esophageal sphincter (UES) at the pharyngo-esophageal junction. It is a true sphincter composed of striated muscle. The function of this sphincter is to prevent the entry of air into the esophagus and reflux of food into the pharynx in the interval between acts of swallowing. Hence, this muscle relaxes during swallowing but contracts in between the acts of swallowing (this action is exactly opposite to that of thyropharyngeus).

**Globus Hystericus**

The lump in the throat sensation occurs due to sudden contraction (spasm) of cricopharyngeus as a result of stress or fear or reflux.
Important Relations of Constrictor Muscles (Fig. 49.2)

i. The interval between the free superior border of superior constrictor and the cranium (sinus of Morgagni) is closed by the pharyngobasilar fascia and buccopharyngeal fascia. The superior border of the muscle is related to auditory tube, tensor palati and levator palati muscles. The levator palati pierces the fasciae to enter the wall of oropharynx while the tensor palati hooks round the pterygoid hamulus to enter the wall of oropharynx to reach the palate.

ii. The stylopharyngeus muscle and glossopharyngeal nerve enter the pharynx through the gap between the upper margin of middle constrictor and the lower margin of superior constrictor muscles.

iii. The internal laryngeal nerve and superior laryngeal artery pierce the thyrohyoid membrane to enter the laryngopharynx through the gap between the lower margin of middle constrictor and the upper margin of inferior constrictor muscles.

iv. The recurrent laryngeal nerve and inferior laryngeal artery pass deep to the lower margin of the inferior constrictor in the tracheo-esophageal groove. The external laryngeal nerve pierces the inferior constrictor on its way to the cricothyroid.

Longitudinal Muscles

i. The stylopharyngeus takes origin from the medial aspect of the base of styloid process. Accompanied by glossopharyngeal nerve it enters the pharynx through the gap between the middle and superior constrictor muscles. It is inserted into the posterior border of thyroid cartilage and the lateral aspect of epiglottis.

ii. The palatopharyngeus takes origin from the palatine aponeurosis and runs vertically downward on the inner aspect of constrictors. It is inserted along with the stylopharyngeus in the posterior border of thyroid cartilage.

iii. The salpingopharyngeus arises from the cartilage of the auditory tube near the pharyngeal opening of the tube. The fibers pass downward to blend with palatopharyngeus and insert along with it in the posterior border of thyroid cartilage.

Buccopharyngeal Fascia

This fascia covers the pharynx externally. It derives its name from the fact that it covers pharyngeal muscles as well as the buccinator muscle. Posteriorly, the buccopharyngeal fascia is in contact with prevertebral muscles and cervical vertebral column. The pharyngeal plexus of nerves lies in the fascia, where it covers the middle constrictor.

Pharyngeal Plexus of Nerves

The following nerves take part in the formation of the pharyngeal plexus.

i. Pharyngeal branch of vagus, which carries fibers of cranial part of accessory nerve.

ii. Pharyngeal branch of glossopharyngeal nerve.

iii. Sympathetic nerves from superior cervical ganglion.

Nerve Supply of Pharyngeal Muscles

i. The pharyngeal plexus of nerves (via vago-accessory complex) supplies the three constrictors, palatopharyngeus and salpingopharyngeus muscles.

ii. The stylopharyngeus muscle alone is supplied by glossopharyngeal nerve.

iii. The inferior constrictor gets additional supply from the recurrent laryngeal and external laryngeal nerves.

Actions of Pharyngeal Muscles

The successive contraction of the constrictor muscles (except the cricopharyngeus) from above downwards propels the food towards the esophagus. During this phase, the longitudinal muscles are relaxed. After the food reaches the esophagus, the longitudinal muscles contract to pull the pharynx upwards in order to bring it back to its original position.

Nasopharynx (Fig. 49.1)

Being the uppermost part of pharynx, it is also called epipharynx. The nasopharynx is always kept patent unlike the other two subdivisions of pharynx because it is part of respiratory passage.

Clinical insight ...

**Killian’s Dehiscence**

This is a potential gap between the thyropharyngeus and cricopharyngeus parts of the inferior constrictor muscle. It is indicated by a dimple in the lining mucosa of the pharynx. It is the weak area of the pharyngeal wall. Hence, pharyngeal diverticulum (Zenker’s diverticulum) develops at this site if the cricopharyngeus fails to relax during swallowing due to neuromuscular coordination. The raised intra-pharyngeal pressure forces the mucosa and submucosa posteriorly through the Killian’s dehiscence. The diverticulum so formed gradually enlarges in downward direction usually on the left side. The symptoms of diverticulum are foul breath, dysphagia and regurgitation of food eaten a day or two earlier. The gold standard of the surgical treatment of Zenker’s diverticulum is diverticulectomy (removal of pharyngeal diverticulum) and cricopharyngeal myotomy (surgical sectioning of cricopharyngeus).
Communications

i. Anteriorly, it communicates with nasal cavities through choanae.
ii. Inferiorly, it communicates with oropharynx through nasopharyngeal isthmus.
iii. It is in communication with middle ear via the auditory tubes.

Functions

i. It is essential for respiration.
ii. It supplies atmospheric air to the middle ear, which equalizes air pressure on lateral and medial aspects of tympanic membrane. Hence, it has important role in hearing.

Walls of Nasopharynx

The nasopharynx has roof, posterior wall, lateral walls, floor and anterior wall. The roof and posterior wall form a continuous sloping surface. The roof consists of a small area of the base of the cranium extending from the pharyngeal tubercle to the line joining the roots of the medial pterygoid plates. It includes part of the body of sphenoid and the basiocciput. The pharyngobasilar fascia and superior constrictor muscle supported by the anterior arch of atlas (on posterior aspect) are the components of the posterior wall.

Features of Roof

i. The nasopharyngeal or pharyngeal tonsil is a lymphoid collection that projects into the nasopharynx from the junction of roof and posterior wall. It is the mucosa associated lymphatic tissue (MALT). It increases in size up to the age of six years and then gradually atrophies. Hypertrophy of nasopharyngeal tonsil is called adenoids. Sometimes, in children the adenoids may obstruct the nasopharynx completely giving rise to mouth breathing.
ii. A midline pharyngeal bursa is present in nasopharyngeal tonsil. This bursa denotes the site of attachment of the notochord to the endoderm of primitive pharynx. It is an epithelial-lined recess extending posteriorly right up to the roof. Infection of this bursa is called pharyngeal bursitis. An abscess in the bursa presents as a cystic swelling on the posterior wall of nasopharynx.
iii. A dimple in the mucosa above the nasopharyngeal tonsil denotes the site of the path of the embryonic Rathke’s pouch. Occasionally, the remnant cells of the Rathke’s pouch give rise to pharyngeal hypophysis, which may turn malignant (craniopharyngioma).

Features of Lateral Wall

i. The tubal orifice, which is the medial opening of the pharyngotympanic (auditory) tube is situated 10 to 12 mm behind and a little below the posterior end of inferior nasal concha. The tubal orifice is bounded above and posteriorly by tubal elevation (torus tubaris) produced by the prominent cartilage of the pharyngeal end of the tube. The tubal elevation is a landmark that helps in locating the tubal orifice during passage of catheter in the tube.
ii. The salpingopharyngeal fold is a mucous fold passing vertically downward from the tubal elevation.
iii. The tubal tonsil is the collection of submucous lymphoid tissue (MALT) lying on the tubal elevation.
iv. The pharyngeal recess or Rosenmuller’s fossa is a depression behind the tubal elevation. This is the commonest site of carcinoma of nasopharynx.

Posterior Nasal Apertures (Choanae)

Anteriorly, the nasopharynx communicates with the nasal cavity through two large and oval apertures called choanae. These apertures are 2.5 cm in length and 1.25 cm in width. Their bony boundaries are, free margin of vomer medially, inferior surface of the body of sphenoid superiorly, medial edge of medial pterygoid plate laterally and posterior margin of hard palate inferiorly.

Features of Floor

i. Anterior part of the floor is formed by the soft palate.
ii. Posterior to the soft palate the floor shows the deficiency (nasopharyngeal or pharyngeal isthmus).
iii. The boundaries of this isthmus are, the posterior surface and free margin of soft palate anteriorly, the Passavant’s ridge posteriorly and the palatopharyngeal arch on each side.

Sensory Supply of Mucosa of Nasopharynx

i. The glossopharyngeal nerve through the pharyngeal plexus.

Clinical insight ...

Inspection of Nasopharynx

The nasopharynx is inspected by a procedure called posterior rhinoscopy. The tongue of the patient is depressed with a tongue depressor and then the rhinoscopic mirror is introduced till it reaches the posterior one-third of the tongue. The light from the head mirror is focused on the rhinoscopic mirror so as to illuminate the nasopharynx. By tilting the mirror in different directions one can see the reflexion of the interior of the nasopharynx.

Contd...
Pharynx

Chapter

The pharyngeal branch of maxillary nerve near the tubal orifice.

Oropharynx (Fig. 49.3)
The oropharynx is located behind the oral cavity, below the nasopharynx and above the laryngopharynx. It communicates with the oral cavity through the oropharyngeal isthmus and with the nasopharynx through the nasopharyngeal isthmus. At its lower end, it continues as laryngopharynx at the level of upper border of epiglottis.

Inspection of Oropharynx (Fig. 49.3)
The oropharynx (including the tonsils) is directly visible when the patient opens the mouth wide. For movements of the soft palate the patient is asked to say Aa. The posterior one-third of the tongue is examined by digital palpation and by indirect laryngoscopy.

Walls of Oropharynx
i. The roof is formed by undersurface of soft palate in anterior part. It is deficient in posterior part due to presence of nasopharyngeal isthmus.

Fig. 49.3: Oropharynx as seen through widely opened mouth

ii. The pharyngeal branch of maxillary nerve near the tubal orifice.

iii. The anterior wall is deficient due to presence of oropharyngeal isthmus. The boundaries of the oropharyngeal isthmus are the soft palate superiorly, dorsal surface of posterior third of tongue inferiorly and the palatoglossal arch on each side.

iv. The posterior wall is supported by the body of second cervical vertebra (axis) and upper part of body of third cervical vertebra.

v. The lateral walls present palatoglossal and palatopharyngeal arches enclosing tonsillar fossa for the palatine tonsils.

Palatine Tonsil (Faucial Tonsil)
The palatine tonsils are the collections of lymphoid tissues in the submucosa of oropharynx. They belong to MALT or mucosa-associated lymphoid tissue. The palatine tonsils are the common site of infection producing sore throat and fever. They are placed one on each side in the tonsillar fossa or tonsillar sinus in the lateral wall of oropharynx. The tonsils are of large size during early childhood but diminish in size after puberty.

Surface Marking
An almond-shaped area over the lower part of masseter muscle, a little above and in front of the angle of mandible marks the tonsil on the surface.

Boundaries of Tonsillar Fossa or Fauces
i. Anterior boundary (also known as anterior pillar of fauces) is the palatoglossal arch, which is the mucosal fold containing the palatoglossal muscle.
ii. Posterior boundary (also known as posterior pillar of fauces) is the palatopharyngeal arch, which is the mucosal fold containing palatopharyngeal muscle.

iii. Lateral wall (Fig. 49.4) forms the tonsillar bed, which consists of pharyngobasilar fascia, superior constrictor (along with few fibers of longitudinal muscles of pharynx), and glossopharyngeal nerve. It has important relations (vide infra). The internal carotid artery lies about 25 mm lateral and behind the tonsil.

Parts of Tonsil and Relations

The tonsil has two poles (upper and lower), two borders (anterior and posterior) and two surfaces (lateral or deep and medial or free).

i. The upper pole of the tonsil extends into the soft palate. A semilunar fold in newborn covers the medial aspect of the upper pole. It is the remnant of embryonic mucosal fold and is replaced by lymphatic tissue after birth.

ii. The lower pole extends into the tongue. A triangular fold of mucosa, which is a remnant of embryonic fold from the palatoglossal arch, covers the lower pole in newborn but it soon obliterates.

iii. The medial or free surface (Fig. 49.4) faces the oropharynx and is covered with non-keratinizing stratified squamous epithelium, which dips into its substance as tonsillar crypts. About 15 to 20 crypts open on the surface giving it a pitted appearance. One of the crypts located near the upper pole is very deep and hence called crypta magna (intratonsillar cleft). It is the remnant of embryonic second pharyngeal pouch. The crypts branch within the substance of the tonsil so that there is an intimate association of the epithelial cells and the lymphocytes in the tonsil, which is referred to as lympho-epithelial symbiosis. This facilitates direct transport of the antigen from the external environment to the tonsillar lymphoid tissue.

iv. The lateral or deep surface is covered with a well-defined hemi capsule. Lateral to the capsule the submucosa (peritonsillar space) contains loose areolar tissue and paratonsillar vein.

Clinical insight ...

Peritonsillar Space

i. Peritonsillar space is the plane of dissection during tonsillectomy. The paratonsillar vein that passes through this space is often a source of postoperative bleeding.

ii. Accumulation of pus in this space in chronic tonsillitis gives rise to peritonsillar abscess or quinsy.

iii. The tonsillar bed is related to certain arteries, which are in jeopardy during tonsillectomy. These arteries are the loop of the facial artery and its ascending palatine branch, ascending pharyngeal artery and the internal carotid artery. The styloglossus muscle, stylopharyngeus muscle and glossopharyngeal nerve are also related to this surface.

Arterial Supply of Tonsil (Fig. 49.5)

The tonsil is supplied by five arteries:

i. Dorsal lingual branch of lingual artery.

ii. Ascending palatine branch of facial artery.
iii. Descending palatine branch of ascending pharyngeal artery.
iv. Tonsillar branch of facial artery (main tonsillar artery).
v. Greater palatine branch of maxillary artery.

Venous Drainage
The venous plexus around the tonsil drains by tonsillar veins, which accompany the tonsillar branch of facial artery. They open into common facial vein. Some veins drain in the paratonsillar vein, which opens into pharyngeal venous plexus or in the common facial vein.

Nerve Supply
The lesser palatine branches of maxillary nerve and the tonsillar branches of glossopharyngeal nerve form a plexus called circulus tonsillaris. This plexus supplies the tonsil, soft palate and oropharyngeal isthmus. The pain of tonsillitis is referred to ear due to common innervation by glossopharyngeal nerve.

Lymphatic Drainage
The lymphatics draining the tonsil pierce the superior constrictor muscle to reach the upper deep cervical nodes (mainly into jugulodigastric nodes). These nodes are called tonsillar nodes since they are enlarged in tonsillitis and are palpable below the angle of mandible.

Waldeyer’s Ring (Fig. 49.6)
This is a ring of lymphatic tissue at the beginning of food and air passages (in the nasopharynx and oropharynx). It is much enlarged in early childhood. This ring is composed of mucosa associated lymphatic tissue (MALT). The characteristic feature of MALT is the close approximation of epithelium and the lymphatic tissue.

Components of Waldeyer’s Ring
i. Palatine tonsils on either side.
ii. Nasopharyngeal tonsil on the posterior wall of nasopharynx.
iii. Tubal tonsils on the lateral walls of nasopharynx.
iv. Lingual tonsils on the dorsum of posterior one-third of tongue in the floor of oropharynx.

Laryngopharynx
The laryngeal part of the pharynx is also known as hypopharynx. It extends from the upper border of epiglottis to the lower border of cricoid cartilage. It communicates above with the oropharynx, anteriorly with the laryngeal cavity and below with the esophagus.

Walls of Laryngopharynx
The laryngopharynx presents anterior, posterior and lateral walls (Fig. 49.7).

Piriform Fossa
The internal laryngeal nerve pierces the thyrohyoid membrane and traverses under the mucosa of the piriform recess from lateral to medial side to enter the laryngeal cavity. Thus, the internal laryngeal nerve is intimately related to the piriform fossa. The foreign bodies like fish bone may get impacted in the fossa. During removal of the foreign body, the internal laryngeal
These recesses form the lateral channels for food on each side. The boundaries of the fossa are, medially aryepiglottic fold and laterally the mucosa covering the inner surface of the thyrohyoid membrane and the lamina of thyroid cartilage.

**Nerve Supply**

The internal laryngeal nerve supplies the mucosa of the laryngopharynx.

**Inspection of Laryngopharynx**

i. In indirect laryngoscopy, the patient is asked to protrude the tongue, which is held by the examiner between thumb and index finger. The laryngeal mirror is then introduced and the light is focused on the mirror to inspect the laryngopharynx and posterior one-third of the tongue.

ii. Direct laryngoscopy is performed under general anesthesia. The laryngoscope is introduced via the oral cavity and the oropharynx into the laryngopharynx.

**Radiological Appearance**

Barium swallow studies show piriform fossa (recess) of laryngopharynx (Fig. 49.8).

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nerve may be injured, if the instrument pierces the mucosa. In the carcinoma of piriform fossa pain is referred to ear due to common innervation by vagus.

The posterior wall is supported by constrictor muscles supported by prevertebral muscles and third to sixth cervical vertebrae.
ANATOMY OF LARYNX

Larynx is the upper part of respiratory tract. Its main function is to protect the lower respiratory tract so that foreign bodies do not enter the trachea. If a foreign body comes in contact with the mucosa of the larynx it reflexly gives rise to violent coughing till the foreign body is expelled. Thus larynx is correctly described as a watchdog of the lungs. Another function of the larynx is production of the voice, hence the name voice box. The framework of the larynx is composed of cartilages and membranes. The laryngeal muscles primarily move the cartilages and through them the vocal cords during respiration and phonation.

Location

The larynx is located in front of the neck opposite the third to sixth cervical vertebrae in adult. It moves vertically up and down during swallowing and phonation. The larynx extends from the upper border of epiglottis to the lower margin of cricoid cartilage. It opens in the laryngopharynx through the laryngeal inlet and is continuous with trachea below. Its anterior aspect is covered with skin, fasciae and strap muscles, namely, omohyoid, sternothyroid, sternohyoid. Its posterior aspect projects in the laryngopharynx.

Differences in Male and Female

Until puberty the larynx of male differs very little from that of female. After puberty the male larynx grows rapidly due to the increase in the size of laryngeal cartilages. The laryngeal prominence (Adam's apple) becomes prominent in males. The laryngeal prominence is produced due to decrease in the thyroid angle, which is 90° in males and 120° in females. The length of vocal cords is approximately 24 mm in males and 16 mm in females. Because of these differences the voice is low pitch in males and high pitch in females.

Differences in Adult and Infant

i. Infant larynx is smaller, funnel-shaped and narrower than the adult (about one-third the size of adult).

ii. The laryngeal cartilages are softer and collapse easily in infant.

iii. The larynx is placed at a higher level in infants. Its upper margin at rest is at the level of axis vertebra and that of the elevated larynx it is at the level of median atlantoaxial joint.

iv. The epiglottis is longer and deeply grooved, which is more suited to protect the air passage during suckling.

v. The submucosa in infant's larynx is thicker and becomes edematous faster after irritation. Therefore the obstruction of the airway takes place faster in infants.

vi. The neonatal subglottic cavity extends posteriorly as well as inferiorly. This point is to be noted during passage of endotracheal tube in infants.

Laryngeal Cartilages (Fig. 50.1)

The skeleton of larynx consists of three unpaired and three paired cartilages. The unpaired cartilages are the epiglottis, the thyroid and the cricoid. The paired cartilages are the arytenoid, cuneiform and the corniculate.

i. The epiglottis is a leaf-shaped elastic cartilage. It forms the anterior wall of the laryngeal inlet. Its upper end projects upwards and backwards behind the hyoid bone (Fig. 50.2) and the base of tongue. Its upper end is free and broad and lower end is narrow and pointed. It has anterior and posterior surfaces and two lateral
Fig. 50.1: Anterior view of framework of larynx

margins. The upper part of anterior surface is covered with stratified squamous epithelium and is connected to the tongue by three mucosal folds, the median and lateral glossoepiglottic folds. The lower part of anterior surface, which is devoid of mucosa, is connected to hyoid bone by hyoepiglottic ligament. Below this attachment, the anterior surface is separated from the thyrohyoid membrane by a space called pre-epiglottic space, which is filled with fat. Each lateral margin provides attachment to the aryepiglottic fold in its lower part. The lower end is attached to inner surface of thyroid angle by thyroepiglottic ligament. The mucosa on the posterior surface of epiglottis is of respiratory type in the lower part and stratified squamous type in the upper part and is pitted by small mucous glands. The branches of internal laryngeal nerve pierce the mucosa on this surface.

2. The thyroid cartilage is the largest of the laryngeal cartilages. It is made of hyaline cartilage hence it tends to calcify and ossify as age advances. Its interesting feature is that it gives attachments to nine pairs of muscles (three on the posterior margin, three on the oblique line, two on the internal surface and one on the inferior margin). The thyroid cartilage consists of two quadrilateral laminae, which meet in the midline anteriorly at the thyroid angle but leave the thyroid notch between them above. The thyroid angle (laryngeal prominence) is called Adam’s apple in males. It is subcutaneous and hence easily palpable. Internally the thyroid angle is covered with mucosa of larynx and gives attachment in the midline to thyroepiglottic ligament, bilateral vestibular ligaments and bilateral vocal ligaments from above downwards. Lateral to the vocal ligament it gives attachments to thyroarytenoid and thyroepigotticus muscles from medial to lateral side. The oblique line on the external surface of each lamina gives attachment to three muscles (sternohyoid, thyrohyoid and inferior constrictor of pharynx). The upper pole of the lateral lobe of thyroid gland is related to this surface as far as the oblique line. The internal surface of the lamina (covered with mucosa) forms the lateral boundary of piriform fossa of laryngopharynx. The superior border corresponds to C4 vertebra. It gives attachment to thyrohyoid membrane, which is attached above to the upper border of the hyoid bone, a bursa intervening between the two. The inferior border corresponds to C5 vertebra. Its anterior part is attached to arch of cricoid by conus elasticus. Rest of the inferior border gives attachment to cricothyroid muscle. The two posterior borders are free. Each receives the common insertion of stylopharyngeus, palatopharyngeus and salpingopharyngeus muscles. The posterior border extends upward as superior horn, which is connected to the tip of greater cornu of hyoid bone by lateral thyrohyoid ligament. The posterior border extends below as inferior horn, which bears an articular facet for the cricoid cartilage at the cricothyroid joint.

3. The cricoid cartilage is the only cartilage of larynx that forms a complete ring around the cavity of larynx. Its shape is like that of a signet ring. Its broad lamina is posterior and narrow arch is anterior to the laryngeal cavity. The cricoid cartilage is of hyaline variety and hence prone to calcification and ossification with age. The cricoid cartilage is a landmark for following events.

i. Its arch can be felt in the midline below the thyroid cartilage and corresponds to C6 vertebra.

ii. At this level pharynx ends and esophagus begins and larynx ends and trachea begins.

iii. It is the only laryngeal cartilage that articulates with thyroid and arytenoid cartilages to form bilateral synovial joints. So the cricoid cartilage is crucial for the movements of the vocal cords.

iv. It denotes the level of middle cervical sympathetic ganglion.

v. The inferior thyroid artery enters the thyroid gland at this level.

vi. The recurrent laryngeal nerve enters the larynx behind the cricothyroid joint.

The external surface of the cricoid arch gives attachments to cricothyroid muscle and to the inferior constrictor of pharynx (cricopharyngeus part). The inferior border gives attachment to cricotracheal ligament. The superior border gives attachment to median cricothyroid ligament (conus elasticus) in the midline and lateral cricothyroid ligament on either side.
The posterior surface of the cricoid lamina shows median ridge for the attachment to the upper end of longitudinal fasciculi of the esophageal muscle. On either side of the median ridge the posterior cricoarytenoid muscle is attached. Posterior to these muscular attachments the cricoid lamina is covered with mucosa of the laryngopharynx, as this aspect of the lamina forms the anterior wall of the laryngopharynx. The internal surface of both the arch and lamina is covered with mucosa of infraglottic larynx.

4. The arytenoid cartilage is a three-sided pyramid (Fig. 50.2). It has base and apex, two processes (vocal and muscular) and three surfaces (posterior, medial and anterolateral). The apex articulates with corniculate cartilage and gives attachment to aryepiglottic fold with its contained aryepiglotticus muscle. The base articulates with the superior aspect of lamina of cricoid to form the cricoarytenoid joint. The muscular process projects laterally and gives attachment to both lateral and posterior cricoarytenoid muscles. The vocal process projects anteriorly and it gives attachment to vocal ligament. The anterolateral surface gives attachment to thyroarytenoid and vocalis muscles. The vestibular ligament is attached just above the vocal ligament. The medial surface is covered with laryngeal mucosa and forms the interarytenoid (intercartilaginous) part of rima glottis along with opposite medial surface. Except the apex and vocal process, which are made of elastic cartilage, the rest of the arytenoid cartilage is hyaline in microstructure.

5. The cuneiform is the nodular elastic cartilage within the posterior end of the aryepiglottic fold.
6. The corniculate is the rod-shaped elastic cartilage that lies anterior to the cuneiform. Both cuneiform and corniculate cartilages support the aryepiglottic fold of their side.

Membranes and Ligaments of Larynx
1. The extrinsic membranes of the larynx lie external to the cavity of the larynx.
   i. The thyrohyoid membrane (Fig. 50.1) stretches between the upper border of thyroid cartilage and the upper border of the body and greater cornua of hyoid bone. It is separated from the body of hyoid bone by a bursa, which facilitates ascent of larynx during swallowing. The internal laryngeal nerve and superior laryngeal vessels pierce it. Its median thick part is called median thyrohyoid ligament. Its posterior margin is thickest and is called lateral thyrohyoid ligament, which connects the ends of greater horn to the upper horn of thyroid cartilage.
   ii. The extrinsic ligaments are cricotracheal ligament between lower margin of cricoid and the first tracheal ring, median (anterior) cricothyroid ligament in the midline of neck and hyoepiglottic ligament between the hyoid bone and epiglottis.
2. The intrinsic membranes are covered on the inner aspect with laryngeal mucosa.
   i. The quadrangular or quadrate membrane is a fibro-elastic membrane stretching between the epiglottis, thyroid angle and arytenoid cartilage. Its free upper margin is in the aryepiglottic fold while its free lower margin forms the vestibular ligament stretching between the thyroid angle and vocal process of arytenoids above the attachment of the vocal ligament.
   ii. The cricovocal membrane is a triangular fibroelastic membrane that stretches between the cricoid, arytenoid and thyroid cartilages. Its upper free margin extending between the middle of the thyroid angle and the tip of vocal process of arytenoid is called vocal ligament. Its lower margin is attached to the arch of cricoid cartilage. The cricovocal membranes of the two sides are continuous across the midline and form the conus elasticus.

Subdivisions of Laryngeal Cavity (Fig. 50.3)
The laryngeal cavity extends from the laryngeal inlet to the lower margin of cricoid cartilage. The inlet of the larynx is an oblique opening bounded anteriorly by the free margin of upper end of epiglottis, on the sides by free
margins of aryepiglottic folds and posteriorly by interarytenoid fold. Two pairs of mucosal folds (upper vestibular and lower vocal) project inside the cavity and divide it into three parts, the vestibule above the vestibular folds, the sinus or ventricle of larynx between the vestibular and vocal folds and the infraglottic or subglottic part below the vocal folds.

**Sinus or Ventricle of Larynx**

It is a deep space between the vestibular and vocal folds and extends for a short distance above and lateral to vestibular folds. A mucous diverticulum called saccule extends upwards blindly from the anterior part of the sinus on each side. The secretion of the mucous glands contained in the saccule lubricates the vocal folds. When the saccule is abnormally enlarged and distended it forms the laryngocele, which is an air containing sac presenting in the neck.

The vestibular folds are called false vocal cords because they do not take part in phonation. They are flaccid folds covered by respiratory epithelium. Each vestibular fold contains vestibular ligament and submucosa with capillaries and mucous glands. The vestibular folds appear pink on laryngoscopy due to the presence of capillaries in the submucosa. The space enclosed between the right and left vestibular folds is called rima vestibuli.

The vocal folds are called true vocal cords since their movements are responsible for phonation. Each vocal fold contains vocal ligament and vocalis muscle. Due to absence of submucosa, the stratified squamous nonkeratinized epithelium tightly covers it. Lack of blood capillaries and the type of covering epithelium give the vocal cords a characteristic pearly white appearance. The cords are nourished and lubricated by mucous secretion of the glands in the saccule (which is aptly called the oil can of larynx). A narrow slit like space enclosed by the vocal folds is called rima glottis. Reinke’s space is a potential space under the epithelium of the vocal folds. Accumulation of fluid here causes fusiform swelling of the folds (Reinke’s edema). Vocal nodules (singer’s or screamers’ nodes) appear on the free edges of both cords at the junction of anterior one third and posterior two thirds. This area shows maximum vibration of the cords. Vocal nodules are the occupational hazards for singers, teachers, actors, etc.

**Rima Glottis (Fig. 50.4)**

This is the narrowest part of the laryngeal cavity. Its anteroposterior diameter is 24 mm in male and 17 mm in female. Its lateral margins are the vocal folds, vocal processes and bases of the arytenoid cartilages. Anteriorly it is limited by the thyroid angle and posteriorly by the interarytenoid mucosal fold. This space consists of two parts, intermembranous (between the vocal cords and intercartilaginous (between vocal processes and medial surfaces of arytenoid cartilages). The intermembranous part contributes to anterior three fifth (or two-thirds) and intercartilaginous part contributes to posterior two fifth (or one-third). The shape of rima glottis undergoes changes due to movements of vocal folds during respiration and phonation.

1. During quiet respiration (position of rest) the intermembranous part is triangular and intercartilaginous

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**Fig. 50.3:** Posterior view of a schematic coronal section showing subdivisions of laryngeal cavity (1) Supraglottic part (vestibule); (2) Ventricle of larynx; (3) Infraglottic (subglottic) part

**Fig. 50.4:** Rima glottis and changes in its shape in adduction and abduction of vocal folds
part is rectangular. The cords are gently abducted and lie about seven mm from the midline.

ii. During forced inspiration the vocal cords are fully abducted and hence the rima assumes rhomboid or diamond shape, where both parts of rima are triangular in shape. The cords lie 9.5 mm from the midline.

iii. In preparation of the phonation both the parts of the rima glottis are closed due to approximation of vocal cords and arytenoid cartilages. The expired air forces open the cords, so that the air is released as small puffs, which vibrate the vocal cords. The rima appears as a small linear chink at the beginning of speech. The cords are in midline. Simultaneously the vocal cords tense by increasing the length so as to alter the pitch of voice.

iv. During whispering the intermembranous part is narrowed due to adduction of the vocal folds but the intercartilaginous part remains widely open to allow air to escape. The shape of rima glottis is described as inverted funnel.

v. In the cadaveric position of the vocal cords the rima glottis is moderately wide as the vocal cords are in intermediate position between adduction and abduction. The cords are about 3.5 mm from the midline. This is also described as neutral or intermediate position.

Mucosa of Laryngeal Cavity
The laryngeal mucosa is respiratory type (pseudostratified ciliated columnar) except in two locations, upper part of the posterior surface of epiglottis and on the vocal cords, where it is wear and tear type (stratified squamous nonkeratinized). The mucosa is loosely attached everywhere (except over the vocal cords) due to the presence of submucosa. There are plenty of mucous glands in the submucosa.

Sensory Nerve Supply and Blood Supply
The internal laryngeal nerve supplies the mucosa above the level of vocal folds while the recurrent laryngeal nerve supplies below this level. The vocal folds in all probability receive innervation from both sources. The laryngeal branches of superior and inferior thyroid arteries supply the larynx. Above the vocal folds the superior laryngeal branch of superior thyroid artery supplies blood while below the vocal folds the inferior laryngeal branch of inferior thyroid artery supplies blood.

Lymphatic Drainage
Above the vocal folds the laryngeal mucosa is drained by lymphatics, which pierce the thyrohyoid membrane and go to upper deep cervical lymph nodes. The infraglottic larynx is drained by lymphatics, which pierce the cricothyroid membrane and go to pretracheal and prelaryngeal nodes and then to lower deep cervical and mediastinal nodes. Carcinoma of larynx spreads by lymphatic route to regional lymph nodes.

Laryngoscopic Examination
The interior of larynx can be inspected by indirect and direct laryngoscopy. The direct laryngoscopy is performed with the help of special instrument under general anesthesia (Fig. 50.5).

Laryngeal Muscles (Fig. 50.6)
The laryngeal muscles are subdivided into intrinsic and extrinsic groups.
1. The intrinsic muscles are confined to the larynx in their attachments. There are seven paired muscles and one unpaired muscle in this group.
2. The extrinsic muscles connect the laryngeal cartilages to neighboring structures. They are responsible for vertical movement of the larynx during phonation and swallowing. They are grouped as elevators and depressors of larynx.
   i. The elevators of the larynx are divided into primary and secondary elevators.
   The primary elevators are attached to the thyroid cartilage from above. The stylopharyngeus, palatopharyngeus, salpingopharyngeus and thyrohyoid are included in this group.
   The secondary elevators are attached to the hyoid bone from above. They consist of mylohyoid, geniohyoid, stylohyoid and digastric muscles.
The depressors of the larynx are attached to the thyroid cartilage or hyoid bone from below. They consist of sternohyoid, sternothyroid and omohyoid muscles.

**Intrinsic Muscles of Larynx**

1. Muscles that increase or decrease the length of the vocal cords:
   i. Cricothyroid
   ii. Posterior cricoarytenoid
   iii. Thyroarytenoid
   iv. Vocalis.
2. Muscles that abduct or adduct the vocal cords:
   i. Posterior cricoarytenoid
   ii. Lateral cricoarytenoid
   iii. Transverse arytenoid.
3. Muscles that open or close the laryngeal inlet:
   i. Thyroepiglottic
   ii. Aryepiglottic
   iii. Oblique part of interarytenoids.

**Cricothyroid Muscle**

This muscle is the only intrinsic muscle that lies external to the larynx as it is attached to the external aspect of cricoid arch and to the inferior margin and inferior horn of thyroid cartilage. It is one of the structures seen in the midline of neck below thyroid cartilage. The right and left muscles are separated anteriorly by median cricothyroid ligament. The two cricothyroid muscles act on cricothyroid joints to lengthen the vocal cords by tilting the cricoid lamina backward and pulling the thyroid cartilage forward. This action produces tension in the vocal cords required for raising the pitch of voice (tuning fork of larynx). It is the only intrinsic laryngeal muscle that is supplied by external laryngeal nerve.

**Thyroarytenoid, Thyroepiglottic and Vocalis Muscles**

The thyroarytenoid muscle arises from the posterior surface of the thyroid angle just lateral to the attachment of vocal cords. It is inserted posteriorly into the anterolateral surface of arytenoid cartilage. Some of the deeper fibers (known as vocalis) originate from the vocal ligament and pass for attachment to the lateral surface of vocal process of arytenoid cartilage. The vocalis has no attachment to thyroid cartilage. The upper lateral fibres of thyroarytenoid turn upward towards epiglottis to form thyroepiglottic muscle. The action of thyroarytenoid muscles is to pull the vocal processes forward thereby slackening or shortening the vocal cords. The vocalis slackens or decreases the length of the posterior part of the vocal cord while the anterior part is kept tense. This action is essential for raising the pitch. The recurrent laryngeal nerve supplies these muscles.

**Posterior Cricoarytenoid Muscle**

It is the most important muscle of larynx. Each muscle arises from the posterior surface of the lamina of cricoid on either side of midline. It is inserted on the back of muscular process of arytenoid cartilage of its side. The muscle acts on the cricoarytenoid joint to rotate the arytenoid with its vocal process laterally so that the muscular process turns posteriorly. In this way abduction of the vocal cords and widening of rima glottis takes place. It is the sole abductor of vocal cords and bilateral paralysis may lead to the adduction of vocal cords and suffocation. Hence, the posterior cricoarytenoid muscles are called safety muscles of larynx. Another action of the muscle is to assist the cricothyroid muscle in lengthening the vocal cords by pulling the arytenoids backwards. The posterior cricoarytenoid receives branches from recurrent laryngeal nerve.

**Lateral Cricoarytenoid Muscle**

It is attached anteriorly to the arch of cricoid and passes in posterosuperior direction to insert in the front of muscular process of arytenoids cartilage. Its action is to pull the muscular process forward and rotate the arytenoids so that its vocal process turns medially. The simultaneous contraction of the right and left muscles results in adduction of the intermembranous parts of vocal cords thereby closing the glottis. The recurrent laryngeal nerve supplies the muscle.
Transverse Arytenoid Muscle
It is the only laryngeal muscle that is unpaired. It passes from the back of the arytenoid of one side to the back of the arytenoid of opposite side. Its contraction causes the adduction of vocal processes and consequent closure of the intercartilaginous part of rima glottis. It receives twigs from both recurrent laryngeal nerves.

Oblique Arytenoid and Aryepiglottic Muscles
The oblique arytenoids muscles are superficial to the transverse muscle. Each muscle passes from the back of muscular process of one arytenoid cartilage to the apex of opposite one, thus crossing each other above the lamina of cricoid. Some fibers of the oblique muscle run in the aryepiglottic mucous fold to form aryepiglottic muscle. These two muscles close the laryngeal inlet by bringing the aryepiglottic folds together and approximating the arytenoid cartilages to the tubercle of epiglottis. The muscles receive supply from recurrent laryngeal nerve.

Clinical insight ...
1. Since, laryngeal cavity is very narrow and it opens into to the laryngopharynx, accidental swallowing of food particle or foreign body into it may lead to acute laryngeal obstruction. This can cause choking due to blockage of air entry in the lungs. It is an acute emergency and unless promptly treated is fatal. Foreign bodies like, buttons, dentures or fish bones may get stuck in the laryngeal cavity. The symptoms of obstruction are stridor (noisy breathing), aphonia and dyspnea. Cyanosis may set in. The tracheostomy is life saving.
2. The surgical treatment of cancer of larynx is laryngectomy (removal of the entire larynx). In such cases breathing may have to be carried out through an artificial opening in the trachea (tracheostome) is given in Figure 50.7.
3. The laryngeal mucosa is supplied by bilateral internal laryngeal nerves (branches of superior laryngeal nerve from vagus) and recurrent laryngeal nerves (branches of vagus).
4. The muscles of larynx are supplied by recurrent laryngeal nerves and external laryngeal nerve (a branch of superior laryngeal nerve). Injury may occur to any of these branches causing specific effects.
   i. Unilateral recurrent laryngeal nerve injury results in ipsilateral paralysis of all the intrinsic muscles except the cricothyroid and transverse arytenoid

Fig. 50.7: Tracheostome (surgical opening in trachea) in postlaryngectomy patient

Contd...

Bilateral recurrent laryngeal nerve injury is also called bilateral abductor paralysis. The vocal cords lie in the median or paramedian.

Unilateral superior laryngeal nerve injury causes paralysis of the cricothyroid muscle (supplied through external laryngeal branch) and ipsilateral anesthesia above the vocal folds. The voice becomes weak and pitch cannot be raised. There is ipsilateral shortening of the vocal cord.

Bilateral superior laryngeal nerve injury results in weak and husky voice. The loss of sensations above the vocal cords gives rise to increased chances of aspiration of fluid in the larynx. Both vocal cords are shortened.
The ear consists of three parts (Fig. 51.1).
1. External ear
2. Middle ear
3. Internal ear

The external ear consists of auricle (pinna) and external acoustic meatus or ear canal. The external acoustic meatus is closed medially by the tympanic membrane.

**Embryologic insight ...**

i. The auricle or pinna develops from the fusion of six tubercles that appear around the dorsal end of first branchial cleft at the sixth week of embryonic life. Three tubercles are cranial to the first branchial cleft while three are on the cranial edge of the second arch. The first tubercle develops in the tragus. The remaining tubercles form the other parts of the auricle. Initially the auricles are located low in the neck region but with the development of mandible they ascend to the side of cranium at the level of eyes.

ii. The external acoustic meatus develops from the ectoderm of the first branchial cleft (Fig. 42.1).
Ear (External and Middle), Eustachian Tube, Mastoid Antrum and Internal Ear

Chapter 51

Gross Features of Auricle (Pinna)
The auricle consists of an irregularly curved elastic cartilage covered with skin. The various elevations and depressions on the cartilage give the auricle its characteristic appearance. It is attached to side of the cranium by ligaments and muscles. There are rudimentary intrinsic and extrinsic auricular muscles in human being. They are supplied by the facial nerve. The auricle has lateral (outer) and medial (cranial or inner) surfaces.

Lateral Surface (Fig. 51.2)
i. The helix is the peripheral prominent ridge curving around anterior, superior and posterior margins of pinna.
ii. The antihelix lies parallel and anterior to the posterior part of helix. It divides above into two branches, which enclose triangular fossa between them.
iii. The scaphoid fossa is the space between helix and antihelix.
iv. The concha of the auricle is a deep space, which is encircled by the antihelix and is continuous with the external acoustic meatus. The crus or anterior end of helix projects into the concha.
v. The conchal area above the crus is called cymba conchae, which is the surface landmark for the suprameatal triangle.
vi. The tragus is the curved projection below the crus. There is no cartilage between the crus and tragus. The antitragus lies opposite the tragus but separated by intertragic notch.
The lobule lies below the tragus and antitragus. It is devoid of cartilage and is the only soft part of the ear.

Nerve Supply of Auricle (Fig. 51.3)
1. The lateral surface receives twigs from three sources.
   i. The great auricular nerve (from cervical plexus) supplies the posterior part of this surface including the lobule.
   ii. The auriculotemporal nerve (from mandibular nerve) supplies the anterior part of this surface excluding the lobule.
   iii. The auricular branch of the vagus supplies a small part of the eminentia (prominence on cranial aspect corresponding to concha on lateral aspect).

2. The medial or cranial surface receives twigs from three sources.
   i. The lesser occipital nerve (from cervical plexus) supplies its upper part.
   ii. The great auricular nerve (from cervical plexus) supplies the larger lower area including the lobule.
   iii. The auricular branch of the vagus supplies a small part of the eminentia (prominence on cranial aspect corresponding to concha on lateral aspect).

External Acoustic Meatus
The external meatus extends from the bottom of the concha to the lateral surface of tympanic membrane.

i. In adult the length of the meatus is 24 mm. In the newborn the external meatus is short and straight. It lacks bony part and has no constrictions.
ii. The length of its anterior wall and floor is more than that of posterior wall and roof because the tympanic membrane is set at an angle of 55 degree with its floor.

iii. The shape of the meatus is sinuous due to two curves. Its outer part is directed upward, backward and medially while its inner part is directed downward, forward and medially.

Parts
i. The cartilaginous part is 8 mm long. It is continuous with auricular cartilage laterally. It is attached to the rim of the bony part of the meatus by fibrous tissue medially. Its anterior wall has two or three deficiencies known as fissures of Santorini through which infections from parotid gland can enter the meatus. It is lined with skin having thick subcutaneous tissue containing ceruminous glands (modified sweat glands). The glands secrete cerumen or earwax. The meatal hair and cerumen protect the ear from insects. The cerumen prevents the maceration of meatal skin by trapped water.

ii. The bony part is 16 mm long. The tympanic plate of temporal bone forms its anterior wall, inferior wall and most of the posterior wall. The squamous part of temporal bone forms the remaining walls. The bony part presents a foramen of Huschke in its floor in children up to the age of four to five years and in some adults. Its skin is thin and devoid of hair and ceruminous glands.

Constrictions
i. At the junction of cartilaginous and bony parts the meatus is narrow. This fact should be borne in mind while removing foreign body from the external meatus. The speculum should not be inserted beyond this constriction.

ii. Isthmus, which is located in the bony part, is 6 mm lateral to the tympanic membrane. It is the narrowest part of meatus.

Relations
Superiorly the bony meatus is related to the middle cranial fossa. Anteriorly the cartilaginous meatus is related to the temporomandibular joint. A blow on the chin may cause the posterior dislocation of the condyle of mandible into the meatus. A part of parotid gland intervenes between the condyle and the meatus. Posteriorly the meatus is related to the mastoid air cells.

Nerve Supply
The auriculotemporal nerve supplies the anterior and superior walls and the auricular branch of vagus supplies the posterior and inferior walls.

Arterial Supply
The posterior auricular artery, deep auricular artery and the auricular branches of superficial temporal artery supply the meatus and the auricle.

Lymphatic Drainage
The lymph vessels from the auricle and the external acoustic meatus drain in the parotid, mastoid and the deep cervical lymph nodes.

Clinical insight ...

- Inflammation of hair follicle in the cartilaginous part of the meatus may cause otitis externa. This causes severe pain because the meatal skin is tightly adherent to the perichondrium.
- Impacted wax is the condition in which excess wax is deposited as a plug in the meatus. The impacted wax may dry up and cause a sense of blocked ear, tinnitus and giddiness. Stimulation of auricular branch of vagus by impacted wax may give rise to reflex coughing (ear cough).
- If there is irritation of lingual nerve as in carcinoma tongue or of inferior alveolar nerve as in caries of lower teeth, it will cause reflex pain in ear canal.
- In Ramsey Hunt syndrome, due to herpes zoster infection of the geniculate ganglion of the facial nerve, vesicular eruptions appear in parts of auricle and external acoustic meatus that are supplied by the auricular branch of the vagus nerve (which carries fibers of facial nerve).

Middle Ear or Tympanic Cavity
The middle ear is an air-filled space in the petrous temporal bone. The middle ear receives atmospheric air from the nasopharynx via the pharyngotympanic tube.

Embryologic insight (Fig. 51.4) ...

- The middle ear develops from the endoderm of tubotympanic recess, which gives rise (besides middle ear) to pharyngotympanic tube, mastoid antrum and mastoid air cells. The middle ear is of adult size at birth.
- The malleus and incus develop in Meckel’s cartilage of first branchial arch while stapes develops from Reichert’s cartilage of second arch. All the three ossicles ossify in cartilage. The ossicles are of adult size in newborn.

Subdivisions
The middle ear cavity is divisible in the tympanic cavity proper (opposite the tympanic membrane) and the
Fig. 51.4: Features on the walls of middle ear (A) Sinus tympani; (B) Fenestra vestibuli; (C) Promontory; (D) Fenestra cochlearis; (E) Processus trochleariformis (Note the canal of facial nerve on the medial and posterior walls)

Epitympanic recess or attic above the level of tympanic membrane.

**Shape and Measurements**

The middle ear is likened to the shape of RBC (biconcave). Its vertical and anteroposterior diameters are each 15 mm. The transverse diameter varies at three levels because the medial and lateral walls of middle ear bulge inside the cavity. At the upper limit of the cavity the transverse diameter is 6 mm, at the central part it is 2 mm and at the lower limit it is 4 mm.

**Walls of Middle Ear (Fig. 51.4)**

The walls of the middle ear are: the roof, floor, lateral wall, anterior wall, medial wall and the posterior wall. Each wall has important features and relations.

**Roof (Tegmental Wall)**

The tegmen tympani, which is a thin plate of petrous temporal bone roofs the middle ear. It separates the middle ear from the middle cranial fossa and temporal lobe of cerebrum. The greater petrosal and lesser petrosal nerves pierce the roof to enter the middle cranial fossa.

**Floor (Jugular Wall)**

The jugular fossa forms the floor, which separates the middle ear from the internal jugular vein. When the bony floor has multiple tiny deficiencies the mucosa of the middle ear forms the floor at these sites. The medial wall of jugular fossa shows an aperture for tympanic branch of glossopharyngeal nerve (Jacobson’s nerve). This nerve enters the middle ear to form tympanic plexus on the promontory of its medial wall.

**Lateral Wall (Tympanic membrane)**

The lateral wall separates the middle ear from the external acoustic meatus. The tympanic membrane is the major part of lateral wall with a small peripheral contribution by the tympanic sulcus. The peripheral margin presents a notch in its superior part. The tympanic membrane is thickened circumferentially except at its superior part, which corresponds to the notch in the tympanic sulcus. The thickened peripheral rim of the membrane is called fibrocartilaginous ring, which fits into the tympanic sulcus. From the margins of the notch anterior and posterior malleolar folds pass to the lateral process of malleus. The posterior canaliculus for chorda tympani nerve is present near the posterior end of the notch. It is the upper opening of the bony canal of chorda tympani nerve, through which the nerve enters the substance of tympanic membrane. The nerve leaves the tympanic membrane through the anterior canaliculus at the anterior end of the notch (Fig. 51.5)

**Structure of Tympanic Membrane**

Tympanic membrane consists of three layers. The outer cuticular layer is continuous with the skin of the external acoustic meatus. The middle layer consists of fibrous tissue. The inner mucosal layer is continuous with the mucosa of middle ear. The chorda tympani nerve passes between the fibrous and mucosal layers in its upper part. The handle of malleus passes between the mucosal layer and fibrous layer from the umbo upwards.

**Embryologic insight ...**

The tympanic membrane develops from first cleft membrane, which consists of endoderm, mesoderm and ectoderm. Thus it is the only structure in the body that develops from all the three germ layers (Fig. 42.1). Its outer cuticular layer develops from ectoderm, the middle fibrous layer from mesoderm and the inner mucosal layer from endoderm.
Parts of Tympanic Membrane (Fig. 51.6)

i. Pars flaccida is a small triangular area of tympanic membrane situated between the malleolar folds. This part is lax on account of the absence of the middle fibrous layer.

ii. Pars tensa is the larger part and kept tense by its firm attachment to the tympanic sulcus.

Quadrants of Tympanic Membrane

i. The lateral surface of the tympanic membrane faces the external meatus and is concave. It is divided into four quadrants by two imaginary lines. The first line passes through the handle of malleus and the second passes through the umbo at right angles to the first line.

ii. The medial surface is convex. The point of maximum convexity on the medial surface, where the tip of the handle of malleus is attached is called umbo.

Speculum Examination (Fig. 51.6)

On inspection through the speculum introduced via the external acoustic meatus, the tympanic membrane looks pearly gray and semitransparent. It is obliquely set at an angle of 55 degree to the metal floor. Hence, its lateral surface faces forwards, laterally and downwards. In the newborn, since there is no bony meatus the tympanic membrane lies horizontally and is very close to the surface. Some structures of the middle ear can be seen through the membrane. The handle of malleus looks like a reddish-yellow streak extending from the umbo upwards. The lateral process of the malleus is seen as a white round prominence at the upper end of the handle of malleus near the roof. The long process of incus is seen behind and parallel to the upper part of handle of malleus. A bright cone of light is seen in the anteroinferior quadrant. This is due to concavity of the lateral surface. The cone of light is lost if the membrane bulges laterally due to any cause.

Blood Supply

i. The lateral surface receives arterial supply from the deep auricular branch of maxillary artery. Its veins drain into external jugular vein.

ii. The medial surface receives arterial supply from tympanic branch of maxillary artery and stylomastoid branch of posterior auricular or occipital artery. The veins drain into transverse sinus and in the venous plexus around pharyngotympanic tube.

Nerve Supply

i. The nerve supply of lateral surface is from the auriculotemporal nerve and auricular branch of vagus nerve.

ii. The nerve supply of medial surface is from the glossopharyngeal nerve through tympanic plexus.

Clinical insight...

i. The arterial supply reaches the membrane from the periphery towards the center. Hence the central part of the membrane (umbo) has poor blood supply. Thus the central part is in danger of perforation when the arteries at the periphery are thrombosed in inflammatory disease of the middle ear.

ii. Myringotomy is the procedure by which a surgical incision is placed in the tympanic membrane to drain the fluid in the middle ear or to inject air into the middle ear in case of blocked pharyngotympanic tube. The incision is placed in the postero-inferior quadrant to avoid injury to chorda tympani nerve and ear ossicles, which are intimately related to the membrane.

iii. Myringoplasty is the procedure by which perforations in the pars tensa are closed with the use of graft from temporal fascia or perichondrium of the tragus (immunologically inert tissues).

iv. The tympanic membrane retracts or its concavity on the lateral surface is increased due to negative intratympanic pressure. This happens if the pharyngotympanic tube is blocked and the already existing air in the middle ear is absorbed. The cone of light is absent in retracted membrane. The membrane bulges if there is excess fluid in the middle ear.

Anterior Wall (Carotid wall)

The anterior wall is narrow due to approximation of medial and lateral walls. Its prominent feature is a large opening of the pharyngotympanic tube. Above this the canal for the tensor tympani muscle opens. The bony septum between
the two canals turns to the medial wall of the middle ear. Below the opening of the auditory tube a thin bony lamina separates the middle ear from the carotid canal and the internal carotid artery. This close relation of middle ear and the internal carotid artery explains the swishing tinnitus (noise in the ear) experienced by the patient in carotid aneurysm. The caroticotympanic branches of the internal carotid artery and the nerves of the same name from the sympathetic plexus around the artery enter the middle ear by piercing the bony lamina.

**Medial Wall (Labyrinthine wall)**

The features of the medial wall are given in Figure 51.4.

i. The promontory is a rounded elevation in the middle of the medial wall. It is produced by the basal turn of cochlea in the internal ear. The tympanic plexus of nerves is located on its surface.

ii. The sinus tympani is a depression posterior to the promontory.

iii. The fenestra vestibuli or oval window is an opening above the sinus tympani. It is closed by the footplate of stapes and the annular ligament. The footplate separates the air of the middle ear from the perilymph in scala vestibuli.

iv. The fenestra cochleae or round window is present below the sinus tympani and is closed by secondary tympanic membrane. The footplate separates the air of the middle ear from the perilymph in scala tympani.

v. Pyramid is a hollow projection from the canal of facial nerve into the middle ear cavity towards the promontory. It contains stapedius muscle. The tendon of stapedius enters the middle ear through a tiny aperture at the apex of pyramid for insertion into the neck of stapes.

vi. The fossa incudis is present lateral to the aditus. Short process of incus is attached to the fossa incudis by ligament.

vii. The chorda tympani nerve enters the tympanic membrane through the posterior canaliculus.

**Contents of Middle Ear**

The air is the actual content. The other contents, which include three ear ossicles two muscles, blood vessels and nerves are covered with mucosa of the middle ear.

**Mucous Membrane**

The mucosa (mucoperiosteum) is continuous with that of nasopharynx through the pharyngotympanic tube and with that of mastoid antrum and air cells. The middle ear is lined by ciliated columnar epithelium except over the posterior part of the medial wall, posterior wall and parts of the medial surface of tympanic membrane, where it is cuboidal.

**Nerve Supply**

The tympanic plexus provides sensory supply to the mucosa. The tympanic plexus is formed by tympanic branch of the glossopharyngeal nerve and caroticotympanic nerves from the sympathetic plexus around internal carotid artery.

**Blood Supply**

The middle ear receives rich arterial supply through several sources, anterior tympanic branch of maxillary artery, stylomastoid branch of occipital (or posterior auricular) artery, petrosal branch of middle meningeal artery, a branch from ascending pharyngeal artery, a branch from artery to the pterygoid canal and caroticotympanic branches of internal carotid artery. The veins drain into pterygoid venous plexus and the superior petrosal sinus.

**Lymphatic Drainage**

The lymphatics from the middle ear drain in the parotid group and upper deep cervical nodes. A few reach the retropharyngeal nodes.
Ear Ossicles

There are three ear ossicles, malleus, incus and stapes.

i. The **malleus** is the largest and derives its name from resemblance to mallet meaning hammer. It has head, handle and the neck, which is the constriction between head and handle. The anterior and lateral processes arise just below the neck. The head lies in the epitympanic recess and articulates with the body of incus at the saddle type of synovial articulation called incudomalleolar joint. The neck gives attachment to tensor tympani tendon.

ii. The **incus** derives its name from resemblance to anvil though actually its shape is more like a premolar tooth. It has body and two processes, long and short. Its body and short process are confined to epitympanic recess. The body articulates with head of malleus. The short process is attached to fossa of incudis in posterior wall of middle ear. The long process goes down parallel to handle of malleus. Its lower end articulates with the head of stapes to form incudostapedial joint, which is ball and socket type of synovial joint.

iii. The **stapes** resembles a stirrup. It is the smallest bone in the body. It has head, neck and two limbs of unequal lengths, which are joined to an oval plate called base or footplate. The neck receives insertion of stapedius. The footplate is attached to the margins of fenestra vestibuli by annular ligament. In otosclerosis there is fixation of stapes leading to conductive deafness. Removing the stapes (stapedectomy) and putting an implant between the incus and fenestra vestibuli is the surgical treatment for restoring the hearing in otosclerosis.

Intratympanic Muscles

i. The tensor tympani muscle takes origin from the cartilaginous part of the pharyngotympanic tube and the adjacent greater wing of the sphenoid. It enters the anterior wall of middle ear via its bony canal and then its tendon takes a sharp turn around the processus cochleariformis of the medial wall of middle ear. It is inserted in the neck of malleus. The tensor tympani muscle receives its nerve supply from the mandibular nerve because it develops from the mesoderm of the first arch. The nerve supplying the tensor tympani reaches it by an indirect route (via the otic ganglion from the branch to the medial pterygoid muscle in the infratemporal fossa).

ii. The stapedius muscle is entirely intratympanic in location. It takes origin from within the pyramid on the posterior wall of middle ear. Its tendon emerges from the aperture at the apex of pyramid and is inserted in neck of stapes. The stapedius is supplied by the facial nerve as it develops from the mesoderm of the second branchial arch.

### Auditoty Tube or Eustachian Tube

The auditory tube is also known as pharyngotympanic tube or Eustachian tube.

It connects the nasopharynx to the middle ear. The function of the tube is to replenish atmospheric air in the middle ear so that both surfaces of the tympanic membrane are subjected to equal pressure. Through the middle ear, the tube supplies air to the mastoid antrum and air cells. The tube opens during deglutition, yawning and sneezing. Otherwise it remains closed.

### Length

In the adult the length of tube is 36 mm.
Direction
From the anterior wall of the middle ear the auditory tube passes downwards, medially and forwards to reach the lateral wall of nasopharynx by passing through the pharyngobasilar fascia above the free margin of the superior constrictor.

Parts (Fig. 51.7)
The auditory tube consists of three parts.
i. The lateral (outer) part is bony. It is 12 mm in length. It is located within petrous temporal bone. It extends from anterior wall of middle ear to the junction between the squamous and petrous parts of temporal bone, where it ends in a jagged margin for attachment to the cartilaginous part. Its epithelium is of ciliated columnar type and is continuous with that of middle ear.
ii. The isthmus is the junction between the bony and cartilaginous parts.
iii. The medial (inner) part is cartilaginous. It is 24 mm in length. The cartilage is of elastic type. This part is fixed to the sulcus tubae (on the base of cranium) bounded by petrous temporal bone and greater wing of sphenoid. Its wall is composed mainly of cartilage but partly of fibrous tissue. A triangular plate of cartilage is bent on itself to form a broad medial lamina and narrow lateral lamina. This forms the posteromedial wall of the tube. Inferolateral wall is made of fibrous tissue. The epithelium is ciliated columnar with subjacent mucous glands. The cartilage projects at the pharyngeal orifice to give rise to tubal elevation (torus tubaris) behind the orifice. This elevation serves as a landmark during the passage of catheter in the tubal orifice.

Diameter
The diameter of the tube is greatest at its pharyngeal opening, least at the isthmus and again increases towards the middle ear.

Location of Pharyngeal Opening
The pharyngeal opening of the tube is the widest part of the tube. It is located 1 to 1.25 cm behind the posterior end of inferior nasal concha.

Muscles Attachment (Fig. 51.7)
i. Salpingopharyngeus is attached to the medial lamina of cartilage near the pharyngeal opening.
ii. Levator palati arises from the medial lamina of the cartilage.
iii. Tensor palati arises from the lateral lamina of cartilage and the membranous wall of the tube. The fibers of tensor palati attached to the membranous wall are called dilator tubae.
iv. The tensor tympani takes origin from the medial lamina of the cartilage.

Actions
i. The salpingopharyngeus and dilator tubae probably open the tube during deglutition.
ii. Levator palati raises the cartilage of the tube thereby releasing tension on the tube and assisting passively to open it.

Nerve Supply
i. The glossopharyngeal nerve through the tympanic plexus in the middle ear supplies the lateral part of the tube.
ii. The pharyngeal branch of the sphenopalatine ganglion (indirect branch of maxillary nerve) supplies the pharyngeal end of the tube.

Blood Supply
The arterial supply of the auditory tube is from the ascending pharyngeal artery, middle meningeal artery and artery of pterygoid canal. The veins drain into the pharyngeal plexus and pterygoid venous plexus.

Lymphatic Drainage
The lymphatics drain into retropharyngeal and upper deep cervical lymph nodes.

Embryologic insight ...
The auditory tube develops from the endoderm of tubotympanic recess, which also develops into middle ear.

Auditory Tube in Newborn
i. The auditory tube is half the length of the adult in the newborn.
ii. Its direction is horizontal thus facilitating spread of infection from the nasopharynx to the middle ear in infants.
iii. Its bony part is wider.
Head and Neck

**Section 454**

**MASTOID OR TYMPANIC ANTRUM**

The mastoid antrum is an air-filled space in the petrous temporal bone. It is in communication with the epitympanic recess of middle ear anteriorly and with mastoid air cells inferiorly (Fig. 51.4). Its capacity is about 1 ml.

**Boundaries of Mastoid Antrum**

1. The anterior wall presents aditus, which leads into the epitympanic recess of the middle ear.
2. The tegmen tympani roofs the antrum and separates it from the middle cranial fossa and the temporal lobe of the cerebrum.
3. Inferiorly it is continuous with mastoid air cells in the mastoid process.
4. Posteriorly it is related to the sigmoid sinus and the cerebellum in the posterior cranial fossa.
5. Medially it is related to lateral semicircular canal of the inner ear.
6. The lateral wall corresponds to the suprameatal triangle of Macewen. This wall is only 2 mm thick at birth but increases at the rate of 1 mm per year to attain final thickness of 12 to 15 mm.

**Boundaries of Suprameatal Triangle**

1. The superior boundary is the supramastoid crest of the squamous temporal bone.
2. The anterior boundary is the posterosuperior margin of the external acoustic meatus.
3. The posterior boundary is a vertical tangent to the posterior margin of external meatus (Fig. 51.8).

**Surface Marking of Suprameatal Triangle**

The cymba conchae of the auricle denotes the location of suprameatal triangle. So for aspiration of pus from the antrum the needle is inserted two mm deep in infants and about 12 to 15 mm deep in adults through the cymba conchae.

**Mastoid Air Cells**

The mastoid air cells may be present in surrounding bones like squamous temporal bone, tip of mastoid process, tegmen tympani, petrous temporal bone and zygomatic bone. The importance of the extramastoidal air cells is that they can be sites of infection.

**Clinical insight ...**

- Its narrow pharyngeal opening is at the level of palate and is without tubal elevation (torus tubarius). Hence, it is difficult to locate the pharyngeal orifice during the procedure of passing a catheter in the tube in infants. Hence there is danger of piercing fossa of Rosenmüller by mistake.
- If the auditory tube is blocked completely, negative pressure builds up in the middle ear due to absorption of the already existing air.
- Long-term obstruction of the auditory tube results in secretory otitis media or glue ear, which leads to conductive deafness especially in school-going children.

**Embryologic insight ...**

The mastoid antrum and air cells develop from the endoderm of tubotympanic recess. The mastoid antrum is of adult size but the mastoid process is absent at birth. The mastoid process begins to grow as a small projection at the end of first year and mastoid air cells invade it at puberty.

**Clinical insight ...**

- The anterior boundary is the posterosuperior margin of the external acoustic meatus.
- The posterior boundary is a vertical tangent to the posterior margin of external meatus behind.
Chapter 51

Internal Ear

The internal ear or labyrinth is located medial to the middle ear in the petrous temporal bone. It has a very complex structure.

Major Subdivisions

i. Outer bony labyrinth filled with perilymph
   ii. Inner membranous labyrinth filled with endolymph and housing the receptors of hearing and equilibrium.

Bony or Osseous Labyrinth (Fig. 51.9)

The bony labyrinth consists of three interconnecting parts, cochlea, vestibule and semicircular canals.

Bony Cochlea

The bony cochlea is a conical structure resembling the shape of the shell of a snail. It consists of a spiral cochlear canal around a central modiolus, which has a broad base and a narrow apex. The cochlear canal takes two and three fourth turns around the modiolus. The basal turn produces the bulge of promontory on the medial wall of middle ear. The base of the modiolus is directed towards the bottom of internal acoustic meatus (sieve-like tractus spiralis foraminosus) through which fibers of cochlear nerve pass. An osseous spiral lamina is a shelf like projection from the modiolus in to the cochlear canal. The modiolus is traversed by linear minute canals for the passage of the fibers of cochlear nerve. The linear canals turn laterally to enter the spiral canal of modiolus. The spiral canal (Rosenthal’s canal) runs in the base of osseous spiral lamina and lodges the spiral ganglion of cochlear nerve. The free edge of spiral lamina presents a C-shaped sulcus, which divides the free edge in to vestibular and tympanic lips. The upper surface of vestibular lip gives attachment to vestibular ligament and its tip to the tectorial membrane. The tip of the tympanic lip gives attachment to basilar membrane. The cochlear canal contains three spaces, cochlear duct (scala media) in the middle, scala tympani below and scala vestibuli above. The scala media is filled with endolymph but the scala tympani and scala vestibuli are filled with perilymph. The scala tympani and scala vestibuli communicate with each other at the apex of cochlea, through an opening called helicotrema. At the base of cochlea the opening of scala tympani (fenestra cochleae) is closed by secondary tympanic membrane but the scala vestibuli continues in to the vestibule. The scala tympani is connected to the subarachnoid space by aqueduct of cochlea or perilymphatic duct or cochlear canaliculus, which is a minute bony canal opening in the subarachnoid space at the inferior surface of the petrous temporal bone in the jugular fossa.

Vestibule

The vestibule is the central part of the bony labyrinth. It lies medial to the tympanic cavity behind the cochlea and in

Complications of Mastoiditis

i. There may be abscesses around the mastoid process, labyrinthitis (inflammation of internal ear), facial paralysis, intracranial abscesses, meningitis and sigmoid sinus thrombosis.
ii. Bezold abscess is formed if the pus breaks through the tip of mastoid process in the fascial sheath of the sternomastoid muscle.
iii. Citelli’s abscess is formed if the pus travels along the posterior belly of digastic and appears as a swelling in the digastic triangle.

Contd...
front of semicircular canals. Its contents are the utricle and sacculle of membranous labyrinth.

The anterior wall of the vestibule shows an opening leading in to the scala vestibuli of cochlear canal. The lateral wall presents fenestra vestibuli on the medial wall of middle ear. It is closed by footplate of stapes and annular ligament. The posterior wall bears five openings of three semicircular canals. The inner surface of medial wall shows two recesses. The spherical recess lodges the sacculle and the fibers of vestibular nerve reach the sacculle through the floor of the recess. The elliptical recess lodges the utricle and the fibers of the vestibular nerve reach the utricle through the floor of this recess. The opening of the bony canal called aqueduct of vestibule (for passage of endolymphatic duct) is located below the elliptical recess. The aqueduct of vestibule reaches the epidural space on the posterior surface of petrous temporal bone.

**Semicircular Canals**
The three semicircular canals are situated posterosuperior to the vestibule. The canals are named, anterior (superior), lateral (horizontal) and posterior. They contain semicircular ducts and lie in planes that are at right angles to each other. Each canal has an ampullated or dilated end and a non-ampullated end. The nonampullated ends of posterior and anterior canals unite to form crus commune. In this way, the semicircular canals open in the vestibule by five openings. The anterior (superior) semicircular canal produces arcuate eminence in the anterior surface of petrous temporal bone in the middle cranial fossa. The lateral semicircular canal is in relation to the medial wall of middle ear, medial wall of mastoid antrum and its aditus. The right and left lateral semicircular canals are in the same plane but the anterior canal of one side is parallel to the posterior canal of the opposite side.

**Perilymph**
The source, circulation and absorption of perilymph are as yet not fully known. The perilymph contains high sodium, low potassium and high protein. The cochlear canaliculus (perilymphatic duct or aqueduct of cochlea) carries the perilymph in to the subarachnoid space at the roof of the jugular foramen. So probably the perilymph is partly derived from CSF and partly from the blood vessels surrounding perilymphatic spaces of the bony labyrinth. The movements of the perilymph follow a definite sequence. The medial movement of the footplate of stapes in fenestra vestibuli produces pressure waves in the perilymph of the vestibule and of the scala vestibuli. The waves are passed on to the perilymph of scala tympani at helicotrema. After producing movements of basilar membrane the waves cause a compensatory bulge of the secondary tympanic membrane in the middle ear. Thus, the wave is generated at fenestra vestibuli and terminated at fenestra cochleae.

**Membranous Labyrinth (Fig. 51.10)**
The membranous labyrinth consists of cochlear duct, utricle and saccule, three semicircular ducts and endolymphatic duct and sac, which together form endolymph filled closed system of channels. The membranous labyrinth contains the receptors or end organs for hearing and balance.

**Cochlear Duct**
The cochlear duct or membranous cochlea or scala media is coiled like the bony cochlea. It is blind at the apex (lagena) but is connected to the saccule by ductus reunions at the base. It is located near the outer part of bony cochlear canal between the scala tympani below and scala vestibuli above. Its boundaries are, basilar membrane inferiorly (which separates it from the scala tympani), the vestibular or Reissner’s membrane superomedially (which separates it from the scala vestibuli) and stria vascularis laterally. The width of the basilar membrane increases from the basal to the apical region of the cochlear duct because the width of the osseous spiral lamina decreases from below upwards. The end organ of hearing, spiral organ of Corti is located inside the cochlear duct.

**Spiral Organ of Corti**
The spiral organ is composed of a special type of sensory epithelium and the tectorial membrane. The epithelium consists of sensory hair cells and different types of supporting cells, which are arranged on the basilar membrane. The pillar cells rest on the basilar membrane by broad bases. The outer and inner pillar cells enclose a central triangular space (tunnel of Corti). This tunnel contains cortilymph, which nourishes the sensory epithelium. Internal to the
inner pillar cells there is a single row of inner hair cells. External to the outer pillar cells there are three or four rows of outer hair cells. The tectorial membrane is a stiff gelatinous plate containing glycoproteins (tectorins). It is attached to the vestibular lip of the spiral lamina. It overlies the apical aspect of the sensory epithelium. The hair or stereocilia of outer hair cells are embedded in it. The vibrations of basilar membrane cause the shearing forces between the tectorial membrane and hair cells. It is these forces that stimulate the outer hair cells as well as the inner hair cells, which transduce sound energy into electrical impulse. The nerve fibers supplying the hair cells (peripheral processes of the bipolar neurons of spiral ganglion) carry the nerve impulse to the cochlear nerve.

The hair cells also receive efferent olivocochlear fibers from the superior olivary nucleus via the Oort’s anastomosis. These fibers are believed to modulate the function of inner hair cells through inhibitory influence of outer hair cells.

Clinical insight...

i. Inflammation of labyrinth is called labyrinthitis.
ii. Noise trauma can lead to hearing loss. Degenerative changes in organ of Corti may occur in people exposed to continuous loud sound over a period of time. The boilermakers, coppersmiths, ironsmiths and artillerymen are susceptible to this condition. Sudden loud sound (loud explosion, gunfire or a powerful cracker) may damage hair cells in organ of Corti or rupture the vestibular membrane.
iii. Presbycusis is the physiological hearing loss associated with aging process.
iv. Cochlear implants are the electronic devices that are used in place of a totally nonfunctioning cochlea.

Utricle and Saccule

i. The utricle is an irregular sac that occupies the elliptical recess of bony vestibule. It receives five openings of the semicircular ducts.
ii. The saccule is a globular sac lying in the spherical recess of the bony vestibule. It is connected to the cochlear duct by the ductus reuniens.
iii. The utriculosaccular duct is Y-shaped. It connects the saccule and utricle to each other. The vertical limb of the Y continues as the endolymphatic duct.
iv. The macula is the sensory epithelium of the utricle and saccule. It consists of large number of hair cells. The cilia of the hair cells project in the gelatinous cap called statoconial or otolithic membrane containing crystals of calcium carbonate (otoliths). The hair cells respond to orientation of head with respect to gravity hence the maculae of utricle and saccule are known as static maculae. Excessive stimulation of utricle and saccule is responsible for motion sickness, in which the person experiences vertigo, nausea and vomiting.

Semicircular Ducts

The semicircular ducts are much smaller in diameter than the semicircular canals of bony labyrinth. The anterior, lateral and posterior ducts open by five openings into the utricle. The ampullary end of each duct bears a raised crest (crista ampullaris), which projects into the lumen. Each ampullary crest carries specialized hair cells. The stereocilia and one kinocilium from the hair cell are inserted in a vertical plate of gelatinous material called cupula. The angular acceleration and deceleration movements of head bring about movements of endolymph in semicircular ducts, which results in deflecting of cupula and stimulation of the hair cells of crest. The peripheral processes of the bipolar neurons of vestibular ganglion provide sensory supply to these hair cells. The ampullary cristae are also known as kinetic labyrinth on account of their function.

Endolymphatic Duct and Sac

The endolymphatic duct continues from the junction of Y-shaped utriculosaccular duct. It is carried in a bony canal (vestibular aqueduct) to the posterior aspect of petrous temporal bone. Its dilated terminal part is called endolymphatic sac, which projects between the periosteum and the dura mater on the posterior surface of petrous temporal bone in the posterior cranial fossa near the sigmoid sinus. The endolymph, which is rich in potassium and poor in sodium, is secreted by stria vascularis within the cochlear duct. It enters the ductus endolymphaticus for removal from its sac in the extradural vascular plexus.

Blood Supply of Labyrinth

i. The labyrinthine artery, more frequently a branch from anterior inferior cerebellar artery (instead of the basilar artery) enters the inner ear via internal acoustic meatus. At the bottom of the meatus it divides in to cochlear and vestibular branches, of which the cochlear branch enters the modiolus.
ii. The stylomastoid branch of either the occipital or the posterior auricular artery may also give additional supply to the labyrinth.
iii. The veins of the labyrinth end in labyrinthine vein, which drains in to the superior petrosal sinus.

Meinere’s Disease

The blockage of the endolymphatic duct or damage to the sac leads to accumulation of endolymph in the membranous labyrinth. This condition is called endolymphatic hydrops or Meniere’s disease. It is characterized by vertigo, hearing loss and tinnitus.

Clinical insight...

i. Inflammation of labyrinth is called labyrinthitis.
ii. Noise trauma can lead to hearing loss. Degenerative changes in organ of Corti may occur in people exposed to continuous loud sound over a period of time. The boilermakers, coppersmiths, ironsmiths and artillerymen are susceptible to this condition. Sudden loud sound (loud explosion, gunfire or a powerful cracker) may damage hair cells in organ of Corti or rupture the vestibular membrane.
iii. Presbycusis is the physiological hearing loss associated with aging process.
iv. Cochlear implants are the electronic devices that are used in place of a totally nonfunctioning cochlea.
Membranous Labyrinth
The ectodermal thickening in the region of hindbrain (in the vicinity of future first branchial cleft) forms the auditory or otic placode in the fourth week of intrauterine life. The placode sinks beneath the surface to form otocyst or auditory vesicle, from which different parts of membranous labyrinth develop. The inner ear achieves adult size by the sixteenth week of intrauterine life.

Congenital Anomalies
i. Michel aplasia is complete absence of inner ear.
ii. Maternal infection with rubella (German measles) during the sixth to ninth weeks of gestation may lead to congenital deaf-mutism due to destruction of organ of Corti. Drugs like streptomycin, thalidomide and chloroquine given to the pregnant woman during early pregnancy may cross the placental barrier and damage the cochlea.
CASE 1

A one-year-old girl was brought to the hospital for check up. Examination revealed that the head of the girl was tilted towards right shoulder and her face was turned towards left and upwards. History revealed that the baby was delivered using forceps during which she suffered soft tissue injury in the neck.

Questions and Solutions

1. Name the muscle of the neck (with its side) involved in birth injury in this case.
   Right sternomastoid muscle

2. What is the clinical condition called?
   Torticollis or wry neck

3. Give the attachments and nerve supply of the involved muscle.
   The sternal head arises from anterior surface of manubrium sterni and clavicular head from superior surface of the medial third of the clavicle. The muscle is inserted into lateral surface of the mastoid process and lateral half of superior nuchal line. It is supplied by spinal accessory nerve.

4. Which blood vessel is present between the two heads of origin of this muscle?
   Internal jugular vein is present in the interval between its two heads of origin. This space is called lesser supraclavicular triangle.

5. Name the nerves related to the posterior margin of this muscle.
   About midpoint of the posterior margin of the sternomastoid seven nerves, bunch together. Hence, it is called nerve point of the neck. The nerves related are, spinal accessory, medial, intermediate and lateral supraclavicular nerves and great auricular, lesser occipital and transverse cutaneous nerve of neck.

6. Describe cervical sinus and name its anomalies found along the anterior margin of this muscle.
   During the branchial phase of the embryo (4th–5th weeks) pharyngeal clefts (surface depressions) give uneven appearance to the neck. Subsequently, the ectoderm covering the second arch grows down faster overlapping the succeeding clefts. This overhanging ectoderm fuses distally with epicardial ridge. The ectoderm-lined closed space is called the cervical sinus. Normally, the sinus soon obliterates. The branchial cyst forms if the sinus obliterates partially. The failure of the sinus to close distally forms a fistula.
   The branchial fistulae and cysts appear along the anterior margin of sternomastoid muscle. The cyst is usually located at the angle of mandible and the fistula is located at the lower end of sternomastoid.

CASE 2

A 12-year-old boy fell from a tree and suffered injury on the forehead near the hairline on the right side. Since there was severe bleeding the boy was rushed to the casualty, where the wound was sutured to control bleeding. After third day, the boy was brought back to the hospital because his both eyes were black.

Questions and Solutions

1. Explain with the help of a diagram the communication between the upper eyelids and the scalp.
   Refer to Figure number 37.2, which shows the continuity of subaponeurotic space with the upper eyelids. This space is closed posteriorly at the bony attachment of
the occipitalis. Laterally, it is closed by the attachment of galea aponeurotica at the superior temporal lines. Anteriorly, the space extends into the upper eyelids because of absence of bony attachments of the frontalis muscles. The blood from the upper eyelids may enter the lower ones also and after clotting, it imparts black color to the eyes.

2. Which layer of scalp contains nerves and blood vessels?
Superficial fascia or dense connective tissue layer contains nerves and blood vessels.

3. Why do scalp wound bleed profusely?
There are two reasons for this. There are rich anastomoses between arteries of two sides hence they bleed from two ends when cut. The cut ends of the arteries do not contract because their walls are pulled by the dense connective tissue to which they are adherent.

4. Name the sensory and motor nerves of the anterior quadrant of scalp.
There are four sensory nerves (supratrochlear, supraorbital, zygomatico-temporal and auriculotemporal). The only one motor nerve is temporal branch of facial nerve.

5. Which vessels pass through the subaponeurotic layer of scalp and what is their clinical importance?
Emissary veins pass through this space. These veins are peculiar in that they connect the extracranial veins with intracranial venous sinuses and they are valveless. These veins may be torn in traction injuries of the scalp and give rise to bleeding in the subaponeurotic space. The emissary veins may act as conduits for spread of infection from the scalp to the meninges or brain.

CASE 3
A 34-year-old woman came to the hospital with a nodular swelling in the midline of the neck. The swelling moved with swallowing. On examination, it was found that she had slight tremors on outstretched hands, her pulse rate was 100 per minute and there was slight bulging of the eyes. Blood levels of T3 and T4 were high and TSH level was low.

Questions and Solutions

1. Name the gland that is responsible for midline swelling in the neck and the clinical condition.
Thyroid gland is enlarged. The clinical condition is toxic goiter or thyrotoxicosis.

2. Give anatomical reason for the movement of swelling with swallowing.
The pretracheal fascia forms the false capsule. A thickening of the false capsule (ligament of Berry) connects the lobe of thyroid to the cricoid cartilage. Because of this firm anchorage to the laryngeal cartilage the thyroid moves with swallowing.

3. Draw a diagram to show the parts and relations of the gland.
Refer to Figure 43.1.

4. What is the clinical importance of the capsules of the gland?
The thyroid gland has two capsules, true and false. The veins pierce the capsules and form venous plexus underneath the true capsule. During thyroidectomy (surgical removal of gland) the veins are ligated and the gland is removed along the intercapsular plane to avoid injury to venous plexus.

5. Give the surgical importance of the arterial supply of the gland.
The superior thyroid artery is in close relation to external laryngeal nerve except at the upper pole of the gland. Hence, the surgeon ligates this artery as close to the upper pole of the gland as possible. The inferior thyroid artery is closely related to recurrent laryngeal nerve near the lower pole of the gland. Hence, the surgeon ligates this artery as much away from the lower pole as possible.

6. Write briefly on the development of the gland.
i. The follicular cells of the thyroid gland develop from the endodermal thyroid diverticulum, which begins in the pharyngeal floor at the site of foramen cecum. The diverticulum becomes the thyroglossal duct, which passes downward through the developing tongue. The duct has peculiar relation to the hyoid bone. At first, it passes in front of the bone then winds round it to come down to pass in front of the thyroid cartilage and cricoid arch. Having reached below they cricoid cartilage by around 7 weeks, the lower end of the duct divides to form lateral lobes and the connection is retained as isthmus.

ii. The parafollicular cells (C cells) develop from cells of caudal pharyngeal complex (ultimobranchial body).

CASE 4
Two days following total thyroidectomy the patient experienced paraesthesia (altered sensation) around the mouth
followed by tingling and numbness in fingers and toes and painful cramps in hands and feet. Blood calcium level was found to be very low.

Questions and Solutions

1. Name the clinical condition giving its physiological basis.
   Tetany is the clinical condition due to deficiency of parathormone.

2. Which structures were inadvertently removed by the surgeon during thyroidectomy?
   The parathyroid glands were inadvertently removed along with thyroid gland as parathyroid glands are intimately related to thyroid gland on posterior aspect of their lateral lobes.

3. How does the surgeon identify these structures during thyroid surgery?
   Glandular branches of inferior thyroid artery are the surgeon’s guide to parathyroid glands. At times, the surgeon resorts to identification by frozen section biopsy (during operation).

4. Give the number and position of these structures.
   There are two pairs of parathyroid glands (superior and inferior). They are located posterior to the thyroid gland in side the false capsule. The superior pair is located at the level of junction of upper and middle one-third of the thyroid lobe. The inferior pair is located near the lower end of the thyroid gland.

5. Mention their development.
   The superior parathyroid glands develop from the endoderm of fourth pouch and the inferior parathyroid from the endoderm of third pouch.

6. Name the cells in parathyroid glands and which one is the source of parathormone (PTH)?
   The cells in parathyroid are called chief cells and oxyphil cells. The chief cells of parathyroid glands secrete parathormone.

CASE 5

A patient had swelling below the lower jaw on the right side. The swelling increased in size during eating. The surgeon inspected the sublingual papilla in the floor of the mouth and did a bidigital examination by putting index finger inside the oral cavity and the thumb outside in front of the angle of the mandible.

Questions and Solutions

1. Which salivary gland is palpated in this case?
   The submandibular salivary gland is palpated by bidigital examination.

2. Name the parts of this gland and the muscle that separates these parts.
   The submandibular gland has larger superficial part and smaller deep part. The two parts are continuous with each other around the posterior free margin of mylohyoid muscle.

3. What is the length of its duct and where does it open?
   The submandibular duct (Wharton’s duct) is 5 cm long. It opens into the floor of the mouth at the summit of the sublingual papilla by the side of the frenulum linguae.

4. Which is the narrowest part of the duct?
   The submandibular duct is narrowest at the oral orifice.

5. Name the radiological investigation done to visualize the duct system of salivary glands.
   Sialography

6. Draw a diagram of secretomotor innervation of this gland.
   Refer to Figure 41.10.

CASE 6

A middle-aged woman complained of pain, tingling and numbness along the medial side of the right forearm and hand. She had difficulty in gripping the objects firmly in the right hand. On examination, the radial pulse was weaker on the right side compared to the left. Adson’s test was positive on right side. Plain X-ray of chest showed cervical rib on the same side. To relieve the symptoms the cervical rib was removed along with its periosteum.

Questions and Solutions

1. What is the morphology of the cervical rib?
   A cervical rib is the enlarged costal element of the 7th cervical vertebra (costotransverse bar, anterior
tubercle and anterior root of the transverse process form the costal element).

2. Which structures are likely to be compressed by the cervical rib?

The neurovascular structures, which are related to the superior surface of the first rib, namely, third part of subclavian artery and lower trunk of brachial plexus on right side.

3. Explain the patient’s inability to hold the objects in the hand.

Because of compression of lower trunk of brachial plexus the motor supply of intrinsic muscles of hand (C8 and T1 segment of spinal cord) via ulnar and median nerves is affected.

4. Give the extent of the compressed artery on the side of the lesion.

The right subclavian artery is one of the terminal branches of the brachiocephalic trunk. It extends from the sternoclavicular joint to the outer margin of the first rib.

5. Explain why the cervical rib is surgically removed along with its periosteum?

If the periosteum is left behind during surgical removal of the rib its inner cellular layer will regenerate the rib.

CASE 7

A 58-year-old man presented with a complaint of rapidly growing painful swelling on the face below the ear lobe on the left side. On examination, the left ear lobe was found to be lifted by the swelling. There was inability to close the left eye and to blow the cheek. The angle of mouth was deviated to the right side.

Questions and Solutions

1. Name the gland that is swollen.
   Parotid gland

2. Name the major structures inside this gland.
   The major structures inside the parotid gland are facial nerve, retromandibular vein and external carotid artery (their order being superficial to deep).

3. Which of these structures is affected?
   Facial nerve

4. How do the branches of affected structure leave from the gland?
   The facial nerve divides into five branches inside the parotid gland. The temporal branch leaves from its base at upper end. The zygomatic, buccal and mandibular branches leave from the anterior margin. The cervical branch leaves from its apex at the lower end.

5. What is the reason for the inability to close the right eye and inability to blow the cheek?
   Inability to close the eye is due to paralysis or weakness of orbicularis oculi. Inability to blow the cheek is due to weakness or paralysis of buccinator muscle.

6. Write briefly on the duct of this gland.
   The parotid duct (Stensen’s duct) collects serous secretions of the gland. It is about 5 cm long. It leaves the gland from its anterior margin and travels forward on the masseter muscle. Its superior relations are, upper buccal branch of facial nerve, transverse facial artery and accessory parotid gland. At the anterior margin of the masseter, the duct turns inwards to pierce in succession the buccal pad of fat, buccopharyngeal fascia, buccinator and buccal mucosa. It opens in the vestibule of the oral cavity opposite the crown of upper second molar tooth.

7. What is the clinical importance of fascial capsule of this gland?
   The fascial capsule of the parotid gland is derived from the deep fascia of neck. It is called parotido-masseteric fascia. It is very tough and unyielding. Therefore, if there is parotid swelling it is intensely painful (the tough fascia does not allow the swelling to expand). The parotid abscess unlike abscess in other locations does not show induration and fluctuation.

CASE 8

A 24-year-old woman survived the knife attack by robbers but was injured in the neck. She was rushed to the hospital because of profuse bleeding from the neck injury. On examination, it was found that there was no deep cut in the neck. She was breathless, cyanotic and had low blood
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pressure. On auscultation, it was observed that churning and splashing sounds masked the normal heart sounds. The physician suspected venous air embolism.

1. **Name the vein that is injured and exposed to atmospheric air.**
   
The external jugular vein is injured.

2. **What is the anatomical reason for the inability of the vein to contract after injury?**
   
The external jugular vein is injured at the point, where it pierces the investing layer of deep cervical fascia. The wall of the vein is adherent to the fascia hence its lumen remains patent. The negative intrathoracic pressure sucks the atmospheric air into the vein.

3. **What is the cause of churning and splashing sound in the heart?**

   The atmospheric air that enters the external jugular vein forms venous air embolus, which travels via the subclavian vein, brachiocephalic vein and superior vena cava to the right atrium and then to right ventricle. The mixing of blood and air in right side of heart produces churning and splashing sounds.

4. **What is the fatal complication of this condition?**

   The air embolus enters the pulmonary trunk and reaches the lungs causing fatal pulmonary embolism.

5. **Which immediate first aid measure can prevent entry of air into this vein?**

   Application of firm pressure (compression) on the bleeding point until the suturing is done.

6. **Describe the formation, course and termination of this vein.**

   The external jugular vein is formed by the union of posterior division of retromandibular vein and posterior auricular vein just below the parotid gland. The vein courses downwards on the anterior surface of sternomastoid muscle being covered with skin, superficial fascia and platysma. It pierces the investing layer of deep cervical fascia in the posterior triangle at the posterior border of sternomastoid 2 to 3 cm above clavicle. Having entered the subclavian triangle, it crosses the brachial plexus and third part of subclavian artery to join the subclavian vein behind the middle of the clavicle.

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**CASE 9**

A 76-year-old woman noticed a hard painless lump in the right side of her neck. On examination, the lump was found to be an enlarged lymph node in the posterior triangle. An open excision biopsy was performed. Two days following the procedure, the patient complained of difficulty in combing her hair with right hand. The surgeon confirmed the loss of hyperabduction on right side. However, the surgeon noted that she was able to turn her face to the left side.

**Questions and Solutions**

1. **Which nerve in the roof of posterior triangle is injured during the biopsy procedure?**

   Spinal accessory nerve on right side.

2. **Name the muscle that is paralyzed.**

   Trapezius of right side

3. **Name the muscle that is supplied by the same nerve but spared in this patient.**

   Sternomastoid right side

4. **What is the anatomical basis of asking the patient to turn the face to the left side?**

   This is to test the function of right sternomastoid muscle.

5. **Name the boundaries and subdivisions of posterior triangle of neck.**

   i. Anterior boundary is formed by posterior margin of sternomastoid muscle.
   ii. Posterior boundary is formed by anterior margin of trapezius muscle.
   iii. The base is formed by the middle-third of the clavicle.
   iv. The apex is located superior nuchal line of the occipital bone between the attachments of the trapezius and sternomastoid.
   v. Fascial roof is the investing layer of deep fascia of neck covered by superficial fascia and skin.
   vi. The muscular floor is covered by fascial carpet of prevertebral fascia. The muscles in the floor from below upwards are scalenus medius, levator scapulae, semispinalis capitis and splenius capitis.

**Subdivisions**

The inferior belly of omohyoid muscle divides the posterior triangle into:
i. An upper occipital triangle.

ii. A lower subclavian or supraclavicular triangle (omoclavicular triangle).

6. Give the importance of lower subdivision of posterior triangle in clinical examination of the patient.

The subclavian triangle is important in the clinical examination of a patient. This region is inspected from the front but palpated from behind.

i. The trunks of the brachial plexus can be felt on deep palpation behind and just above the middle third of the clavicle.

ii. For brachial plexus block the anesthetic agent is injected around the trunks just above the midpoint of clavicle.

iii. Injuries to the trunks of the brachial plexus are commonly due to trauma at birth or due to motorcycle accidents or stab wounds. Injury to the upper trunk causes Erb’s palsy and injury to the lower trunk results in Klumpke’s palsy.

iv. The supraclavicular lymph nodes are palpated at this site. The left supraclavicular nodes are enlarged in cancer of the stomach, colon or testis. These nodes are called Virchow’s nodes. If the left supraclavicular lymph nodes are enlarged in cancer of stomach it is called Troisier’s sign.

v. The subclavian vein at this site is often used for central venous access. Through the central venous catheter it is safe to give powerful drugs and it can also be used for long-term feeding in a serious patient (in cases where all the peripheral veins are thrombosed or collapsed).

vi. The pulsations of the subclavian artery can be felt on deep pressure behind the middle-third of the clavicle. The bleeding due to severe lacerations of the brachial or axillary artery can be controlled by compressing the third part of the subclavian artery downward and backward against upper surface of the first rib.

CASE 10

A 45-year-old man living in high altitude in Himalayas developed a pulsatile swelling in the left side of the neck. He sought medical assistance due to frequent episodes of fainting. Examination revealed that the swelling was located in the carotid triangle and it moved transversely but not vertically. A provisional diagnosis of potato tumor of neck was made.

Questions and Answers

1. Give the boundaries and contents of carotid triangle.

The carotid triangle presents three boundaries (anterosuperior, anteroinferior and posterior), floor and roof.

The anterosuperior boundary is formed by posterior belly of digastric and the stylohyoid muscles.

The anteroinferior boundary is formed by superior belly of omohyoid muscle.

The posterior boundary is formed by anterior margin of the sternomastoid muscle.

The floor consists of parts of four muscles, hyoglossus and thyrohyoid anteriorly and middle and inferior constrictors of the pharynx posteriorly.

The roof consists of skin, superficial fascia with platysma and the investing layer of deep fascia of neck.

Contents

i. The bifurcation of common carotid artery into internal and external carotid arteries takes place at the level of upper margin of thyroid cartilage. The internal carotid, external carotid and common carotid arteries are inside the carotid sheath along with internal jugular vein and vagus nerve. The external carotid artery gives five of its branches in the triangle. The carotid sinus is a localized dilatation at the bifurcation of common carotid artery. The carotid body is small reddish structure containing glomus cells and ganglion cells behind the bifurcation.

ii. The vagus nerve passes vertically downward in posterior position inside the carotid sheath. It gives superior laryngeal nerve, which divides into internal and external laryngeal nerves here.

iii. The spinal accessory nerve crosses the superolateral angle of the carotid triangle to enter the sternomastoid muscle.

iv. The hypoglossal nerve enters the carotid triangle deep to the posterior belly of digastric between the internal jugular vein and internal carotid artery. It crosses superficial to internal carotid artery, external carotid artery and the loop of the lingual artery from lateral to medial side. Here, the nerve gives off superior root of ansa cervicalis and a branch to thyrohyoid muscle. The ansa cervicalis is formed in the anterior wall of the carotid sheath.

v. The cervical sympathetic chain extends vertically posterior to the carotid sheath in front of the prevertebral fascia.

vi. The jugulo-digastric and jugulo-omohyoid lymph nodes are located in the vicinity of the internal jugular vein.
2. Name the structure in carotid triangle that causes potato tumor of neck in people exposed to hypoxic atmosphere (high altitudes).
   Carotid body

3. What is the location of this structure?
   The carotid body is located posterior to bifurcation of common carotid artery.

4. What is the dilatation of common carotid artery at its bifurcation called?
   Carotid Sinus

5. What are the effects of compression of this dilated part by the potato tumor?
   It precipitates an attack of carotid sinus syndrome. The cardinal signs of this syndrome are fainting, hypotension and bradycardia.

6. Give the main innervation of this dilated part.
   The carotid sinus is innervated by sinus branch of glossopharyngeal nerve.

CASE 11
A 52-year-old man with history of chronic smoking came to the ENT consultant with complaints of recurrent sinusitis, weight loss and severe pain in upper teeth and right cheek. On examination, it was noted that his right cheek was swollen and there was proptosis of right eye. CT scan confirmed presence of growth in the paranasal air sinus.

Questions and Solutions

1. Name the sinus involved.
   Maxillary air sinus

2. Name the structures involved if the growth in this sinus spreads anteriorly, medially, posteriorly and upwards.
   If the growth spreads anteriorly it invades the soft tissues of the cheek (causing swelling of cheek).
   If it spreads medially it invades the nasal cavity.
   Posterior spread leads to infiltration into infratemporal and sphenopalatine fossae.
   Upward spread leads to infiltration into the orbit.

3. Describe the opening of this air sinus into nasal cavity.
   The maxillary sinus opens hiatus semilunaris of the middle meatus of the nasal cavity by an opening that is located high up on its medial wall. The high location of the opening does not favor natural drainage. Moreover, the position of the opening in hiatus semilunaris compared to opening of the frontal sinus favors drainage from the frontal to the maxillary sinus. This is the reason maxillary sinus is described as reservoir of frontal sinus.

4. Which route is used for antral puncture for drainage of pus from this sinus?
   Accumulation of pus in the maxillary sinus is drained by a method called antral puncture, which is done through the inferior meatus of nasal cavity.

5. Name the nerves closely related to this sinus.
   The infraorbital nerve travels in the roof. The anterior superior alveolar nerve runs in a canal in the anterior wall. The posterior superior alveolar nerve is related to posterior wall. The pain due to sinusitis may be referred to the upper teeth and face.

CASE 12
A man presented in the hospital with painful vesicles in the area of distribution of ophthalmic division of the trigeminal nerve due to herpes zoster (shingles).

Questions and Solutions

1. Which neurons are affected in herpes zoster of ophthalmic nerve?
   Pseudounipolar neurons in the trigeminal ganglion are involved in herpes zoster.

2. Where does the ophthalmic nerve begin?
   The ophthalmic nerve begins in the trigeminal ganglion in the middle cranial fossa.

3. Where does the ophthalmic nerve divide? Name its terminal branches.
   The ophthalmic nerve courses in the lateral wall of the cavernous sinus, where it divides into nasociliary, frontal and lacrimal nerves.
4. **How do the terminal branches leave the cranium?**
   The lacrimal, frontal and nasociliary leave the cranium to enter the orbit via superior orbital fissure.

5. **Which of the terminal branches crosses the optic nerve in the orbit?**
   The nasociliary nerve crosses the optic nerve from lateral to medial inside the orbit.

6. **Describe the course and distribution of this terminal branch.**
   Refer to chapter 46.

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**CASE 13**

A 10-year-old boy came to the hospital with a history of recurrent attacks of sore throat. On inspection of the oropharynx, the palatine tonsils almost touched each other in the midline.

**Questions and Solutions**

1. **What is crypta magna?**
   A deep tonsillar crypt located near the upper pole is known as crypta magna or intratonsillar cleft.

2. **Give its developmental significance?**
   It is the remnant of second pharyngeal pouch.

3. **Name the main structures forming tonsillar bed.**
   The pharyngobasilar fascia, superior constrictor muscle and the buccopharyngeal fascia form the bed of the tonsil.

4. **Describe the arterial supply of tonsil.**
   The tonsil is richly supplied with following arteries:
   i. Dorsal lingual branch of lingual artery.
   ii. Ascending palatine branch of facial artery.
   iii. Descending palatine branch of ascending pharyngeal artery.
   iv. Tonsillar branch of facial artery (main tonsillar artery).
   v. Greater palatine branch of maxillary artery.

5. **Which nerve is in danger during tonsillectomy?**
   The glossoopharyngeal nerve is in danger.

6. **Which is the tonsillar lymph node?**
   The jugulo-digastric lymph nodes are called tonsillar nodes.

7. **Name the components of Waldeyer’s ring.**
   Lingual tonsils, palatine tonsils, tubal tonsils and pharyngeal tonsil are the components of Waldeyer’s ring.

8. **Name the epithelium lining the medial surface of the tonsil. Give reason for its pitting appearance.**
   The medial or pharyngeal surface of tonsil is lined by stratified squamous nonkeratinized epithelium.
   The epithelium dips into the substance of the tonsil as tonsillar crypts. The openings of about 15 to 20 crypts on the medial surface give it a pitted appearance.

9. **Write briefly on peritonsillar space.**
   The submucosa in relation to the lateral surface of tonsil is known as peritonsillar space. It separates the tonsillar hemicapsule from the tonsillar bed. The peritonsillar space is filled with areolar tissue and the paratonsillar vein passes through it. Since the plane of dissection passes through this space during tonsillectomy (surgical removal of tonsil) the paratonsillar vein is likely to injure causing postoperative bleeding. Pus accumulates in this space in chronic tonsillitis resulting in abscess formation, which is known as peritonsillar abscess or quinsy.

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**CASE 14**

A student yawned widely during afternoon anatomy lecture class. To his dismay he could not close his mouth. His jaw was stuck.

**Questions and Solutions**

1. **Name the joint that is dislocated.**
   Temporomandibular joint

2. **Give the type of this joint and name the bones taking part in it.**
   It is a bicondylar type of synovial joint. Bones taking part in it are the condyle of the mandible and the mandibular fossa of squamous temporal bone.
3. Which bone is mobile in this articulation?
The mandible is mobile.

4. Name the parts of the articular disc and the muscle attached to the disc.
From anterior to posterior the parts are, anterior extension, anterior thick band, intermediate zone, posterior thick band and bilaminar zone. The lateral pterygoid muscle is inserted into it.

5. Name the movements of the joint and the muscles responsible for them.
Elevation and depression (opening the mouth), protrusion and retraction and chewing or side-to-side movements take place in the joint. For muscles of mastication refer to chapter 45.

6. Which part of the ear is a close relation of this joint?
Bony part of external acoustic meatus is closely related to the joint.

7. How is the anterior dislocation of the TMJ reduced?
The mandible is depressed posteriorly by exerting pressure on lower molar teeth with the help of both thumbs. This will overcome the spasm of pterygoid muscles. Simultaneously, the assistant elevates the chin so that head of mandible is pushed in the fossa.

CASE 15
A 4-year-old child swallowed a shirt button. Since the child began to suffocate she was rushed to the hospital, where on X-ray examination impaction of foreign body in the larynx was confirmed.

Questions and Solutions
1. Which is the narrowest part of laryngeal cavity?
Rima glottis is the narrowest part of laryngeal cavity.

2. Give the attachments and contents of the vocal folds?
The vocal folds extend from the vocal process of arytenoid to inner surface of the middle of thyroid angle. Each fold contains vocal ligament and vocalis muscle.

3. What is the color of the vocal folds?
The color of the vocal folds is pearly white.

4. Name the parts of rima glottis.
The parts of rima glottis are, anterior three-fifth intermembranous and posterior two-fifth intercartilaginous.

5. Which muscle is called the safety muscle of larynx and why?
Posterior cricoarytenoid muscle is the safety muscle of the larynx. It is so called because being the only abductor of the vocal folds it keeps the rima glottis open to allow air to enter the lungs.

6. Enumerate the cartilages of the larynx and describe the leaf-shaped cartilage.
The skeleton of the larynx consists of three unpaired and three paired cartilages. The unpaired cartilages are the epiglottis, the thyroid and the cricoid. The paired cartilages are the arytenoid, cuneiform and the corniculate.

The epiglottis is the leaf shaped cartilage. Histologically, it is elastic type of cartilage. It forms the anterior wall of the laryngeal inlet. Its upper end projects upwards and backwards behind the hyoid bone and the base of tongue. Its upper end is free and broad and lower end is narrow and pointed. It has anterior and posterior surfaces and two lateral margins. The upper part of anterior surface is covered with stratified squamous epithelium and is connected to the tongue by three mucosal folds, the median and lateral glossoepiglottic folds. The lower part of anterior surface, which is devoid of mucosa, is connected to hyoid bone by hyoepiglottic ligament. Below this attachment, the anterior surface is separated from the thyrohyoid membrane by a space called pre-epiglottic space, which is filled with fat. Each lateral margin provides attachment to the aryepiglottic fold in its lower part. The lower end is attached to inner surface of thyroid angle by thyroepiglottic ligament. The mucosa on the posterior surface of epiglottis is of respiratory type in the lower part and stratified squamous type in the upper part and is pitted by small mucous glands. The branches of internal laryngeal nerve pierce the mucosa on this surface.

7. Name the emergency operation for restoring the airway in case of blocked glottis.
Tracheostomy

8. Which anatomical layers in the midline of neck are encountered during surgical approach to trachea?
The skin, superficial fascia with platysma, investing layer of deep cervical fascia, infrahyoid group of strap muscles and pretracheal fascia are encountered in succession from superficial to deep.
1. Which of the following lymph nodes are called Virchow nodes?
   a. Right supraclavicular
   b. Left supraclavicular
   c. Right infraclavicular
   d. Left infraclavicular

2. Which of the following veins pierces the fascial roof of posterior triangle?
   a. External jugular
   b. Subclavian
   c. Transverse cervical
   d. Suprascapular

3. Following are the derivatives of third arch mesoderm except:
   a. Stylopharyngeus
   b. Palatopharyngeus
   c. Lower half of the body of hyoid bone
   d. Greater horn of hyoid bone

4. Superior parathyroid glands develop from
   a. Mesoderm of third arch
   b. Mesoderm of fourth arch
   c. Endoderm of third arch
   d. Endoderm of fourth arch

5. The ligament of Berry fixes the thyroid gland to
   a. Thyroid cartilage
   b. Cricoid cartilage
   c. First tracheal ring
   d. Hyoid bone

6. Hypoglossal nerve crosses the following arteries (in the neck) anteriorly except
   a. Occipital
   b. Lingual
   c. Internal carotid
   d. External carotid

7. The absence of tears is due to lesion in
   a. Trigeminal ganglion
   b. Ciliary ganglion
   c. Sphenopalatine ganglion
   d. Superior cervical sympathetic ganglion

8. The cutaneous branch of posterior primary ramus of C2 is called
   a. Lesser occipital
   b. Greater occipital
   c. Posterior auricular
   d. Great auricular

9. Which structure is located behind the prevertebral layer of cervical fascia?
   a. Sympathetic chain
   b. Carotid sheath
   c. Subclavian artery
   d. Subclavian vein

10. The branches of subclavian artery supply the following structures except
    a. Thyroid gland
    b. Second intercostal space
    c. Submandibular gland
    d. Supraspinatus

11. The arcuate eminence is produced by
    a. Anterior semicircular canal
    b. Posterior semicircular canal
    c. Lateral semicircular canal
    d. Vestibule

12. The following nerve hooks round the spinal accessory nerve
    a. Great auricular
    b. Greater occipital
    c. Lesser occipital
    d. Supracleavicular

13. The philtrum of the upper lip develops from
    a. Lateral nasal process
    b. Globular process
    c. Maxillary process
    d. Fusion of maxillary and globular processes

14. The suprasternal space contains all except
    a. Interclavicular ligament
    b. Jugular arch
    c. Clavicular head of sternomastoid
    d. Lymph node
15. Which one is not the tributary of internal jugular vein?
   a. Inferior petrosal sinus
   b. Superior thyroid vein
   c. Middle thyroid vein
   d. Inferior thyroid vein

16. Which of the following pairs correctly describes the sources of parathormone and calcitonin?
   a. Oxyphil and chief
   b. Parafollicular and follicular
   c. Parafollicular and follicular
   d. Chief and parafollicular

17. The external carotid artery divides at the level of
   a. Superior margin of thyroid cartilage
   b. Angle of mandible
   c. Neck of mandible
   d. Condyle of mandible

18. The safety muscle of the tongue is
   a. Intrinsic
   b. Hyoglossus
   c. Genioglossus
   d. Styloglossus

19. Which of the following laryngeal cartilages is a complete ring?
   a. Epiglottis
   b. Thyroid
   c. Arytenoid
   d. Cricoid

20. The cornea is supplied by following nerves
   a. Supraorbital
   b. Long ciliary
   c. Short ciliary
   d. Infraorbital

21. Which cranial nerve gives sensory supply to middle ear?
   a. Trigeminal
   b. Facial
   c. Glossopharyngeal
   d. Vagus

22. Which of the following form the inner nuclear layer of retina?
   a. Bipolar
   b. Rods and cones
   c. Ganglion
   d. Amacrine

23. The tympanic membrane develops from
   a. Ectoderm and endoderm of first cleft membrane only
   b. Ectoderm and mesoderm of first cleft membrane
   c. All the germ layers of second cleft membrane
   d. All the germ layers of first cleft membrane

24. The paralysis of left genioglossus muscle causes
   a. Deviation of the tongue to the right on protrusion
   b. Total inability to protrude the tongue
   c. Deviation of the tongue to the left on protrusion
   d. Loss of taste sensations on the left half of tongue

25. Piriform fossa is located in
   a. Laryngeal inlet
   b. Laryngopharynx
   c. Oropharynx
   d. Nasopharynx

26. The medial wall of orbit is formed by the following bones except
   a. Lamina papyracea
   b. Lacrimal bone
   c. Lesser wing of sphenoid
   d. Frontal process of maxilla

27. What is true about nasopharynx?
   a. Is always patent
   b. Is located below the soft palate
   c. Choanae open into its posterior wall
   d. Is connected to the inner ear

28. Which latero-medial sequence of the following regions is correct?
   a. Pterygopalatine fossa-sphenopalatine foramen nasal cavity infratemporal fossa
   b. Sphenopalatine foramen-nasal cavity-infratemporal fossa-ptyerygopalatine fossa
   c. Infratemporal fossa-ptyerygopalatine fossa-sphenopalatine foramen-nasal cavity
   d. Sphenopalatine foramen-infratemporal fossa-neral cavity-ptyerygopalatine fossa

29. The circumvallate papillae develop from
   a. Hypobranchial eminence
   b. Lingual swellings
   c. Tuberculum impar
   d. Second arch endoderm

30. The scala media and scala vestibuli are separated by
   a. Basilar membrane
   b. Tectorial membrane
31. Constriction of pupil results due to lesion of all the following except
   a. Ciliary ganglion
   b. Internal carotid nerve
   c. Middle cervical sympathetic ganglion
   d. First white ramus communicans

32. Which of the following nerves is outside the common tendinous ring?
   a. Oculomotor
   b. Trochlear
   c. Abducent
   d. Nasociliary

33. Killian’s dehiscence is seen in posterior wall of
   a. Oropharynx
   b. Larynx
   c. Nasopharynx
   d. Laryngopharynx

34. Medial wall of the middle ear shows
   a. Pyramid
   b. Promontory
   c. Canal for tensor tympani
   d. Canal for chorda tympani

35. A knife wound just behind the sternomastoid and above the clavicle caused numbness of skin over the clavicle and acromion. Which of the following cutaneous nerves is injured?
   a. Lesser occipital
   b. Transverse cervical
   c. Great auricular
   d. SuprACLAVICULAR

36. Which movement is tested for inferior oblique muscle of eyeball?
   a. Depression in laterally rotated eyeball
   b. Elevation in laterally rotated eyeball

37. The triangle in which superior limb of ansa cervicalis originates from hypoglossal nerve is
   a. Carotid
   b. Muscular
   c. Occipital
   d. Digastric

38. A 30-year-old woman came to the doctor with the complaint of severe pain in nose, upper lip and upper teeth, which was triggered by face washing. Which of the following nerves is responsible for the symptoms?
   a. Facial
   b. Maxillary
   c. Mandibular
   d. Great auricular

39. What is the vertebral extent of thyroid gland?
   a. C3 to C6
   b. C4 to C7
   c. C6 to T2
   d. C5 to T1

40. The internal carotid artery pulsations can be felt through
   a. Carotid triangle
   b. Below mastoid process
   c. Tonsillar fossa
   d. Behind last molar tooth

**KEY TO MCQs**
1-b, 2-a, 3-b, 4-d, 5-b, 6-a, 7-c, 8-b, 9-c, 10-c, 11-d, 12-c, 13-b, 14-c, 15-d, 16-d, 17-c 18-c, 19-d, 20-b, 21-c, 22-a, 23-d, 24-c, 25-b, 26-c, 27-a, 28-c, 29-a, 30-c, 31-a, 32-b, 33-d, 34-b, 35-d, 36-c, 37-a, 38-b, 39-d, 40-c.
VERTEBRAL COLUMN AND SPINAL CORD, CRANIAL CAVITY AND BRAIN
DEEP MUSCLES OR INTRINSIC MUSCLES

The deep or intrinsic muscles of the back are a complex group of muscles extending from the sacrum to the skull. They are collectively called the postvertebral muscles and are very well developed in human beings. In an upright position, the weight falls in front of the vertebral column because the line of gravity passes in front of it. Therefore, the postural tone of the postvertebral muscles is responsible for maintaining the normal curvatures of the vertebral column.

Nerve Supply
All deep muscles of back receive nerve supply from the dorsal rami of the spinal nerves.

Classification of Postvertebral Muscles
From superficial to deeper level the muscles are classified in four groups:
1. Splenius muscle is the one in which the muscle fibers are directed upward and laterally.
2. Erector spinae group of muscles are those in which the muscle fibers run vertically.
3. Transversospinalis group is the one in which muscle fibers run upward and medially.
4. Interspinales and intertransversarii are short segmental and the deepest muscles.

Splenius Muscles
The word splenius means a bandage. This muscle wraps round the other deep muscles of the neck like a bandage. The splenius consists of splenius capitis and splenius cervicis muscles.

1. The splenius capitis takes origin from the lower half of the ligamentum nuchae and spines of the seventh cervical and upper three to four thoracic vertebrae. It is inserted into the mastoid process and the lateral third of superior nuchal line. (Note: The splenius capitis appears in the upper part of the floor of the posterior triangle of the neck).
2. The splenius cervicis takes origin from the spines of third to sixth thoracic vertebrae and is inserted into the posterior tubercles of the transverse processes of the upper two to three cervical vertebrae.

Actions
Acting together the muscles of the two sides draw the head directly backward. Acting alone the muscle turns the head laterally (lateral flexion).

Erector Spinae or Sacrospinalis
This is a very long and complex muscle, composed of as many as nine muscles. It extends from the sacrum to the cranium. The posterior layer of thoracolumbar fascia covers its thoracolumbar part.

Origin
The origin of erector spinae is U-shaped. The lateral limb of the U is attached to the posterior segment of iliac crest and lateral sacral crest. Its medial limb is attached to the median crest of sacrum, lumbar and lower thoracic spines and their supraspinous ligaments.
In the lumbar region the muscle expands to form a thick fleshy mass, which can be felt in the living. This fleshy mass divides into three columns in the upper lumbar region. Each column is composed of three muscles. The following columns are arranged from lateral to medial side:

i. **Iliocostocervicalis** consists of iliocostalis lumborum, iliocostalis thoracis and iliocostalis cervicis.

ii. **Longissimus** consists of longissimus thoracis, longissimus cervicis and longissimus capitis.

iii. **Spinalis** consists of spinalis thoracis, spinalis cervicis and spinalis capitis.

These various muscles are inserted into the spines and transverse processes of thoracic and cervical vertebrae, lower ribs and in the cranium. The longissimus column alone is attached to the skull. The longissimus capitis is attached to the mastoid process.

**Actions**

i. When the right and left muscles act together they produce extension of vertebral column from the forward flexed position.

ii. Acting singly the muscles cause lateral flexion of the trunk and rotation to the same side.

**Testing Function of Erector Spinae**

The power of erector spinae is tested by asking the patient to lift shoulders and head against resistance while lying in prone position.

**Transversospinalis**

The muscles in this group lie deeper to the erector spinae. Their fibers run medially and upward from the transverse processes to the adjacent spinous processes. They help in stabilizing the vertebrae during movements. This group consists of three subgroups. The semispinalis subgroup consists of semispinalis thoracis, semispinalis cervicis and semispinalis capitis. Besides this, there are multifidus and rotators. They are supplied by dorsal rami of cervical and spinal nerves. Collectively, they are the postural muscles. But they are extensors, lateral flexors and rotators of the head and vertebral column.

**Semispinalis Capitis**

The semispinalis capitis is situated in the back of the neck under cover of the splenius capitis. It may appear in the floor of the posterior triangle of the neck and it forms the roof of the suboccipital triangle at the back of the neck. The muscle takes origin from the tips of transverse processes of the upper six thoracic vertebrae and from the articular processes of the fourth, fifth and sixth cervical vertebrae. It travels upwards for insertion into medial part of the area between the superior and inferior nuchal lines on the occipital bone. It is supplied by suboccipital nerve.

**Suboccipital Triangle**

The suboccipital triangle is situated in the back of the neck under cover of semispinalis capitis.

**Boundaries (Fig. 53.1)**

The suboccipital triangle has superomedial, superolateral (lateral) and inferomedial (inferior) boundaries.

i. The superomedial boundary is formed by rectus capitis posterior major and minor muscles.

ii. The superolateral boundary is formed by obliquus capitis superior muscle.

iii. The inferomedial boundary is formed by obliquus capitis inferior muscle.

iv. The roof is formed by semispinalis capitis muscle. The greater occipital nerve winds round the obliquus capitis inferior and pierces the muscular roof to enter the posterior quadrant of scalp. The occipital artery crosses the roof of the triangle to reach the posterior quadrant of the scalp.

v. The floor is composed of posterior atlanto-occipital membrane and posterior arch of atlas.

**Contents**

i. Vertebral artery

ii. Suboccipital plexus of veins

iii. Dorsal ramus of first cervical nerve (suboccipital nerve).

**Suboccipital Muscles**

i. The rectus capitis posterior major muscle originates from the spine of axis by a pointed tendon and is inserted into the squamous part of occipital bone below the lateral part of the inferior nuchal line.

ii. The rectus capitis posterior minor muscle originates by a small pointed tendon from the tubercle on the posterior arch of atlas and is inserted into the medial part of squamous part of occipital bone below the inferior nuchal line.

**Clinical insight ...**

The erector spinae is an important postural muscle. If it becomes weak in old age or in persons, who do not take adequate exercise, the vertebral column tends to bend forward, which may predispose to disc prolapse. Exercise and brisk walking help in maintaining the tone of erector spinae.
iii. The obliquus capitis superior muscle takes origin by tendinous fibers from the superior surface of the transverse process of atlas and is inserted into the lateral part of squamous part of occipital bone between the superior and inferior nuchal lines.

iv. The obliquus capitis inferior muscle takes origin from the spine of the axis and is inserted into the posterior aspect of the transverse process of atlas.

**Actions**

The rectus capitis superior major and minor muscles are the extensors of the head at the atlanto-occipital joints. The oblique muscles rotate the head and the atlas on the axis at atlantoaxial joints.

**Clinical insight ...**

**Cisternal Puncture**

This is a procedure to approach the cisterna magna in the posterior cranial fossa through suboccipital triangle and the foramen magnum for obtaining a CSF sample.

**Vertebral Artery (Fig. 53.2)**

The vertebral artery is a branch of the first part of the subclavian artery at the root of the neck. The vertebral artery has a very long course. It is divided into following four parts:
1. The first part extends from its origin to the foramen transversarium of sixth cervical vertebra.
2. The second part is located within the foramina in the transverse processes of upper six cervical vertebrae.
3. The third part extends from the foramen transversarium of atlas to the foramen magnum. It is located in the suboccipital triangle on the superior surface of the posterior arch of atlas.
4. The fourth part is its intracranial part. The termination of the vertebral arteries is unique in that the arteries of the two sides unite at the pontomedullary junction to form the basilar artery in the midline.

Relations of First Part
The first part lies in the scalenovertebral triangle (Fig. 44.10).
   i. Anteriorly, it is related to the vertebral vein and the inferior thyroid artery. It is crossed by the thoracic duct on the left side below the loop of the inferior thyroid artery.
   ii. Posteriorly, it is related to the ventral rami of seventh and eighth cervical nerves. The stellate ganglion is partly behind the vertebral artery.

Relations of Second Part
i. The second part is related posteriorly to cervical ventral rami in the intervals between the transverse processes of the adjoining vertebrae and is surrounded by the vertebral venous plexus and the sympathetic fibers (derived from the stellate ganglion).
   ii. At the foramen transversarium of the axis, the vertebral artery takes a wide curve to turn laterally and upward to reach the foramen transversarium of atlas. This wide curve (loop) is necessary so that the artery is not compressed every time the head is laterally flexed and it also helps in reducing the intracranial arterial pressure.

Relations of Third Part
The third part emerges from the foramen transversarium of atlas and turns medially to enter the suboccipital triangle (Fig. 53.1), where it grooves the superior surface of the posterior arch of the atlas and is closely related to the dorsal ramus of the first cervical nerve (suboccipital nerve). A rich venous plexus surrounds the vertebral artery in the suboccipital triangle. It leaves the triangle by passing medially through the gap between the lateral margin of posterior atlanto-occipital membrane and the lateral mass of atlas.

Relations of Fourth Part
The fourth part pierces the dura mater and enters the foramen magnum. In the posterior cranial fossa the vertebral arteries course upward on the anterior aspect of the medulla oblongata. The right and left vertebral arteries unite to form a single basilar artery in the midline at the pontomedullary junction.

Extracranial Branches (Fig. 53.2)
   i. The spinal branches arise from the second and third parts and enter the intervertebral foramina to take part in the supply the contents of the vertebral canal. The radicular branches of the spinal arteries supply the nerve roots (refer to chapter 55).
   ii. The muscular branches supply the deep muscles in the upper part of the neck and form rich anastomoses with adjacent arteries.

Intracranial Branches
   i. Posterior spinal
   ii. Anterior spinal
   iii. Medullary branches
   iv. Posterior inferior cerebellar artery (PICA)

Vertebral Vein
The venous plexus surrounding the vertebral artery in the suboccipital triangle accompanies the second part of the vertebral artery and enters the scalenovertebral triangle to become the vertebral vein, which opens into the brachiocephalic vein of its side.

Vertebral Angiography (Fig. 53.3)
It is a radiological procedure to visualize the vertebral artery and its branches.

![Fig. 53.3: Digital subtraction angiogram (DSA) of vertebral arteries](image-url)
Subclavian Steal Syndrome (Fig. 53.4)

If the subclavian artery is narrowed at its origin (from the arch of aorta or from the brachiocephalic trunk), the arterial supply of upper limb of that side is reduced. The narrowed subclavian artery is filled with blood in the most unusual way. The blood in the vertebral artery of the normal (opposite) side is shunted (at the point of the union of the two vertebral arteries inside the cranium) into the vertebral artery of the affected side. There is reversal of blood flow in the vertebral artery of the affected side so that it is able to fill the subclavian artery beyond the stenosis. This is likely to result in shortage of blood to the brainstem especially during times of increased demand of blood in the upper limb (e.g. exercise) of the affected side. The syndrome presents as a combination of symptoms and signs due to ischemia of upper limb (pain, tingling, low blood pressure and weaker pulse) of normal side with symptoms of medullary insufficiency such as giddiness and fainting. Stenosis of the subclavian artery can be confirmed by subclavian angiography.

Developmental Sources of Vertebral Artery

i. The first part of vertebral artery develops from the dorsal branch of the seventh intersegmental artery.

ii. The second part from the postcostal anastomosis.

iii. The third part develops from the spinal branch of the first cervical intersegmental artery.

iv. The fourth part develops from the intracranial prolongation of the preneural anastomosis.

Fig. 53.4: Subclavian steal syndrome. As a result of narrowing (stenosis) of right subclavian artery proximal to origin of vertebral artery, the blood is siphoned from left to right vertebral artery across the midline at the site of their union. There is reversal of blood flow in right vertebral artery.
The vertebral column (Fig. 54.1) is also described by the terms such as the spine or spinal column or backbone. It forms the central axis of the body. It consists of a number of vertebrae joined to each other by a series of articulations. The vertebral column is a flexible but strong pillar that supports the skull, trunk, and limbs. It transmits body weight to the lower extremity through the sacroiliac joints. It provides a large site for attachment of the muscles of posture and locomotion. The bodies of the vertebrae are active sites of hemopoiesis throughout life. The vertebral column encloses a canal, in which the spinal meninges, spinal cord and the cauda equina are protected.

**Length of Vertebral Column**

The average length of the vertebral column in adult male is 70 cm and in adult female is 60 cm. The vertebral bodies contribute the four-fifths and the intervertebral discs contribute one-fifth of the total length of the column.

**Number of Vertebrae**

i. Seven cervical
ii. Twelve thoracic
iii. Five lumbar
iv. Sacrum is a single bone composed of five fused sacral vertebrae
v. Coccyx is a single bone composed of four fused coccygeal vertebrae.

**Parts of Vertebra**

The vertebra consists of the centrum or body anteriorly and the vertebral arch posteriorly. These two parts enclose a cavity called vertebral foramen. The bodies of adjacent movable vertebrae articulate with each other by intervertebral discs. The first cervical vertebra (atlas) has no body hence, there is no disc between the atlas and the second
Vertebral Column

Chapter

The vertebral arch consists of two pedicles, two laminae which bear seven processes, namely, two pairs of articular processes (zygapophyses), one pair of transverse processes and a spinous process. The pedicles connect the body to the laminae and bear the superior and inferior vertebral notches.

**Embryologic insight ...**

**Development Sources of Vertebra**

- **i.** The mesenchyme of the bilateral sclerotome (derived from somites) condenses around the notochord (Fig. 54.2)
- **ii.** The centrum of vertebra develops from the fusion of cranial half of cranial sclerotome and the cranial half of the succeeding sclerotome.
- **iii.** The anterior sclerotome forms the centrum whereas the posterior sclerotome forms the vertebral arch.

**Costal Elements**

The costal element is the anterior part of the vertebral arch of the developing vertebra. It may form a rib or it may remain incorporated inside the transverse process of the definitive vertebra. The true transverse process is the posterior part of the vertebral arch.

**Cervical Vertebra**

The costal element forms major part of the transverse process (anterior root, anterior tubercle, costotransverse bar and posterior tubercle).

**Cervical Rib**

The costal element of the seventh cervical vertebra enlarges to form a cervical rib, which may be complete or incomplete or merely represented by a fibrous cord (Fig. 24.2).

**Thoracic Vertebra**

The costal element forms the rib.

**Lumbar Vertebra**

The costal element becomes the definitive transverse process.

**Sacrum and Coccyx**

- **i.** The costal elements of the upper two to three pieces form the anterior part of the lateral mass of the sacrum.
- **ii.** In the coccygeal vertebrae, the costal elements are absent.

**Congenital Anomalies of Vertebrae**

- **i.** Spina bifida results from the failure of fusion of the right and left centers of ossification of the vertebral arches. If it is not associated with spinal cord defects it is called spina bifida occulta. Occasionally, the defect in the vertebral arches is so large that the spinal meninges only or spinal meninges with spinal cord may protrude through it. This causes a midline swelling in the back (Fig. 54.3). If the meninges protrude it is called meningocele. If the meninges and spinal cord protrude then it is known as meningocelemyelocele.
- **ii.** Hemivertebra is due to defective fusion of anterior sclerotome.
- **iii.** Spondylolisthesis is the anterior displacement of the vertebral column, usually at the lumbosacral articulation. The fifth lumbar vertebra is in two pieces due to the defect in its pedicle. This defect may result in stretching of S1 nerve roots causing symptoms like backache and root pain.
- **iv.** Sacrococcygeal teratoma (Fig. 54.4) is a congenital condition in which the fetus is born with a swelling from the coccygeal vertebrae. This tumor is composed of tissues from all the germ layers. It originates from caudal end of primitive streak.
Vertebral Column and Spinal Cord, Cranial Cavity and Brain

Section 5

Intervertebral Joints
i. The joints between the bodies of adjacent vertebrae (intervertebral joints) are the secondary cartilaginous joints or synphyses.
ii. The zygapophyseal or facet joints between the articular processes of adjacent vertebrae are synovial joints.
iii. The laminae of adjacent vertebrae are connected by ligamenta flava. Hence, the joints between laminae are called vertebral syndesmoses.

Boundaries of Intervertebral Foramina
i. Superiorly by the inferior vertebral notch of the vertebra above.
ii. Inferiorly by the superior vertebral notch of the vertebra below.
iii. Anteriorly by the intervertebral disc and adjacent vertebral bodies.
iv. Posteriorly by the capsule of the facet joint.

Contents of Intervertebral Foramen
i. Spinal nerve and its recurrent meningeal branch.
ii. Spinal branches of regional arteries.
iii. Intervertebral veins.
In narrowing or stenosis of the foramen, the spinal nerve is compressed or irritated producing shooting pain. A few causes of stenosis are disc prolapse, osteoarthritis of facet joints and osteophytes (bony spurs).

Vertebral Canal
The body and the vertebral arch together enclose the vertebral foramen. In the articulated column, the vertebral foramina of all the vertebrae make up the vertebral canal.

Extent
Superiorly, the cervical vertebral canal is continuous with the posterior cranial fossa through the foramen magnum. Inferiorly, the lumbar vertebral canal is continuous with sacral canal. The caudal opening of the sacral canal is the sacral hiatus.

Shape
In the cervical and lumbar regions, which exhibit free mobility the vertebral canal is large and triangular. In the thoracic region, where the movement is restricted it is small and circular.

Contents
The spinal cord and its three meninges lie in the vertebral canal up to the level of the lower border of L1 vertebra. Below this level, the lumbar and sacral vertebral canal contain the cauda equina, arachnoid mater and dura mater. The arachnoid mater and the dura mater cover the cauda equina up to the lower border of sacral second vertebra, beyond which the sacral canal contains the filum terminale, fifth sacral and coccygeal nerve roots, which exit via the sacral hiatus.

Curvatures of Vertebral Column (Fig. 54.5)
In the intrauterine life, the vertebral column has forward concavity because the fetus lies in the position of universal flexion. After birth, the vertebral column shows two types of curvatures.

Variations
i. The sacralization of the fifth lumbar vertebra is the condition in which the fifth lumbar vertebra fuses with the sacrum reducing the number of movable vertebrae to twenty-three.
ii. The lumbarization of first sacral vertebra is a condition in which the first sacral vertebra separates from the sacrum and assumes the features of the lumbar vertebra. In such cases, the number of movable vertebrae is increased to twenty-five.
iii. The occipitalization of atlas is a condition in which atlas is fused with occipital bone.
ii. The secondary curvatures with forward convexity develop in cervical and lumbar regions. The cervical curvature develops when the child begins to hold the head upright by about third months after birth. The lumbar curvature develops when the child begins to sit by about six or seven months old and is more marked when the child begins to walk.

Clinical insight ...

Abnormal Curvatures

i. Kyphosis (hunchback) means anterior concavity of the vertebral column. In the thoracic region, the concavity is exaggerated while in cervical and lumbar regions the convexity is reduced. The osteoporosis of the vertebrae and degeneration of the discs in old age predispose to kyphosis.

ii. Lordosis (swayback) means the posterior concavity of the vertebral column. The normal lumbar lordosis is exaggerated in pregnancy.

iii. Scoliosis means the lateral curvature of the vertebral column as a result of maldevelopment of a vertebra, for example, hemivertebra.

Ligaments of Vertebral Column (Fig. 54.6)

i. The anterior longitudinal ligament is outside the vertebral canal. It is attached to the anterior surfaces of the vertebral bodies and the intervertebral discs. It extends from the sacrum to the tubercle of atlas, from where it continues upwards as anterior atlanto-occipital membrane.

ii. The posterior longitudinal ligament is located inside the vertebral canal. It is attached to the posterior surfaces of the discs and adjacent margins of the vertebral bodies. It is not attached to the posterior surfaces of the bodies because the basivertebral veins emerge from the vertebral bodies on this aspect to empty in to the internal vertebral venous plexus. This ligament extends from the sacrum to the lower margin of the posterior surface of the body of axis. It is continued upwards as the membrana tectoria, which passes through the foramen magnum to attach to the basilar part of occipital bone near the margin of the foramen magnum.

iii. The ligamentum flavum derives the name from its yellow color (flavum means yellow). The ligamenta flava consisting of yellow elastic tissue connects the adjacent laminae to each other. The elasticity of the ligamenta flava restores the vertebral column to erect posture after flexion. These ligaments are described as muscle spacers. The uppermost ligamentum flavum is attached to the posterior arch of atlas from where it is continued upwards as the posterior atlanto-occipital membrane to be attached to the posterior margin of foramen magnum.

iv. The interspinous ligaments connect the adjacent spines to each other.

v. The supraspinous ligaments connect the tips of the adjacent spines to each other.
vi. The ligamentum nuchae is composed of greatly thickened interspinous and supraspinous ligaments of cervical part of vertebral column. The upper attachment of the ligamentum nuchae is to the external occipital crest.

**Intervertebral Discs**
The intervertebral discs are the main connecting bonds between the bodies of adjacent vertebrae. The discs are thickest and wedge shaped in the cervical and lumbar regions, where the vertebral column is highly mobile.

**Parts of Disc (Figs 54.7A and B)**
The disc is composed of two parts.

i. The inner part is called nucleus pulposus. It is the remnant of notochord. The nucleus pulposus is a mass of gelatinous material containing mucopolysaccharides with large amount of water. It is normally under pressure. The semifluid nature of the nucleus pulposus allows the disc to change shape and permit movement of one vertebra over the other.

ii. The outer part is called annulus fibrosus. It is a fibrocartilage. It forms a tough casing for the nucleus pulposus.

**Diurnal Variation**
Diurnal variation means changes in the disc during the course of a day.

i. During daytime, when the individual is up and about the water content of the disc gradually reduces, thus reducing the height of the individual by half to 1 cm.

ii. During night (resting time) the loss is made up by reabsorption of water.

Therefore, the height is highest in early morning and lowest at the end of the day (before retiring to bed).

**Age Changes**
In old age, the nucleus pulposus is gradually invaded by fibrocartilage. This reduces the elasticity of the vertebral column. There is degeneration of the collagen fibers of annulus fibrosus. Hence, the discs become thin and less elastic. The shrinking height and kyphotic deformity in old age are due to atrophy of discs and osteoporosis of vertebrae.

**Embryologic insight ...**
The nucleus pulposus develops from the notochord and the annulus fibrosus develops from the sclerotome of the somite.

**Clinical insight ...**

**Disc Prolapse (Figs 54.7 and 54.8)**
The disc prolapse is also known as herniation of disc or slipped disc. This is very common between L4 and L5 vertebrae. The nucleus pulposus protrudes through the crack in the annulus fibrosus. The weakest part of the annulus lies just lateral to the posterior longitudinal ligament on either side. This part of the annulus is thin due to lack of support by strong ligaments. Hence, the annulus ruptures at this point as a result of exertion like lifting heavy weight. The nucleus pulposus herniates in posterolateral direction and narrows the intervertebral foramen compressing the fifth lumbar spinal nerve. The patient experiences severe back pain and sciatica. The pain increases on coughing or sneezing. The movements of vertebral column are restricted due to muscle spasm. This may cause diminished sensation in L5 dermatome and weakness of extensor hallucis longus muscle. MRI scanning demonstrates the disc and its prolapse.

**Craniovertebral Joints**
These are the joints between the atlas, axis and occipital bone. The two atlanto-occipital joints are the uppermost joints of the vertebral column. There are three joints between the atlas and axis, a median atlantoaxial joint and lateral atlantoaxial joints. The atlanto-occipital joints permit movements of flexion and extension of head around a transverse axis while the atlantoaxial joints permit rotation of the head around a vertical axis. Thus, we say “yes” at the atlanto-occipital joints and “no” at atlantoaxial joints. These movements of the head are adapted for eye-head co-ordination.

i. In the atlanto-occipital joint the kidney shaped large superior articular facets on the atlas articulate with the similar facets on the occipital condyles. The anterior
and posterior atlanto-occipital membranes strengthen the fibrous capsule of the joint. The right and left joints act as one unit in producing the flexion and extension of head.

ii. The atlantoaxial joints consist of three synovial articulations. The lateral joints are between the inferior articular processes of the atlas and the superior articular processes of the axis. The median joint is between the facet on the anterior arch of atlas and the dens of axis. It is a pivot type of joint, in which the dens rotates in the ring formed by the articular facet and the transverse ligament of the atlas. The movements of rotation of head take place in the atlanto-axial joints.

**Ligaments Connecting Axis and Occipital Bone**

i. Apical ligament passes through the foramen magnum. It connects the tip of the dens to the basilar part of occipital bone closer to foramen magnum. It is a remnant of notochord.

ii. Alar ligaments are attached to the sides of the dens. Superiorly, they are attached to the medial sides of the occipital condyles.

iii. Membrana tectoria extends from the posterior surface of the body of axis to the upper surface of basilar part of occipital bone.

iv. Cruciate ligament has a strong transverse part, which is the transverse ligament of atlas. It has a vertical part consisting of a strong upper part and a weak lower part.

**Lumbosacral Joint**

This is the joint between the fifth lumbar vertebra and the base of the sacrum. It is the intervertebral joint of secondary cartilaginous type or symphysis. The intervertebral disc is thicker anteriorly because of which the lumbosacral angle is prominent. This is the reason for the normal lumbar lordosis. The lumbosacral joint is supported by the iliolumbar ligament, which extends from the tip of the fifth lumbar transverse process to the iliac crest and by the lumbosacral ligament, which is the lower part of iliolumbar ligament and is attached to the posterior part of ala of sacrum.

**Sacrococcygeal Joint**

This is an intervertebral joint of secondary cartilaginous type or symphysis between the last piece of sacrum and the coccyx. Its disc is very thin. The ventral sacroccocygeal ligament is present in place of the anterior longitudinal ligament. The dorsal sacroccocygeal ligament is divided into superficial and deep parts, which close the sacral hiatus. The intercornual ligaments connect the sacral and coccygeal cornua.

**Movements of Vertebral Column**

The movements of vertebral column are flexion, extension, lateral flexion and rotation. The flexion, extension and lateral flexion are extensive in cervical and lumbar spine whereas the movements of thoracic spine are restricted because of ribs and their articulations with sternum. The movement of rotation is severely restricted in lumbar spine.

**Movements of Cervical Spine**

i. The flexion is produced by the longus cervicis, scalenus anterior and sternomastoid muscles of both sides.

ii. The extension is produced by the splenius capitis and erector spine muscles of both sides.

iii. The lateral flexion is due to contraction of the scalenus anterior and medius, sternomastoid and trapezius muscles of one side.

iv. The rotation is the combined action of the sternomastoid of one side and splenius cervicis of the opposite side.

**Movements of Thoracic Spine**

The rotation of thoracic spine is produced by the actions of the semispinalis thoracis, multifidus and rotators. The muscles of the anterior abdominal wall assist.
**Movements of Lumbar Spine**

i. The flexion is produced by rectus abdominis and psoas major muscles. In flexion against resistance (e.g. when raising head and shoulder from supine position), the muscles of anterior abdominal wall contract.

ii. The extension is produced by the erector spinae and transversospinalis group of muscles.

iii. The lateral flexion is by the erector spinae, transversospinalis group, quadratus lumborum, and muscles of anterior abdominal wall.

**Arterial Supply**

The vertebrae receive rich arterial supply because their marrow is a site of erythropoesis. They receive blood from the paired spinal branches (of regional arteries), which enter the intervertebral foramina. The discs are avascular structures. They are nourished by diffusion from the adjoining vertebrae.

**Venous Drainage**

The vertebral venous plexuses are divisible into internal and external groups (Fig. 54.9).

The internal vertebral venous plexus (Batson’s vertebral venous plexus) is located inside the extradural space (epidural space) in the vertebral canal. It is devoid of valves. This plexus receives blood from the vertebral bodies via the basivertebral veins.

The external vertebral venous plexus communicates with the internal plexus through the intervertebral veins. The external vertebral plexus drains into the segmental veins at different levels.

**Basivertebral Veins (Fig. 54.9)**

These veins have physiological, clinical and embryological importance.

i. The large size of the veins reflects the importance of their functional role in carrying products of erythropoesis from the vertebral body to the internal vertebral venous plexus.

ii. Being valveless, they carry cancer cells from distant sites to the vertebral bodies. The retrograde flow of venous blood in pelvic veins or posterior intercostal veins may bring malignant cells from the primary in the prostate or the breast to the vertebral canal.

iii. The basivertebral veins emerge from the foramen, which is placed ventrally in the central part of vertebral body. This signifies their segmental position during development and implies that vertebral body develops by fusion of sclerotomes of two adjacent somites.

**Clinical and embryologic insight ...**

**1. Lumbar Puncture (Figs 54.10 and 54.11)**

It is a procedure by which CSF sample is withdrawn from the subarachnoid space or anesthetic solution is introduced into it. The patient lies on his or her side curled up tightly to flex the lumbar spine so as to open up the interval between the laminae of the lumbar vertebrae. The line passing through the highest points of the iliac crests cuts the midline between the spines of L3 and L4 vertebrae. The needle inserted at this point in the midline passes through, skin, fasciae, supraspinous ligament, interspinous ligament, ligamentum flavum, dura mater and arachnoid mater before reaching subarachnoid space. Figure 54.11 depicts the lumbar puncture in a patient.

**2. Caudal (Sacral) Analgesia (Fig. 54.12)**

The caudal analgesia or anesthesia is given in obstetric practice for painless labor. To carry out the procedure at first the sacral hiatus is identified by palpating the sacral cornu about 5 cm above the tip of coccyx. The other method is to join the two posterior superior iliac spines by a line, which forms the base of the equilateral triangle. The apex of the triangle lies over the sacral hiatus. The needle passes through the posterior sacrococcygeal ligament to enter the sacral hiatus. The volume of sacral canal is 20 to 25 ml and this much quantity of anesthetic solution is sufficient to block the sacral spinal nerves supplying the perineum.

3. **Pott’s spine or tuberculosis of the vertebral column is common in thoracic spine. It causes pain, restriction of movements and deformity. Retropharyngeal abscess, psoas abscess and paraplegia are common complications. Flexion test (picking a coin from the floor) is a valuable test for Pott’s disease. A patient suffering from this disease is unable to bend the spine.**

**Contd...**
4. Cervical spondylosis is a condition characterized by the degeneration of the facet joints in the lower cervical vertebrae and formation of osteophytes. It is common in those, whose occupation involves prolonged flexion of neck. The patient presents with pain in the neck with or without radiation to the arm. The cervical collar is often advised for relief of symptoms.

5. The vertebral fractures (Fig. 54.13) are common in automobile (RTA) and aeroplane accidents. The most feared complication of the vertebral fracture is injury to the spinal cord and cauda equina. First aid to a patient with injury to the vertebral column is very important. The patient must be carefully shifted in the face down position so as to prevent injury to the spinal cord by flexion of the vertebral column.

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**Fig. 54.10:** The site of lumbar puncture (midline of inter cristal line) and anatomical layers pierced to reach subarachnoid space

**Fig. 54.11:** Lumbar puncture in a patient

**Fig. 54.12:** Procedure of caudal analgesia in which the needle is introduced into the sacral canal via sacral hiatus to give epidural anesthesia

**Fig. 54.13:** Fracture of seventh cervical vertebra (indicated by arrow) in road traffic accident

Contd...
ANATOMY OF SPINAL CORD

The spinal cord is the elongated part of the central nervous system (Fig. 55.1). It is located inside the upper two-thirds of the vertebral canal. The spinal cord gives origin to thirty-one pairs of spinal nerves, which provide sensory and motor innervation to the entire body excluding the head region. The spinal cord contains the preganglionic sympathetic neurons (thoracolumbar outflow) for the sympathetic nerve supply of the entire body. It also contains preganglionic parasympathetic neurons in second, third and fourth sacral segments.

Development of Spinal Cord

It is described in chapter 57.

Extent

The spinal cord is the continuation of the lower end of medulla oblongata. It extends from the level of upper border of the posterior arch of atlas to the lower margin of first lumbar vertebra in the adult. Until third month of intrauterine life, the spinal cord and vertebral column coincide in length. At birth, the tip of the conus medullaris (lower tapering end of spinal cord) is at the level of lower margin of third lumbar vertebra.

Length

The length of spinal cord is about 45 cm in adult male and 42 cm in adult female.

Fig. 55.1: Continuity of spinal cord with brain (above) and with cauda equina (below)
Spinal Meninges (Fig. 55.2)
The spinal cord is surrounded by three meninges. The dura mater or pachymeninx (tough membrane) is the outermost. It is followed by arachnoid mater (spidery membrane). The innermost is the pia mater (delicate membrane). The arachnoid and pia together are known as leptomeninges.

There are three spaces surrounding the spinal cord. The epidural space is located outer to the dura mater. The subdural space is between the dura mater and arachnoid mater. The subarachnoid space is between the arachnoid mater and the pia mater. It contains cerebrospinal fluid (CSF).

Spinal Dura Mater
The spinal dura mater is continuous with the inner or meningeal layer of the cranial dura mater at the foramen magnum. It can be likened to a test tube since it is attached to the rim of the foramen magnum at its commencement and ends as a blind sac at the level of the lower margin of the second sacral vertebra. The dura mater lies free in the vertebral canal as the epidural space separates it from the periosteum of the vertebrae. The blind dural sac at the lower end is pierced by the filum terminale, fifth sacral nerve roots, and first coccygeal nerve roots.

The nerve supply of spinal dura mater is derived from the recurrent meningeal branches of the spinal nerves.

Epidural Space
The epidural space contains loose areolar tissue, internal vertebral venous plexus, roots of spinal nerves, spinal branches of regional arteries, recurrent meningeal branches of spinal nerves, and semifluid fat. The epidural anaesthesia is given in this space to numb the spinal nerves that traverse the space. This approach is used in relief of pain in cancer patients, in whom analgesics or pain relieving medicines have no effect. Beyond the lower limit of the dura mater the wide epidural space in the sacral canal extends up to the sacral hiatus. The anesthetic is introduced in this space through the sacral hiatus (Fig. 54.12).

Subdural Space
This space is the potential space between the dura mater and arachnoid mater.

Arachnoid mater
This is a transparent and avascular membrane continuous with the cranial subarachnoid mater above. Its lower limit coincides with that of the dura mater.

Subarachnoid Space
This space contains cerebrospinal fluid. It is of uniform size up to the conus medullaris beyond which it expands. The enlarged subarachnoid space is called the lumbar cistern. The lumbar cistern extends up to the second sacral vertebra. It contains cauda equina, which is a bunch of nerve roots surrounding the filum terminale. The lumbar cistern is approached to collect a sample of CSF for laboratory investigations and to inject spinal anesthetic between L3 and L4 vertebrae (Fig. 54.10).

Pia Mater
It is a vascular membrane that closely invests the surface of the spinal cord. The pia mater is modified in some places as follows.

i. The filum terminale is a slender filament of pia mater beyond the conus medullaris. It is about 20 cm long. It pierces the blind end of the dural sac and is subdivided into the filum terminale internum inside the dural sac (15 cm) and filum terminale externum outside the dural sac (5 cm). It leaves the sacral canal through the sacral hiatus and is fused with the dorsal surface of the first piece of coccyx.

ii. Linea splendens is a thickened band of pia mater along the anterior median fissure of the spinal cord.

iii. The ligamenta denticulata (Fig. 55.3) are ribbon-like lateral extensions of the pia mater between the attachments of ventral and dorsal nerve roots. Each band sends twenty-one teeth-like projections, which pass through the subarachnoid space to gain attachment to the inner surface of the dura mater. The last ligamentum denticulatum extends obliquely downwards between the twelfth thoracic and first lumbar spinal nerves. Its identification helps the surgeon in locating the first lumbar nerve during operation.
Enlargements of Spinal Cord

The spinal cord shows cervical and lumbosacral enlargements as it gives origin to the nerves that take part in cervical and brachial plexuses in cervical region and lumbar and sacral plexuses in lumbosacral region.

Surface Features of Spinal Cord (Fig. 55.8)

i. The anterior surface is marked by a deep anterior median fissure, which contains anterior spinal artery.
ii. The posterior surface is marked by a shallow posterior median sulcus.
iii. The rootlets of the dorsal or sensory roots of spinal nerves enter the cord at the posterolateral sulcus on either side.
iv. The rootlets of the ventral or motor roots of spinal nerves emerge through the anterolateral sulcus on either side.

Spinal Nerves (Fig. 55.4)

There are thirty one pairs of spinal nerves, eight cervical, twelve thoracic, five lumbar, five sacral and one pair of coccygeal nerve.

i. Each spinal nerve is formed by the union of ventral and dorsal rootlets in the intervertebral foramen.
ii. The dorsal root bears a dorsal root ganglion or spinal ganglion just before its union with the ventral root. The dorsal root ganglion contains pseudounipolar neurons. The central processes of these neurons form the dorsal rootlets and their peripheral processes bring the sensory impulses from the skin, muscles, joints, etc.
iii. The ventral root carries motor fibers for the innervation of the muscles.
iv. After emerging from the intervertebral foramen each spinal nerve divides into a dorsal and a ventral ramus.

Sympathetic Connections of Spinal Nerves

The thoracic spinal nerves and first two lumbar spinal nerves are connected to the sympathetic chain (lying adjacent to the vertebral column) by white rami communicans (WRC). These fourteen pairs of white rami convey preganglionic sympathetic fibers to the adjacent sympathetic chain of respective side. After the synapse in the appropriate sympathetic ganglia each spinal nerve receives postganglionic sympathetic fibers via gray rami communicans (GRC). In this way the thirty one pairs of spinal nerves receive postganglionic sympathetic fibers via thirty one pairs of GRC to distribute sympathetic fibers to the blood vessels, smooth muscles of viscera, arrector piliromuscles and glands.

Spinal Segments (Fig. 55.5)

A part of spinal cord giving origin to a pair of spinal nerves is called the spinal segment. There are thirty one segments of spinal cord. The area of skin supplied by one spinal segment or its dorsal root is called a dermatome. The C1 dermatome does not exist since the C1 spinal nerve has no sensory fibers in it. Figure 55.6 depicts the dermatomes of body. The working knowledge of dermatomes is essential for neurological examination of the patient.

Vertebral Levels of Spinal Segments

Since the spinal cord is shorter than the vertebral column, the segments of the spinal cord do not coincide with the overlying vertebrae. This is to be borne in mind while determining the segmental level of spinal cord injury in the fracture of a particular vertebra. A simple working rule to identify the vertebral levels of spinal segments is as follows. Add two to the number of vertebra with respect to vertebrae C2 to T10 to find the level of corresponding spinal segments (for example C2 vertebral spine corresponds to C4 spinal segment). The spines of T11 and T12 correspond to all five lumbar segments. The L1 spine corresponds to all five sacral and coccygeal segments.
Exit of Spinal Nerves

i. Each spinal nerve emerges through the intervertebral foramen except the following four nerves. The first cervical nerve lies above the posterior arch of the atlas. The second cervical nerve emerges between the posterior arch of atlas and the vertebral arch of axis. The fifth sacral and first coccygeal nerves leave via sacral hiatus.

ii. The first to seventh cervical nerves leave above the numerically corresponding vertebra.

iii. The eighth cervical nerve leaves above the first thoracic vertebra.

iv. The remaining spinal nerves leave below the numerically corresponding vertebra.

Cauda Equina (Figs 55.7A and B)
The meaning of the term cauda equina is tail of a horse. A leash of nerves suspended from the conus medullaris in the lumbar cistern, is called the cauda equina. It is composed of lumbar, sacral and coccygeal nerve roots (both dorsal and ventral) surrounding the filum terminale. The second to fourth sacral ventral roots carry with them preganglionic parasympathetic fibers. The dura mater and arachnoid mater surround the cauda equina up to the level of second sacral vertebra. The lumbar cistern is approached in the interval between L3 and L4 spines by lumbar puncture. This avoids the injury to the spinal cord by the needle because the roots of cauda equina slip away from the needle or even if injured they have the capacity for regeneration.

Internal Structure (Fig. 55.8)
The interior of spinal cord is divided into symmetrical halves by means of a ventral median fissure and a posterior median septum (which dips inwards from the posteromedian sulcus). The spinal cord has an H-shaped core of gray matter consisting of the cell bodies of neurons and the neuroglia. The white matter surrounds the gray matter and consists of myelinated and unmyelinated nerve fibers and neuroglia.
i. The gray matter is divisible into a larger anterior column or horn and a narrow elongated posterior column or horn, on each side. A horizontal bar of gray matter known as gray commissure connects the right and left halves of the gray matter.

ii. The white matter is divided into two halves by the anterior median fissure and the posterior median septum. Each half of the white matter is subdivided into anterior, lateral and posterior funiculi. A small strip of white matter in front of the gray commissure is called white or anterior commissure, which is the connecting link between the white matter of the two sides.

Central Canal of Spinal Cord

The central canal of the spinal cord containing CSF traverses the gray commissure. The canal is lined with ciliated simple columnar epithelium. Superiorly the canal is continuous with the central canal of the closed part of medulla oblongata. Inferiorly, in the conus medullaris the canal expands slightly to form terminal ventricle.

Gray Matter (Fig. 55.9)

The cell bodies of the multipolar neurons and plenty of interneurons including Renshaw cells make up the gray matter of the spinal cord. The gray matter is divided into
three horns, anterior (or motor), intermediate or lateral (or visceral) and posterior (or sensory).

i. The anterior horn is short and bulbous. The neurons in the anterior horn are the lower motor neurons, which are subdivided into alpha neurons and gamma neurons. The alpha neurons supply the extrafusal fibers of skeletal muscles. The gamma neurons supply the intrafusal fibers of the neuromuscular spindles in the skeletal muscles.

ii. The anterior horn shows central, medial and lateral groups of neurons. The neurons of the central group in the upper five cervical segments form the spinal nucleus of accessory nerve and those mainly of the fourth cervical segment form the phrenic nucleus. The neurons in the medial group extend through the cord and supply the striated muscles of the neck and trunk. The lateral group neurons are confined to the cervical and lumbar enlargements of the spinal cord and are involved in the supply of limb muscles. A ventrolateral group in the first and second sacral segments only is named after Onuf. The neurons in this group supply perineal muscles (anal and urethral muscles). Hence damage to this nucleus results in rectal and urinary incontinence.

iii. The posterior horn is narrow and tapering. Its tip touches the surface of the cord. It is divisible into apex, head, neck and base. It contains sensory neurons. The neuronal groups in this horn are, substantia gelatiosa, nucleus proprius, nucleus dorsalis or Clarke’s column and visceral afferent.

iv. The intermediate or lateral horn is composed of intermediolateral and intermedial nuclei. The intermediolateral nucleus is equal to the preganglionic sympathetic nucleus, in T1 to L2 segments of the cord (thoracolumbar outflow). The intermedial nucleus is present in S2 to S4 segments of spinal cord. It is equal to the preganglionic parasympathetic nucleus (sacral parasympathetic outflow).

### White Matter (Fig. 55.10)

The spinal white matter is divided by sulci into dorsal, lateral and ventral funiculi.

i. The posterior funiculus is located between the posterior median septum and posterior gray horn. Above the level of sixth thoracic segment it presents two fasciculi, medially placed fasciculus gracilis and laterally placed fasciculus cuneus.

ii. The lateral funiculus is located between the posterior gray horn and the anterior gray horn. It contains a number of tracts.

iii. The ventral funiculus is located between the ventral median fissure and anterior gray horn.

### White Commissure

The part of white matter (lying in front of gray matter) connecting the right and left halves of spinal cord is called white commissure. The crossing of the fibers of spinothalamic tracts takes place here hence any damage to white commissure results in bilateral loss of pain and temperature (refer to syringomyelia in lesions of spinal cord).

### Major Ascending Tracts

The ascending or sensory tracts usually consist of a chain of the first, second, and third order neurons. The first order

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**Fig. 55.9:** Spinal gray matter Rexed’s laminae shown by Roman numbers I to X
There are two spinothalamic tracts (anterior and lateral). The anterior (ventral) spinothalamic tract carries light (simple nondiscriminative) touch. The lateral spinothalamic tract carries pain and temperature sensations.

### Anterior Spinothalamic Tract

i. The first order neurons are located in the dorsal root ganglia of the spinal nerves. The central processes of these neurons enter the spinal cord close to the posterior horn in dorsal funiculus and ascend ipsilaterally for about seven segments.

ii. These axons terminate on the second order neurons, located in laminae IV to VI in the posterior horn. The axons of the second order neurons cross in the narrow white commissure and ascend in contralateral anterior funiculus as anterior spinothalamic tract.

iii. After passing through the brainstem the anterior spinothalamic tract terminates in the third order neurons, which are present in the VPL nucleus of thalamus.

iv. The axons of the third order neurons (forming superior thalamic radiation) project via the posterior limb of internal capsule and corona radiata to the postcentral gyrus (areas 3, 1, 2) of cerebral cortex.

### Lateral Spinothalamic Tract (Fig. 55.11)

i. The first order neurons are found in the dorsal root ganglia of the spinal nerves. The central processes of these neurons enter the spinal cord via the dorsolateral tract of Lissauer and ascend ipsilaterally for two segments.

ii. They terminating on the second order neurons located in laminae IV to VI. The axons of the second order neurons cross in the white commissure and ascend in the anterior part of the lateral funiculus as the lateral spinothalamic tract. It is important to appreciate that a lesion in white commissure at C8 segment will lead to loss of pain and temperature sensation in T2 dermatome since T2 fibers cross at C8 segment.

iii. The lateral spinothalamic tract ascends in the brainstem as part of spinal lemniscus, (which is formed by merging of lateral spinothalamic, anterior spinothalamic and spinotectal tracts) to terminate in the nucleus VPL of thalamus (third order neurons).

iv. Its projection to the cerebral cortex is like that of the anterior spinothalamic path.
There are two tracts in the posterior column. The medially paced tract is called fasciculus gracilis (tract of Gall) and laterally placed tract is called fasciculus cuneatus (tract of Burdach). They carry the sensations of discriminative or fine touch, pressure, vibration, conscious sense of position and movements (conscious proprioception) and stereognosis. The tract of Burdach serves the upper limb and upper part of the trunk. The tract of Gall serves the lower limb and lower part of trunk.

i. The first order neurons in the spinal ganglia receive the sensations. The central processes of these neurons enter the spinal cord via the dorsal rootlets and form the fasciculus gracilis and fasciculus cuneatus.

ii. The fasciculus gracilis and fasciculus cuneatus terminate in the gracile and cuneate nuclei respectively in medulla oblongata. The axons of second order neurons present in these nuclei are called internal arcuate fibers, which cross over in the medulla in the sensory decussation to give rise to medial lemniscus on each side.

iii. The medial lemniscus ascends in the brainstem to terminate into the third order neurons, which are present in the nucleus VPL of thalamus. The axons of these neurons pass through the posterior limb of internal capsule and corona radiata to area 2, 1 and 3 of the postcentral gyrus of cerebral cortex.

**Clinical insight ...**

i. The lesion of the lateral spinothalamic tract results in contralateral loss of pain and temperature sensations in two segments below the level of lesion.

ii. The surgical sectioning of lateral spinothalamic tract is done to relieve intractable pain in some patients. To access the lateral spinothalamic tract the incision is placed in front of the ligamentum denticulatum.

**Clinical insight ...**

**Lesion of posterior column tracts**

It results in ipsilateral loss of conscious proprioception, loss of fine touch and vibration below the level of lesion.

**Know More ...**

Landgren and Silfvexius in 1971 propounded the theory of an alternate path for conscious proprioception from the lower limb. This theory is gaining support among neuroscientists. This path is unique as it is a 4-neuron path. The sensation is carried via the central processes of first order neurons (dorsal ganglion) to the neurons of Clarke’s column (second order neurons). Further, the sensation is carried upwards through the fibres in the dorsal...
Spinocerebellar Tracts

The spinocerebellar tracts (Fig. 55.13) are two neuron pathways that carry proprioceptive impulses from muscle spindles and Golgi tendon organs (unconscious proprioception) to the cerebellum. The tracts involved in this function are posterior spinocerebellar, anterior spinocerebellar, cuneocerebellar and rostral cuneocerebellar.

Posterior Spinocerebellar Tract

This tract carries unconscious proprioceptive sensation from the lower extremity and trunk.

i. The first order neurons are located in spinal ganglia of C8 to L3.

ii. The central processes of the ganglion cells terminate on the nucleus dorsalis of Clarke (lamina VII), which are the second order neurons in C8 to L3 segments.

iii. The axons of these neurons ascend in the posterior spinocerebellar tract, which is situated in the lateral funiculus. The tract passes through the medulla oblongata and reaches the cerebellum via inferior cerebellar peduncle. It terminates ipsilaterally in the cerebellar cortex as mossy fibers.

Anterior Spinocerebellar Tract

This tract is concerned with coordinated movement and posture of the entire lower extremity.

i. The first order neurons on this tract are the cells of spinal ganglia in L2 to S3 segments.

ii. The central processes of these neurons terminate on the cells of nucleus dorsalis of Clarke in lamina VII at the base of the anterior horn in L2 to S3 segments. These are the second order neurons and their axons decussate in white commissure to ascend as anterior spinocerebellar tract in the lateral funiculus. This crossed tract passes through the medulla oblongata and the pons to reach the midbrain, where it enters the superior cerebellar peduncle and terminates in the cerebellar cortex as mossy fibers on contralateral side.

Cuneocerebellar Tract

This tract carries unconscious proprioceptive sensation from the upper half of body and the upper extremity. It travels inside the fasciculus cuneatus.

i. The first order neurons are located in C2 to T8 spinal ganglia.

ii. The central processes of the first order neurons enter the spinal cord and ascend along with fasciculus cuneatus to terminate on the second order neurons in the accessory cuneate nucleus in the medulla oblongata.

iii. The axons of the second order neurons are called the posterior external arcuate fibers (cuneocerebellar tract). They reach the cerebellum via inferior cerebellar peduncle.

(Note: The accessory cuneate nucleus is equivalent to the nucleus dorsalis of Clarke and cuneocerebellar tract is equivalent to the posterior spinocerebellar tract).
Rostral Cuneocerebellar Tract
The rostral spinocerebellar tract serves the upper limb. It is equivalent to the anterior spinocerebellar tract of the lower limb. The exact location of the neurons of its origin in the cervical spinal cord is not confirmed. The tract reaches the cerebellum via the inferior and superior cerebellar peduncles.

Lissauer’s Tract
The dorsolateral bundle or Lissauer’s tract is situated between the apex of posterior horn and the surface of the spinal cord. It is present throughout the spinal cord. The tract consists of fibers from dorsal rootlets carrying pain and temperature sensations. The tract is continuous above with the spinal tract of trigeminal nerve.

Major Descending Tracts
The descending spinal tracts influence the motor neurons in the spinal cord. Their cells of origin are located either in the cerebrum or in the brainstem.

Corticospinal Tract (Fig. 55.14)
There are two corticospinal tracts, the anterior and lateral. They begin in the medulla oblongata after the pyramidal decussation. The corticospinal fibers from the cerebral cortex pass through various parts of the cerebrum and the brainstem to reach the medulla oblongata, where 80 to 85% fibers decussate to form lateral corticospinal tract. The uncrossed fibers descend as anterior corticospinal tract. These uncrossed fibers finally cross by passing through the white commissure. The majority of corticospinal fibers influence the anterior horn cells via the intenuncial neurons. Only about 10% of fibers directly terminate on the anterior horn cells. Thus the corticospinal fibers control the voluntary skilled movements of the opposite side of body through the anterior horn cells. The detailed description of the tract is given in chapter 63.

Descending Autonomic Pathways
These tracts begin in the higher centers of autonomic functions (hypothalamus and reticular formation) and terminate on the intermediolateral column in T1 to L2 segments of spinal cord. These pathways are located in posterior part of lateral funiculus and their lesion causes Horner’s syndrome.

Rubrospinal Tract
The rubrospinal tract is a crossed tract from red nucleus of midbrain and is located in lateral funiculus. It extends along the entire length of the spinal cord and terminates on the motor neurons and other adjacent neurons (laminae VII, VIII and IX). This tract helps in maintaining the tone of the skeletal muscles, particularly in upper limb.

Vestibulospinal Tract
The vestibulospinal tract takes origin from the lateral vestibular nucleus and terminates on neurons in laminae VII, VIII and IX. This tract maintains the equilibrium and posture of the body and limbs.

Tectospinal Tract
The tectospinal tract begins in the midbrain from the dorsal tegmental decussation of the fibres from the superior colliculi. It travels down in the brainstem and occupies the anterior funiculus. The fibers terminate like the rubrospinal and vestibulospinal tracts.

Olivospinal Tract
The olivospinal tract originates in the inferior olivary nucleus in the medulla oblongata and terminates in relation to the anterior horn cells.

Reticulospinal Tract
The reticulospinal tracts (lateral and medial) originate in the reticular formation in the brainstem and descend into the spinal cord to terminate in relation of the anterior horn cells. These tracts play a role in maintenance of muscle tone.
Fasciculus Proprius (intersegmental tract)
These are short ascending and descending tracts that interconnect the neurons of the adjacent segments of spinal cord. They are centrally located in all the three funiculi surrounding the gray matter. Traced superiorly, the ventral fasciculus proprius is in continuation with the lower end of the medial longitudinal fasciculus (MLF) of brainstem.

Arterial Supply of Spinal Cord
The spinal cord receives arteries from several sources (Fig. 55.15A) as it is an elongated structure. A few of these arteries may be supplying a large part of the spinal cord and if this major source is diseased or damaged, the spinal cord undergoes necrosis leading to very serious complications like paraplegia (paralysis of both lower limbs) or monoplegia (paralysis of a single limb). The arterial supply of the cord is derived from following arteries.

1. A single midline anterior spinal artery
2. Two pairs of posterior spinal arteries.
3. The radicular arteries.

Anterior Spinal Artery
The anterior spinal artery is formed in the posterior cranial fossa by the union of the right and left anterior spinal arteries (which are the branches of the fourth part of the vertebral artery). The anterior spinal artery descends through the foramen magnum and runs down in the anterior median fissure of the spinal cord.

Posterior Spinal Arteries
The right and left posterior spinal arteries are the branches of the fourth part of the vertebral arteries. Each posterior spinal artery descends through the foramen magnum as two branches, which pass one in front and the other behind the dorsal roots of the spinal nerves.

Radicular Arteries (Fig. 55.15B)
The paired anterior and posterior radicular arteries originate from spinal branches of second and third
parts of vertebral arteries, ascending cervical arteries (from inferior thyroid), deep cervical arteries (from costocervical trunk), posterior intercostal arteries (from thoracic aorta), lumbar arteries (from abdominal aorta) and lateral sacral arteries (from internal iliac artery). The majority of the radicular arteries do not reach the longitudinally oriented spinal arteries because they are exhausted in the supply of the roots of the spinal nerves. However, a few radicular arteries that are larger supply the spinal cord.

**Arteria Radicularis Magna**

One of the anterior radicular branches (usually on the left side) is very large. It is called the arteria radicularis magna or artery of Adamkiewicz. The position of this artery is variable. It usually takes origin from the tenth or eleventh posterior intercostal or subcostal arteries. It is the main supply to the lower two-thirds of the spinal cord.

**Intrinsic Blood Supply (Fig. 55.15B)**

The central branches of the anterior spinal artery (replenished by arteria radicularis magna) supply about anterior two thirds of the cross sectional area of the spinal cord (which includes anterior gray matter, part of dorsal gray matter, anterior and lateral funiculi). The central branches of the posterior spinal arteries supply the posterior horn and the posterior funiculus.

**Clinical insight ...**

**Lesion of Arteria Radicularis Magna**

The arteria radicularis magna may be injured during surgery or may not be filled due to occlusion of the feeder artery (the artery that gives origin to the radicular artery) for example in atherosclerosis of thoracic aorta, dissecting aneurysm of thoracic aorta and emboli from the heart. Lack of blood is arteria radicularis magna, will deprive the blood supply of spinal cord from midthoracic region downwards leading to infarction of the anterior two-third of the spinal cord (anterior spinal artery syndrome). This presents clinically as acute flaccid paraplegia and bilateral loss of pain and temperature below the level of lesion (with complete preservation of joint position sense, touch and stereognosis).

**Venous Drainage (Fig. 55.16)**

The spinal veins drain into six plexiform longitudinal channels, which surround the cord.

i. The anteromedian channel runs along anterior median fissure.

ii. The posteromedian channels run in the posterior median sulcus.

iii. The paired anterolateral channels run anterior to the ventral roots.

iv. The paired posterolateral channels run posterior to the dorsal roots.

v. Superiorly, the venous channels are continuous with the cranial venous sinuses.

vi. They also communicate with the internal vertebral venous plexuses, which drain via the intervertebral veins in to the regional veins.

**Radiology of Spinal Cord**

The subarachnoid space is outlined by the injection of contrast media (iodized oil) in the subarachnoid space by lumbar puncture. The normal myelogram (Fig. 55.17) shows the pointed lateral projections at regular intervals at the intervertebral space, where the lateral extensions of the subarachnoid space around the spinal nerves are present. The presence of a tumor or the prolapsed disc will obstruct the movement of the contrast medium. The MRI and CT scans are the modern methods to visualize spinal cord.

**UMN Vs LMN**

The spinal cord may show combined upper motor neuron and lower motor neuron lesions. This is due to the fact that spinal cord contains corticospinal fibers which are the axons of the upper motor neuron (whose cell bodies are located in cerebral cortex) and it also contains the cell bodies of lower motor neurons in the ventral horn as depicted in Figure 55.18. Thus, the upper motor neuron (UMN) lesion in spinal cord is the lesion of corticospinal tracts. The lower motor neuron (LMN) lesion in spinal cord means the lesion of cell bodies of anterior horn cells.
i. The fundamental difference in UMN and LMN lesions is that UMN lesions result in paralysis of voluntary movements but LMN lesions cause paralysis of individual muscles or muscle groups.

ii. The UMN lesion causes spastic paralysis. The spasticity is due to increased tone of the voluntary muscles as result of continuous activity of the monosynaptic stretch reflex. The LMN lesion causes flaccid paralysis due to loss of tone of the voluntary muscles. There is wasting and atrophy of muscles.

iii. There is hyperreflexia (exaggerated deep tendon reflexes) in UMN and loss of tendon reflexes in LMN lesion.

iv. There is positive Babinski sign in UMN lesion while this is negative in LMN lesion (refer to pyramidal tract in chapter 63).

### Clinical insight...

#### Lesions of Spinal Cord (Fig. 55.19)

i. Syringomyelia is a degenerative disease of the gray and white commissures usually in the cervical cord. There is cavitation in the gray commissure causing enlargement of the central canal, which extends in ventral direction destroying the crossing spinothalamic fibers in the white commissure. The syringomyelia in cervical cord presents as bilateral loss of pain and temperature in upper limbs (without loss of touch).

ii. The tabes dorsalis or tertiary syphilis affects the intraspinal part of posterior roots and posterior column tracts. This results in loss of position sense, vibratory sense, sense of stereognosis and two-point discrimination on the same side below the level of lesion. Romberg’s sign is positive, in which on closing the eyes, the patient loses balance.

iii. The subacute combined degeneration of spinal cord occurs in vitamin B12 deficiency. One of the causes of this deficiency is pernicious anemia. The posterior columns and the lateral corticospinal tracts undergo degeneration on both sides. It usually affects the lumbosacral region of the cord. There is bilateral loss of position and vibratory sense and spastic paraplegia with exaggerated tendon reflexes and positive Babinski sign.

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**Fig. 55.17:** Radiological appearance of spinal cord after myelography

**Fig. 55.18:** Position of UMN and LMN in brain and spinal cord

**Fig. 55.19:** Lesions of spinal cord
Chapter 55: Brown Sequard syndrome due to spinal cord lesion at right T10 segment

Contd...

iv. Brown Sequard syndrome or hemisection of spinal cord is characterized by ipsilateral spastic paralysis (UMN) due to lesion of corticospinal tract. The sensory deficits due to involvement of spinothalamic and dorsal column tracts below the level of lesion are as follows, contralateral loss of pain and temperature sensation and ipsilateral loss of conscious proprioception, joint sense, vibration (Fig. 55.20). In addition, there may be ipsilateral lower motor neuron paralysis at the level of the lesion due to injury to anterior horn cells and ipsilateral loss of sensations on the dermatome of that particular segment of the cord due to injury to posterior horn cells.

v. In complete transection at or above the C4 level of spinal cord, the patient dies due to paralysis of diaphragm. If the cervical cord below the level of C5 is transected the effect is quadriplegia in which all the four limbs are paralyzed. The transection in the thoracic segments of the spinal cord leads to paraplegia. In both quadriplegia and paraplegia the voluntary control over the bladder function is lost.

vi. The cauda equina syndrome occurs due to compression of cauda equina (as in acute disc prolapse between the L2 to L3 levels or fracture of lumbar vertebrae). This results in severe pain in both lower limbs and flaccid paraplegia. The retention of urine is due to compression of preganglionic parasympathetic fibers in S2 to S4 ventral roots.

vii. In conus medullaris syndrome, the conus medullaris is compressed. It involves S2, S3, S4 segments. The features are, saddle anesthesia, root pain in both lower limbs, sexual dysfunction, bladder and bowel dysfunction. There is no motor loss.

viii. In anterior poliomyelitis there is infection of anterior horn cells by polio virus. This causes LMN paralysis of isolated muscles (like gluteus medius and minimus) or of a group of muscles.
The cranial cavity (Fig. 56.1) contains the brain covered with meninges and surrounded by cerebrospinal fluid (CSF). It also contains some important blood vessels (like cerebral arteries, middle meningeal vessels, dural venous sinuses) and intracranial parts of cranial nerves.

**CRANIAL MENINGES**

There are three meningeal layers inside the cranium. The dura mater or pachymeninx is the outermost layer. The arachnoid mater is the middle layer. The pia mater is the innermost layer. The arachnoid and pia mater together are called the leptomeninges.

The meninges are related to three spaces.

i. The extradural (epidural) space is a potential space between the dura mater and the adjacent bone. This space becomes apparent when extradural bleeding takes place due to rupture of meningeal vessels.

ii. The subdural space is present between the dura mater and the arachnoid mater. The superior cerebral veins pass through it. Their rupture is the cause of subdural hemorrhage.

iii. The subarachnoid space between the arachnoid mater and the pia mater contains CSF. The rupture of cerebral arteries or their branches at the base of brain is the cause of the subarachnoid hemorrhage.

**Cranial Dura Mater**

The peculiarity of the cranial dura mater is that it is divisible into outer and inner layers.

i. The outer layer of dura mater is the endosteal layer, which is actually the endocranium of the cranial bones. It is continuous with the pericranium at the foramina in the cranial bones. At the foramen magnum, it is continuous with the pericranium covering the occipital bone. The branches of middle meningeal artery and accompanying veins ascend on the external surface of the endosteal layer in the extradural space.

ii. The inner layer of dura mater is called the meningeal layer. At the foramen magnum, it is continuous with the spinal dura mater. The two layers of the dura mater are adherent to each other except in places, where the

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**Fig. 56.1: Radiograph of lateral view of skull showing interior of cranial cavity**
Cranial Meninges, Middle Meningeal Artery and Pituitary Gland

Chapter 501

Dural Folds (Fig. 56.2.)

The cranial dura mater forms four folds by reduplication of its inner layer.

i. Falx cerebri
ii. Tentorium cerebelli
iii. Diaphragma sellae
iv. Falx cerebelli.

The dural folds help in stabilizing the brain during movements of the head. If the brain moves within the cranial cavity it may exert strain on the thin walled veins that pass through the subdural space. Therefore, to prevent the rupture of these veins it is necessary to have strong dural folds inside the cranial cavity.

Falx Cerebri

The falx cerebri derives its name from its sickle shape. It forms a vertical partition in the longitudinal fissure between the cerebral hemispheres. The falx cerebri is attached anteriorly to the frontal crest of frontal bone and crista galli of ethmoid bone. Superiorly, it is attached to the midline of the vault as far back as the internal occipital protuberance. Inferiorly, it presents a free margin anteriorly and is attached to the tentorium cerebelli posteriorly.

Venous Sinuses Related to Falx Cerebri

i. The superior sagittal sinus in its attached superior margin.
ii. The inferior sagittal sinus in its free inferior margin.
iii. The straight sinus along the line of attachment of falx cerebri and tentorium cerebelli.

Tentorium Cerebelli

The tentorium cerebelli is a tent-shaped fold of dura mater, which roofs the posterior cranial fossa. It forms a partition between the cerebellar lobes and the occipital lobes of the cerebrum. It takes the weight of the cerebrum off the cerebellum. This dural fold has an attached margin and a free margin encircling an opening called tentorial notch. Peripherally, it is attached to the posterior clinoid process, superior margin of petrous temporal bone and internal surface of the occipital bone. In the posterior cranial fossa, it is attached to the inferior margin of the falx cerebri in the midline.

Venous Sinuses Related to Tentorium Cerebelli

The attached margin of tentorium cerebelli contains following three venous sinuses:

i. The superior petrosal sinus is located along the line of attachment to the superior margin of the petrous temporal bone.
ii. The transverse sinus is located along the attachments to the lips of the sulcus of transverse sinus on occipital bone (from the internal occipital protuberance to the base of the petrous temporal bone).
iii. The straight sinus is located along its line of attachment to the falx cerebri.

The free and attached margins of the tentorium cerebelli cross each other at the apex of the petrous temporal bone.

Tentorial Notch (Fig. 56.3)

i. The free margin of the tentorium cerebelli encloses a U-shaped tentorial notch, which gives passage to the midbrain, oculomotor nerves and the posterior cerebral arteries.
ii. The narrow subarachnoid space between the boundary of the notch and the midbrain is the only

Fig. 56.2: Major folds of cranial dura mater (falx cerebri and tentorium cerebelli)

Fig. 56.3: Attachments of tentorium cerebelli and U-shaped tentorial notch
communication between the subarachnoid space of supratentorial and infratentorial compartments of the cranial cavity.

iii. The obstruction of the subarachnoid space in the tentorial notch results in communicating hydrocephalus.

iv. A large extradural hemorrhage (Fig. 56.9) in the supratentorial compartment may cause herniation of the uncus of the temporal lobe through the notch.

Diaphragma Sellae

The diaphragma sellae is a circular dural fold. It forms the roof of the hypophyseal fossa and is pierced by the infundibulum of the pituitary gland. This dural fold is attached to the tuberculum sellae in front and dorsum sellae behind. It encloses the anterior and posterior intercavernous sinuses in its attached margins.

Falx Cerebelli

The falx cerebelli lies in the posterior cranial fossa. It is attached to the inferior surface of the tentorium cerebelli and to the internal occipital crest. It contains the occipital sinus.

Nerve Supply of Dura mater

i. The dura mater in the anterior cranial fossa receives sensory twigs from the anterior and posterior ethmoidal nerves and the anterior filaments of the meningeal branches of maxillary and mandibular nerves.

ii. The dura mater of the middle cranial fossa receives sensory twigs from the nervus spinosus, which is the meningeal branch of the mandibular nerve. The meningeal branches of the maxillary nerve and the direct branches from the trigeminal ganglion also provide additional twigs.

iii. The dura mater of posterior cranial fossa receives twigs from the ascending meningeal branches of upper cervical nerves. The tentorium cerebelli receives branches from the tentorial nerve, which is the recurrent meningeal branch of ophthalmic division of trigeminal nerve. The meningeal branches of vagus and hypoglossal nerves also contribute.

Blood Supply

i. The meningeal branches of the anterior and posterior ethmoidal arteries and of the middle meningeal artery, supply the dura mater in the anterior cranial fossa.

ii. The dura mater of the middle cranial fossa receives arterial blood from the middle and accessory meningeal arteries, ascending pharyngeal artery, internal carotid artery and the recurrent branch of lacrimal artery.

iii. The dura mater of the posterior cranial fossa receives twigs from the occipital artery, vertebral artery and meningeal branch of ascending pharyngeal artery.

Dural Venous Sinuses

The dural venous sinuses are enclosed between the two layers of dura mater. They drain blood from the brain, meninges and the cranial bones. They are lined by endothelium, are devoid of muscular tissue in their walls and do not possess valves.

Classification (Fig. 56.4)

The dural venous sinuses are broadly classified into the posterosuperior group and the anteroinferior group. The radiological procedure to visualize the dural venous sinuses is called dural sinus venography (Fig. 56.5).
**Superior Sagittal Sinus**
This sinus is present along the attached margin of the falx cerebri. It lies deep to the bregma and the sagittal suture. In children up to the age of one and half years, the sinus lies subjacent to the anterior fontanelle (through which it may be approached if other veins are collapsed).

**Origin and Termination**
The superior sagittal sinus extends from the crista galli in front to the internal occipital protuberance behind. Usually it ends by continuing as the right transverse sinus. At the termination of the superior sagittal sinus there is a dilatation known as confluence of sinuses, where as many as five sinuses communicate (superior sagittal, straight, right and left transverse and the occipital).

**Surface Marking**
The sinus can be marked on the surface by a line joining the glabella to the inion.

**Tributaries**
About 10 to 12 thin-walled superior cerebral veins open against the flow of blood in the superior sagittal sinus. They cross the subdural space to enter the superior sagittal sinus through the dura mater. They enter the sinus obliquely so that their openings are directed anteriorly. This unusual feature helps the superior cerebral veins to remain patent.

**Special Features of Superior Sagittal Sinus**
1. The lateral venous lacunae are cleft like lateral extensions of the sinus between the two layers of the dura mater. A small frontal lacuna lateralis is the most anteriorly placed. The parietal lacuna lateralis is the largest and overlies the upper part of the motor area of brain. The occipital lacuna lateralis is intermediate in size. The lacunae absorb the CSF through the arachnoid granulations that project inside them. Besides, they receive the diploic and meningeal veins. The lacunae and the arachnoid granulations increase in size with age.
2. The arachnoid granulations, which are the projections of the arachnoid mater, are most numerous in the superior sagittal sinus. The arachnoid mater passes through minute apertures in the dura mater to project in the sinuses. When such projections are microscopic they are called arachnoid villi. When the aggregations of the villi become macroscopic they are called arachnoid granulations. In early life only villi are present but with advancing age the granulations develop. In old age the granulations are so large that they produce pits on the inner surface of the skull bones. The arachnoid villi and granulations are the sites of absorption of CSF from the subarachnoid space in to the venous blood. These valvular bodies prevent reflux of blood in the subarachnoid space.

**Communications**
The superior sagittal sinus communicates with the nasal cavity through the emissary vein passing through the foramen cecum and with the veins of scalp through the emissary vein passing through the parietal emissary foramen. The superior anastomotic vein connects it to the superficial middle cerebral vein. Infection can reach the sinus through the nasal cavity or scalp or through the infected sigmoid or transverse sinuses.

**Clinical insight ...**
In thrombosis of the superior sagittal sinus, the absorption of the CSF is interfered with leading to higher pressure of CSF and consequent rise in intracranial pressure.

**Inferior Sagittal Sinus**
This sinus is located in the inferior margin of the falx cerebri. It joins the great cerebral vein of Galen to form the straight sinus. Another way of describing its termination is that it continues as the straight sinus. According to this description, the great cerebral vein becomes the tributary of the straight sinus.

**Straight Sinus**
This sinus lies in the junction of falx cerebri and the tentorium cerebelli. It runs in the postero-inferior direction in the line of union of the two dural folds. It becomes continuous usually with the left transverse sinus at the internal occipital protuberance. The area of drainage of the straight sinus includes veins from the posterior and central parts of the cerebrum, falx cerebri and tentorium cerebelli. The great cerebral vein is the important vein draining the interior of the brain. The termination of this vein in the straight sinus is guarded by a small mass of sinusoidal plexus of vessels. This acts like a valve when engorged, thus, preventing outflow of venous blood from the vein in the sinus. This is probably to reduce the formation of CSF in the ventricles.

**Occipital Sinus**
It is a small venous sinus situated in the attached margin of the falx cerebri. It extends from the foramen magnum to the internal occipital protuberance. Its anterior end bifurcates to communicate with the sigmoid sinus of each side. Its posterior end opens in the confluence of sinuses. The occipital sinus communicates with the internal vertebral venous plexus.

**Transverse Sinuses**
The right and left transverse sinuses begin at the internal occipital protuberance. The right sinus is the continuation of superior sagittal sinus in the majority of cases and the left is the continuation of the inferior sagittal sinus.
Accordingly, the size of the right transverse sinus is larger compared to the left. The transverse sinus lies in the attached margin of the tentorium cerebelli grooving the inner surface of the occipital bone. It terminates by becoming the sigmoid sinus at the posteroinferior angle of parietal bone, which is also grooved. The sinus is related to the occipital lobe of the cerebrum above and to the cerebellum below.

**Tributaries**
The tributaries of the transverse sinus are, inferior cerebral veins, diploic veins, inferior anastomotic vein connecting to the superficial middle cerebral vein, inferior cerebellar veins and superior petrosal sinus.

**Surface Marking**
A line that begins at the inion and ends at the base of the mastoid process represents the sinus on the surface.

**Sigmoid Sinuses**
The sigmoid sinuses are S-shaped. They are the continuations of the transverse sinuses. Each sinus deeply grooves the mastoid part of temporal bone. In this location it is very close to the mastoid air cells laterally. The mastoid antrum and the vertical part of the facial nerve lie anterior to it while the cerebellum lies posteriorly. These close relations have clinical importance. The sigmoid sinus thrombosis, internal jugular vein thrombosis and cerebellar abscess are the complications of mastoiditis. The sigmoid sinus curves forwards to enter the posterior compartment of the jugular foramen, where it becomes the superior bulb of the internal jugular vein. It receives veins from the cerebellum.

**Communications**
It communicates with the scalp veins by emissary veins passing through mastoid emissary foramen and with suboccipital venous plexus by condylar emissary veins.

**Surface Marking**
It starts at the base of the mastoid process and passes down just anterior to the posterior border of the mastoid to reach a point 1 cm above its tip.

**Cavernous Sinuses (Fig. 56.6)**
These venous sinuses are located in the middle cranial fossa on the side of the body of sphenoid bone. The name cavernous is derived from the trabeculated or spongy appearance of the interior of sinus. Each sinus extends from the medial end of the superior orbital fissure to the apex of the petrous temporal bone. It is two centimeter long and one centimeter wide.

The sinus presents a roof, floor, lateral and medial walls. The meningeal layer of dura mater forms the roof and lateral wall and endosteal layer forms the floor and medial wall of the sinus.

**Close Relations of Cavernous Sinus (Fig. 56.6)**
1. Four nerves travel in the lateral wall of the sinus. From above downward, they are:
   i. Oculomotor nerve
   ii. Trochlear nerve
   iii. Ophthalmic division of trigeminal nerve
   iv. Maxillary division of trigeminal nerve.
2. Following two structures closely related to the floor are separated from the interior of the sinus by endothelium.
   i. The internal carotid artery surrounded by sympathetic plexus passes forwards through the sinus in close contact with the floor (the artery produces a groove on the body of the sphenoid bone).
   ii. The abducent nerve passes forwards in inferolateral relation to the internal carotid artery.
3. The internal carotid artery comes out of the sinus by piercing its roof.
4. The medial relations of the sinus are:
   i. Sphenoid air sinus in the body of sphenoid bone inferomedially.
   ii. Hypophysis cerebri.

**Relations of Cavernous Sinus to Surrounding Structures**
1. The trigeminal ganglion and mandibular division of trigeminal nerve are related posterolaterally.
2. The optic chiasma and internal carotid artery (after the artery emerges from the roof of the sinus) are present above it.

**Tributaries of Cavernous Sinus (Fig. 56.7)**
1. Superior ophthalmic vein
2. Inferior ophthalmic vein
3. Central vein of retina
4. Middle meningeal sinus (vein)
5. Sphenoparietal sinus
Cranial Meninges, Middle Meningeal Artery and Pituitary Gland

Chapter 56

Draining Channels
i. The superior petrosal sinus drains the cavernous sinus into the junction of transverse and sigmoid sinuses.
ii. The inferior petrosal sinus empties into the internal jugular vein after coming out of cranium through the jugular foramen.

Communications
i. The cavernous sinus communicates with the pterygoid venous plexus (in the infratemporal fossa) by an emissary vein passing through either the foramen ovale or the emissary sphenoidal foramen or Vesalius foramen. This route communicating cavernous sinus with dangerous area of face (Fig. 56.7).
ii. The superior ophthalmic veins connect it with the facial vein.
iii. The right and left cavernous sinuses interconnect by intercavernous sinuses.
(Note the difference between the tributaries, draining channels and communications).

Clinical insight ...
1. Cranial sinus thrombosis occurs usually from the infection (for example an infected pimple) on the dangerous area of the face. The symptoms and signs of the cavernous sinus thrombosis are due to involvement of the structures in its close relation.
   i. Exophthalmos or proptosis occurs due to engorgement of ophthalmic veins.

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Fig. 56.7: Direct tributaries, draining channels and communications of cavernous sinus
(Note the venous route of spread of infection from dangerous area of face to cavernous sinus)

Superior Petrosal Sinuses
Each sinus begins from the posterior end of the cavernous sinus. It runs backward and laterally in the attached margin of tentorium cerebelli along the superior margin of petrous temporal bone and ends by joining the transverse sinus at its junction with the sigmoid sinus. It receives veins from cerebrum, cerebellum and middle ear.

Inferior Petrosal Sinuses
Each sinus begins at the posterior end of the cavernous sinus and ends in the internal jugular vein. It lies in the groove between the petrous part of temporal bone and basilar part of occipital bone. The inferior petrosal sinus is the only dural venous sinus that leaves the cranium. It passes through the anterior compartment of the jugular foramen to join the internal jugular vein and thus becomes the first tributary of the internal jugular vein. This sinus receives veins from the internal ear, medulla, pons and inferior surface of cerebrum. The right and left inferior petrosal sinuses are interconnected by basilar venous plexuses, which lie on the anterior surface of clivus between the layers of dura mater. The basilar venous plexuses are in communication with the internal vertebral venous plexus.

Emissary Veins
These tiny veins pass through the foramina of the cranium and connect the intracranial venous sinuses with the extracranial veins. The function of the emissary veins is to equalize the venous pressure within and outside the
cranium. Being valveless blood can flow in both directions in them. The importance of these veins lies in the fact that they are the vehicles of infection from outside into the intracranial sinuses leading to venous thrombosis.

**Examples of Emissary Veins**

i. Mastoid emissary vein passes through the mastoid foramen and connects the sigmoid sinus to the scalp veins (posterior auricular and occipital veins).

ii. The superior sagittal sinus is connected to the veins of scalp through the parietal emissary vein and to the veins of nasal cavity by emissary veins passing through the foramen cecum.

iii. The cavernous sinus is connected to the pterygoid venous plexus by emissary vein passing through the emissary sphenoidal foramen of Vesalius, emissary vein passing through foramen lacerum and through foramen ovale.

iv. Anterior condylar emissary vein connects the sigmoid sinus to the internal jugular vein.

v. Posterior condylar emissary vein connects the veins of suboccipital triangle to the sigmoid sinus.

**Diploic Veins**

These veins drain the diploe of the skull bones. The diploe are the venous spaces between the outer and inner tables of the flat bones of the skull. They are valveless.

**Arachnoid Mater**

The arachnoid mater is separated from the dura mater by a thin film of fluid in the potential subdural space. The arachnoid mater is very thin, avascular and transparent membrane. It lines the internal surface of the dura mater. It projects as villi and granulations in the venous sinuses. The arachnoid granulations or Pacchionian bodies are the hypertrophied arachnoid villi.

**Subarachnoid Space**

This space is filled with CSF and lies between the arachnoid mater and pia mater. This fluid-filled space around the semifluid soft brain acts as a buffer in protecting it from injury. The two meningeal layers are held tightly to each other by dense trabeculae. The subarachnoid space contains the larger arteries and veins of the brain.

**Subarachnoid Cisterns**

There are certain locations where the arachnoid mater is separated from the pia mater by wide subarachnoid space. In such locations the subarachnoid space is wider and hence called cistern, which contains pool of CSF.

i. The cerebellomedullary cistern is the biggest subarachnoid cistern and hence called the cisterna magna. It occupies the interval between the inferior surface of cerebellum and the posterior aspect of medulla oblongata. It receives the median aperture of the fourth ventricle called foramen of Magendie. This cistern is approached to collect CSF samples (cisternal puncture) via the suboccipital triangle.

ii. The cisterna pontis lies in front of the pons and medulla oblongata and contains the vertebral and basilar arteries.

iii. The interpeduncular cistern is seen at the base of the brain in the interpeduncular fossa. It contains the circle of Willis. The pulsations of the cerebral arteries taking part in the arterial circle help the propulsion of the CSF to the surface of the cerebral hemisphere.

iv. The cistern of the lateral sulcus contains the middle cerebral vessels.

v. The cisterna ambiens lies inferior to the splenium of the corpus callosum. The great cerebral vein is its content and the pineal gland protrudes into it.

**Clinical insight ...**

### Subarachnoid Hemorrhage

The subarachnoid hemorrhage results from rupture of a congenital berry aneurysm in the subarchnoid space at the base of the brain. The symptoms are of sudden onset. They include severe headache, stiffness of neck and loss of consciousness. The diagnosis is established by the presence of blood in the CSF.

### Meningioma

The cells of arachnoid mater proliferate to give rise to meningioma.

### Meningitis

The inflammation of pia-arachnoid either due to bacteria or viruses is called meningitis.

**Pia Mater**

The cranial pia mater is a delicate highly vascular membrane that closely invests the surface of the brain. It dips into the cerebral sulci. Between the pia mater and the surface of the brain there is a subpial space. The pial plexus of blood vessels supplies branches to the brain. The older concept that the blood vessels entering the brain are encircled by perivascular space filled with CSF is no longer valid. The special modifications of the cranial pia mater are the tela choroidea and choroid plexuses. Tela choroidea is a vascularized double fold of pia mater. The choroid plexus is formed, when the tela choroidea is covered with ependyma and extends into the ventricle to secrete CSF.
**MIDDLE MENINGEAL ARTERY**

The middle meningeal artery supplies a large number of structures besides the dura mater. Being superficially placed inside the cranium it is vulnerable to trauma.

**Origin**

The middle meningeal artery takes origin from the first part of the maxillary artery in the infratemporal fossa (Fig. 45.3). It is surrounded by two roots of the auriculo-temporal nerve at its origin.

**Course and Termination**

i. The middle meningeal artery ascends towards the roof of the infratemporal fossa, where it enters the middle cranial fossa via the foramen spinosum accompanied by the nervus spinosus (meningeal branch of the mandibular nerve).

ii. In the middle cranial fossa the trunk of the middle meningeal artery and its branches are located in the extradural space. The artery passes anterolaterally on the floor of the middle cranial fossa and then divides into anterior (frontal) branch and posterior (parietal) branch on the greater wing of the sphenoid.

iii. The anterior or frontal branch lies in a groove on the greater wing of sphenoid at the pterion. Thereafter, it breaks up into branches that supply the dura mater and the cranial bones as far back as the vertex. One branch grooves the anteroinferior angle of the parietal bone and overlies the precentral sulcus of the brain.

iv. The posterior or parietal branch arches backward on the squamous part of the temporal bone to supply the dura mater and the cranial bones as far as the lambda.

**Branches**

The middle meningeal artery primarily supplies the cranial bones, diploei and the dura mater. Apart from this, it has the following named branches:

i. Ganglionic branches supply the trigeminal ganglion.

ii. Petrosal branch passes through the greater petrosal hiatus to enter the petrous temporal bone and supply the facial nerve, geniculate ganglion and the middle ear.

iii. Superior tympanic branch enters the middle ear along the canal for tensor tympani muscle.

iv. Anastomotic branch enters the orbit through the lateral part of superior orbital fissure to anastomose with the recurrent meningeal branch of lacrimal artery.

v. Temporal branches enter the temporal fossa to anastomose with deep temporal branches of maxillary artery.

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**Extradural Hemorrhage**

i. The fracture of the side of the skull involving the pterion is likely to tear the anterior branch of middle meningeal artery. The arterial injury causes gradual accumulation of blood in the extradural space. Initially, the symptoms of confusion and irritability are seen. Later on, a hematoma forms, which may exert pressure on the underlying precentral gyrus causing hemiplegia.

ii. A large and long-standing extradural hematoma (Fig. 56.9) in the supratentorial compartment may cause herniation of the uncus of the temporal lobe through the tentorial notch. In such cases, midbrain is shifted to the opposite side and its crus cerebri is compressed by the sharp edge of the tentorium.
Middle Meningeal Vein or Sinus

The vein accompanying the middle meningeal artery is called the middle meningeal sinus. It behaves more like an emissary vein. It opens in the lateral lacuna of the superior sagittal sinus. Its frontal and parietal tributaries groove the inner aspects of the parietal bone (the veins being actually in contact with the bone). The termination of the two tributaries is variable. The parietal tributary passes through the foramen spinosum to open in pterygoid venous plexus. The frontal tributary may reach the pterygoid plexus through the foramen ovale or it may open in the sphenoparietal or cavernous sinus. The middle meningeal sinuses receive diploic and cerebral veins.

PITUITARY GLAND

The pituitary gland or the hypophysis is the endocrine gland that controls the growth, metabolism, reproductive function, and water conservation in the body. The pituitary is a pea-shaped gland weighing about 500 mg.

Lobes

The pituitary consists of two lobes (adenohypophysis and neurohypophysis), which are anatomically, structurally, and developmentally different from each other. The adenohypophysis is larger than the neurohypophysis and accounts for 75 percent of the total weight of the gland.

Location

The pituitary is placed inside the hypophyseal fossa of the sphenoid bone. It is suspended from the floor of the third ventricle (formed by hypothalamus) by the infundibulum.

Embryologic insight ...

Developmental Sources (Fig. 56.10)

i. The adenohypophysis develops from Rathke’s pouch (surface ectoderm of stomodeum).
ii. The neurohypophysis develops from neuroectoderm of diencephalon.

Details of Developmental Process

i. The adenohypophysis develops from Rathke’s pouch, which extends from the roof of the stomodeum towards the brain. The anterior wall of the Rathke’s pouch proliferates to form pars distalis and the thin posterior wall forms the pars intermedia. The original cleft largely obliterates but its remnants (colloid follicles) are present between pars distalis and pars intermedia (some regard the intraglandular cleft as persistent part of Rathke’s pouch).

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Fig. 56.9: Effects of large extradural hematoma on left side. (Note the herniation of uncus of temporal lobe of cerebrum into the tentorial notch and the shift of midbrain to the right producing compression of corticospinal fibers in the crus of midbrain)

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This causes compression of corticospinal fibers in the crus cerebri in addition to compression of third cranial nerve and posterior cerebral artery. To prevent these serious complications immediate treatment consists of ligating the bleeding vessel through a burr hole at pterion.

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The pituitary gland or the hypophysis is the endocrine gland that controls the growth, metabolism, reproductive function, and water conservation in the body. The pituitary is a pea-shaped gland weighing about 500 mg.

Lobes

The pituitary consists of two lobes (adenohypophysis and neurohypophysis), which are anatomically, structurally and developmentally different from each other. The adenohypophysis is larger than the neurohypophysis and accounts for 75 percent of the total weight of the gland.

Location

The pituitary is placed inside the hypophyseal fossa of the sphenoid bone. It is suspended from the floor of the third ventricle (formed by hypothalamus) by the infundibulum.

Embryologic insight ...

Developmental Sources (Fig. 56.10)

i. The adenohypophysis develops from Rathke’s pouch (surface ectoderm of stomodeum).
ii. The neurohypophysis develops from neuroectoderm of diencephalon.

Details of Developmental Process

i. The adenohypophysis develops from Rathke’s pouch, which extends from the roof of the stomodeum towards the brain. The anterior wall of the Rathke’s pouch proliferates to form pars distalis and the thin posterior wall forms the pars intermedia. The original cleft largely obliterates but its remnants (colloid follicles) are present between pars distalis and pars intermedia (some regard the intraglandular cleft as persistent part of Rathke’s pouch).

Contd...

Fig. 56.10: Development sources of pituitary gland
(Note that the cleft inside the adenohypophysis is the remnant of Rathke’s pouch)
The original site of attachment of the Rathke’s pouch in the stomodeum, shifts posteriorly in the roof of the nasopharynx and is indicated by a dimple in the mucosa above the nasopharyngeal tonsil in the adult.

The neurohypophysis develops from the down growth (towards Rathke’s pouch) from the base of diencephalon part of developing brain.

**Congenital Anomalies**

- A remnant of Rathke’s pouch left in the roof of nasopharynx is called pharyngeal hypophysis.
- Remnants of Rathke’s pouch may give origin to tumors called craniopharyngiomas, which are found inside the sphenoid bone.

### Subdivisions of Pituitary (Fig. 56.11)

1. The adenohypophysis consists of three parts.
   - The pars distalis or pars anterior or anterior lobe
   - Pars intermedia
   - Pars tuberalis.

2. The neurohypophysis consists of three parts.
   - Pars nervosa or posterior lobe
   - Infundibular stem
   - Median eminence (which is the part of tuber cinereum of hypothalamus from which infundibular stem begins).

### Infundibulum

The infundibulum is the functional link between pituitary and hypothalamus. It belongs to both subdivisions of the pituitary. The stem of the infundibulum carries neural fibers from the hypothalamus to the pars nervosa. The part of adenohypophysis that surrounds the infundibular stem is known as pars tuberalis. The infundibulum is composed of the infundibular stem (hypothalamo-hypophyseal tract), hypophyseal portal vessels and pars tuberalis.

### Relations of Pituitary (Figs 56.6 and 56.12)

1. The dural relations of the gland are as follows:
   - The dural fold called diaphragma sellae separates the pituitary from the hypothalamus.
   - The infundibulum passes through the central aperture in the diaphragma sellae. The pituitary is surrounded by dura mater all around.
   - The capsule of the gland is adherent to the dura mater hence subdural and subarachnoid spaces are absent around the gland. This is to ensure that pituitary is protected from the effects of high CSF pressure. The empty sella syndrome occurs, when the central aperture in the diaphragma sellae is large and the pia-arachnoid herniates through it into the pituitary fossa. This leads to accumulation of CSF in the herniated subarachnoid space with consequent compression and atrophy of the gland.

2. Inferiorly, the gland is related to the sphenoidal air sinuses.

3. The optic chiasma is located very close anteriorly and superiorly and hence pituitary growths present with visual symptoms.

4. On either side, the pituitary is related to the cavernous sinus and its contents.
Connections with Hypothalamus (Fig. 56.13)

i. The neurohypophysis is directly connected to the supraoptic and paraventricular nuclei of the hypothalamus via hypothalam hypophyseal or supraopticohypophyseal tract. Vasopressin and ADH produced by the neurons in these nuclei are transported by the nerve fibers in the tract and are stored in the nerve terminals (Herring bodies) in the neurohypophysis. The hormones are released in the venous sinusoids as per the demand.

ii. The adenohypophysis communicates with the hypothalamus via the portal blood vessels, which transport releasing hormones and release inhibiting hormones to the adenohypophysis. These hormones are secreted by the tuberal infundibular or arcuate nuclei and are carried by the tuberoinfundibular tract to the capillary bed in the median eminence. The hypothalamo hypophyseal portal veins begin in this capillary bed and terminate in the capillary bed in the adenohypophysis. Figure 56.14 illustrates the role of hypothalamus as master orchestrator of endocrine system.

Blood Supply (Fig. 56.15)

1. The adenohypophysis receives blood from two sources (arterial and portal venous).
   i. The superior hypophysial arteries are the branches of the internal carotid artery.
   ii. The long and short portal veins originate in the primary plexus formed by the superior hypophyseal arteries in the vicinity of the median eminence and reach the pars distalis through the infundibulum. The portal veins break up into secondary plexus in the substance of the pars distalis. Thus, the hypophyseal portal veins begin in the capillary bed at the median eminence and terminate in the capillary bed in the adenohypophysis and carry the releasing and release inhibiting hormones (factors) from the hypothalamus to the adenohypophysis.

2. The neurohypophysis receives arterial blood from the inferior hypophysial arteries, which are the branches of internal carotid artery.

3. The veins of the pituitary drain into the cavernous or inter-cavernous sinuses.

Structure of Adenohypophysis

The adenohypophysis is highly cellular with abundant vasculature comprised hypothalamohypophyseal venous sinusoids. The following main types of cells are observed on routine hematoxylin and eosin staining.

Chromophobes (Cells without Affinity for Dyes)
These cells form a small percentage.

Acidophils (Cells with Affinity for Acidic Dyes)
These are of two types.
1. The somatotrophs secrete growth hormone or somatotropin.
2. The mammotrophs secrete lactogenic hormone or prolactin or PRL.

**Basophils (Cells with Affinity for Basic Dyes)**

The basophils are of three types.

i. The gonadotrophs secrete FSH (follicle stimulating hormone), LH (luteinising hormone) or ICSH (interstitial cell stimulating hormone). They are regulated by gonadotropin releasing hormone.

ii. The thyrotrophs secrete TSH (thyroid stimulating hormone), which is controlled by thyrotropin releasing hormone.

iii. The corticotrophs secrete ACTH, which is regulated by corticotropin release hormone.

**Cells of Pars Intermedia**

These cells secrete MSH (melanocyte stimulating hormone). They are believed to be under the control of both MSH release and MSH-inhibitory factors.

**Structure of Neurohypophysis**

i. The neurohypophysis consists mainly of unmyelinated nerve fibers of the hypothalamo hypophyseal tract. The neurohypophysis does not secrete any hormones but it stores and releases oxytocin and aldosterone (ADH). These hormones are stored in the nerve terminals, which when dilated, are called Herring bodies.

ii. The neuroglial cells called pituicytes support these nerve fibers.

iii. Venous sinusoids.

**Clinical insight ...**

1. The commonest tumor of the pituitary is the adenoma arising from chromophobe cells. It compresses the structures in relation to the gland leading to diverse signs and symptoms.
   i. Pressure on the central part of optic chiasma results in loss of right and left temporal fields of vision (bitemporal hemianopia).
   ii. Pressure on the cavernous sinus gives rise to exophthalmos and paralysis of the muscles of the eyeball supplied by third, fourth and sixth cranial nerves.
   iii. Downward growth of the tumor may break the sella turcica and cause the enlargement of the hypophyseal fossa, which is seen on a plain radiograph of the cranium as ballooning of the sella turcica.

2. An adenoma of acidophils results in excessive secretion of growth hormone causing gigantism in childhood and acromegaly in adults.

3. An adenoma of basophils is small hence does not produce pressure effects. It secretes excess of ACTH causing Cushing’s syndrome, in which there is abnormal deposition of fat on face (mooning of face), neck and trunk. Females are more prone to this condition.

4. PRL secreting tumors are also common type of pituitary tumors. The high level of PRL in this condition causes loss of reproductive functions and inappropriate milk production (galactorrhea).

5. The pituitary gland can be removed surgically.
   i. In transnasal transsphenoidal approach the pituitary is approached via the roof of the nasal cavity (by removing the rostrum of the sphenoid) and then through the sphenoid sinus.
   ii. In transorbital-transethmo-sphenoidal route the lamina papyracea of the ethmoid is entered first to reach the ethmoidal sinuses. Then the partitions of the ethmoidal air cells are broken.
CENTRAL NERVOUS SYSTEM

The central nervous system (CNS) consists of brain and spinal cord. The adult brain contains about 100 billion neurons. It weighs 1300 to 1400 g. The brain is the enlarged, convoluted, and highly developed portion of the central nervous system in human being. In the living state, the brain is very soft and gelatinous. The brain is protected by the rigid cranial cavity inner to which, it is invested by a succession of three meninges. The subarachnoid space-filled with cerebrospinal fluid acts as a shock absorber and gives added protection, when the head receives jolts.

i. The cerebrum and the diencephalon are located in the supratentorial compartment of the cranial cavity.

ii. From the base of the diencephalon (hypothalamus), the hypophysis cerebri is suspended by the infundibulum.

iii. The hindbrain is located in the posterior cranial fossa below the tentorium cerebelli and consists of the pons, medulla oblongata and the cerebellum.

iv. The midbrain is located between the pons, diencephalon and cerebrum.

v. The brainstem consists of midbrain, pons and medulla oblongata.

Main Parts of Brain
The various parts of brain has been described in Table 57.1.

Gray Matter and White Matter
i. In the cerebrum and cerebellum, the gray matter is on the surface and is called cortex while the white matter forms the core.

DEVELOPMENT

The brain and spinal cord develop from the neural tube (Fig. 57.1).

Neural Tube
The neural tube has a central canal, roof plate, floor plate and the lateral walls. The central canal is diamond-shaped to begin with. The roof and floor plates are thin and without neural tissue. The lateral walls are composed of three
layers, namely outer marginal, middle mantle and inner ependymal.

**Development of Spinal Cord (Fig. 57.2)**

The caudal part of the neural tube develops into the spinal cord.

i. Appearance of sulcus limitans divides the mantle layer into the alar (dorsal or sensory) lamina and the basal (ventral or motor) lamina.

ii. The alar lamina gives origin to sensory neurons in posterior horn.

iii. The basal lamina gives origin to motor neurons in anterior horn.

iv. The marginal layer enlarges to form the three funiculi of the spinal cord. As the posterior funiculi increase in thickness their medial surfaces come into contact, thus obliterating the dorsal part of the central canal of the neural tube. The ependymal lining of the obliterated central canal forms the posterior median septum, which is composed of neuroglial tissue only.

**Positional Changes in Spinal Cord**

i. Until the third month of intrauterine life the spinal cord extends the entire length of the vertebral column.

ii. At birth, the lower end of the spinal cord is at level of the lower border of the third lumbar vertebra.

iii. In the adult, the spinal cord ends at the lower border of first lumbar vertebra.

Below this level, the vertebral canal contains cauda equina, which is composed of filum terminale and the roots of the lumbar, sacral and coccygeal nerves.

**Spina Bifida Defects**

The spina bifida usually is found in the sacro-lumbar region. The Figure 57.3 shows a still born baby with meningocele. Spina bifida with myeloschisis or rachischisis is the most severe anomaly, in which the neural tube is exposed on the surface of the back. These defects are due to failure of the closure of the posterior neuropore. It is believed to be due to deficiency of folic acid in the mother. Periconceptional (around the time of the fertilization) folic acid intake by mothers is widely practiced to prevent the occurrence of neural tube defects.

**Clinical insight ...**

### Spina Bifida Defects

The spina bifida usually is found in the sacro-lumbar region. The Figure 57.3 shows a still born baby with meningocele. Spina bifida with myeloschisis or rachischisis is the most severe anomaly, in which the neural tube is exposed on the surface of the back. These defects are due to failure of the closure of the posterior neuropore. It is believed to be due to deficiency of folic acid in the mother. Periconceptional (around the time of the fertilization) folic acid intake by mothers is widely practiced to prevent the occurrence of neural tube defects.
Development of Brain

The cranial part of the neural tube dilates to form three primary brain vesicles.

Primary Brain Vesicles

i. Prosencephalon or forebrain
ii. Mesencephalon or midbrain
iii. Rhombencephalon or hindbrain (Fig. 57.4).

There are two bends or flexures in the neural tube at this stage, which are concave ventrally. The cervical flexure is present at the junction of spinal cord and rhombencephalon. The cephalic flexure is located in the region of mesencephalon. These flexures divide the neural tube into five secondary vesicles.

Secondary Brain Vesicles

i. The prosencephalon divides into the telencephalon and diencephalon.
ii. The mesencephalon remains as such.
iii. The rhombencephalon divides by an acute pontine flexure (concave dorsally) into cranial part called metencephalon and caudal part called myelencephalon.

The cavity of the rhombencephalon or hindbrain develops into fourth ventricle. The cavity of mesencephalon becomes the cerebral aqueduct. The cavity of diencephalon becomes the cavity of third ventricle and the cavity of each telencephalic vesicle becomes the lateral ventricle.

Effect of Pontine Flexure

The roof plate of the hindbrain (rhombencephalon) is stretched in lateral directions due to the acute pontine flexure in such a way that the alar laminae come to lie dorsolateral to the basal laminae. Therefore, both the laminae lie in the floor of the fourth ventricle side by side.

Functional Classification of Neurons in Developing Brain (Fig. 57.5)

The neurons in the opened out rhombencephalon arrange into seven functionally different columns. Each column contains nuclei of cranial nerves performing specific function.

i. General somatic efferent (GSE) neurons are closer to the midline and supply the skeletal muscles developed from somites. The nuclei in this group are hypoglossal, abducent, trochlear and oculomotor nuclei.
ii. Special visceral efferent (SVE) or branchial efferent (BE) neurons are lateral to GSE column. The nuclei in this group are nucleus ambiguous, motor nucleus of facial nerve and motor nucleus of trigeminal nerve. They supply the skeletal muscles developed from mesoderm of the branchial arches.

iii. General visceral efferent (GVE) neurons consist of parasympathetic cranial outflow for the glands and smooth muscles. The nuclei in this group are, dorsal nucleus of vagus, inferior salivatory nucleus, superior salivatory nucleus and Edinger-Westphal nucleus.

Columns Derived from Alar Lamina

i. General visceral afferent (GVA) neurons receive sensations from the viscera. The nucleus of tractus solitarius and dorsal nucleus of vagus represent this group.

ii. Special visceral afferent (SVA) neurons receive sensation of taste. The nucleus of tractus solitarius receives taste fibers from the facial, glossopharyngeal and vagus nerves.

iii. General somatic afferent (GSA) neurons receive sensations from skin of head and face via the trigeminal nerve. The nuclei in this group are nucleus of the spinal tract of CNV, principal sensory nucleus of CNV and the mesencephalic nucleus of CNV.

iv. Special somatic afferent (SSA) neurons receive sensations of hearing and balance and are present in the cochlear and vestibular nuclei.

Derivatives of Myelencephalon

It develops into medulla oblongata and contains the caudal or medullary half of fourth ventricle and the central canal of medulla oblongata in its closed part.

Derivatives of Metencephalon

It develops into the pons and cerebellum.

Development of Cerebellum

The cerebellum develops from the rhombic lips, which are the thickenings of the alar laminae at the junction of roof plate and the alar laminae of metencephalon. The right and left rhombic lips fuse across the roof to form a dumb-bell shaped cerebellar rudiment. The midline part of the cerebellar rudiment forms the vermis and the lateral portions form the cerebellar hemispheres. The fissura posterolateralis is the first fissure to develop as it separates the flocculonodular lobe (archicerebellum) from the rest of the cerebellum. The second fissure to develop is the fissura prima which separates the anterior lobe (spinocerebellum) from the middle lobe (neocerebellum). Subsequently, the other fissures develop.

Derivatives of Mesencephalon

The narrow central cavity of the mesencephalon becomes the cerebral aqueduct. The alar lamina forms the colliculi and the substantia nigra. The basal lamina gives origin to motor nuclei. The mesencephalic nucleus of trigeminal nerve is unique in being the only nucleus in the brain, which is composed of pseudounipolar neurons (derived from the neural crest).

Derivatives of Diencephalon

i. In the region of the diencephalon, the neural tube does not possess basal lamina. So the derivatives of the diencephalon (epithalamus, thalamus, hypothalamus, metathalamus and subthalamus) originate from the alar lamina only.

ii. The optic vesicles (optic cup and optic stalk) projecting from the diencephalon form the retina, optic nerve, optic chiasma and optic tract.

Derivatives of Telencephalon

The telencephalon consists of right and left cerebral vesicles containing the cavity of lateral ventricle in each. The cerebral vesicle expands in all directions to form the temporal, occipital, parietal and frontal lobes. The choroid fissure develops along the medial ependymal wall of the hemisphere. In this location, the vascularized piamater comes in direct contact with the ependyma to facilitate the entry of choroid plexus into the interior of the ventricle.

Cerebral Cortex

The thickened wall of the cerebral vesicle is called pallium, which differentiates into the cerebral cortex.

Archipallium

The hippocampus and dentate gyrus develop during the seventh week. Hence, the hippocampus is called the archipallium.

Paleopallium

The piriform cortex (which includes uncus, anterior part of parahippocampal gyrus and anterior perforated substance) with predominantly olfactory connections develops next and is called paleopallium.

Neopallium

The neopallium is represented by the entire cerebral cortex except the derivatives of archipallium and paleopallium.
The cortex surrounding the lateral sulcus grows faster so that the cortex of the lateral sulcus is submerged to form the insula.

**Fig. 57.6:** Degenerated mass of brain tissue in a newborn with anencephaly as a result of nonclosure of anterior neuropore and defect in the cranial vault

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**Clinical insight ...**

**Congenital Anomalies**

i. Anencephaly (Fig. 57.6) is one of the common types of neural tube defect (NTD), in which the cranial vault is fully or partially absent. It results from failure of anterior neuropore to close. Anencephalic fetuses usually are born dead or die within a few days or hours after birth. The malformed brain is exposed and appears as a discoid mass of highly vascularized tissue consisting of rudimentary cerebral hemispheres. The fetus lacks the mechanism of swallowing, which results in hydramnios. Assessing the level of AFP (alpha fetoprotein) in amniotic fluid helps in prenatal diagnosis (AFP level is high). Peri-conceptional folic acid therapy to the mother (giving folic acid tablets to the mother around the time of conception) is an effective method of prevention.

ii. Arnold-Chiari syndrome occurs due to cerebello-medullary malformation in which cerebellar tonsils and medulla oblongata herniate through a congenitally large foramen magnum resulting in a wide spectrum of symptoms and signs.

iii. Dandy-Walker syndrome is the congenital dilatation of the fourth ventricle due to atresia of foramina of Luschka and Magendie.

iv. Lissencephaly or agyria is the absence of sulci and gyri in the cerebral cortex.
The base of the brain is its inferior aspect between the two cerebral hemispheres.

**Features Visible at Base of Brain**
A pair of olfactory bulbs and tracts is present most anteriorly. The optic chiasma is a prominent midline structure, where the optic nerves decussate and the optic tracts begin. The lamina terminalis stretches between the dorsum of optic chiasma and the rostrum of corpus callosum. The vallecula of the cerebrum is a depression lateral to the optic chiasma.

**Anterior Perforated Structure**
The anterior perforated substance is the surface gray matter seen in the roof of the vallecula. It is pierced by anterolateral group of central branches of the circle of Willis. Laterally the anterior perforated substance is continuous with the limen insulae. Superiorly, it is continuous directly with the head of caudate nucleus providing the only link between the surface gray matter and the intracerebral gray matter. The stem of the lateral sulcus begins in the base of brain lateral to the anterior perforated substance. The internal carotid artery terminates as the anterior and middle cerebral arteries at the vallecula. The middle cerebral artery enters the stem of the lateral sulcus and the anterior cerebral artery turns medially to enter the longitudinal fissure. The basilar vein is formed at this site by the union of deep middle cerebral vein, anterior cerebral vein and striate veins (coming out of the anterior perforated substance).

**Interpeduncular Fossa**
This is a depressed area at the base of the brain. The interpeduncular cistern of subarachnoid space lies in the fossa. The circle of Willis lies in this cistern.

**Fig. 58.1A:** Positions of cranial nerves at inferior surface of brain

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### Chapter Contents

- **BASE OF BRAIN**
  - Features Visible at Base of Brain
  - Anterior Perforated Substance

- **BRAINSTEM**
  - Medulla Oblongata
  - Pons
  - Midbrain

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BASE OF BRAIN AND BRAINSTEM

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Boundaries (Fig. 58.1B)

i. The optic chiasma forms the anterior boundary.
ii. The optic tract forms the anterolateral boundary on each side.
iii. The crus cerebri of the midbrain bound the fossa posterolaterally on each side.
iv. The small midline part of the upper border of pons forms the posterior boundary.

Structures in the Fossa

i. The oculomotor nerve emerges from the medial side of each crus cerebri to enter the fossa.
ii. The posterior perforated substance is located in the midline between the right and left crura cerebri of midbrain and the upper margin of pons. It is pierced by the postero-median group of central arteries from the circle of Willis.
iii. The mamillary bodies (part of hypothalamus) are two rounded swellings present anterior to the posterior perforated substance.
iv. The tuber cinereum (a part of hypothalamus) is the raised area of gray matter bounded anteriorly by optic chiasma, laterally by optic tracts and posteriorly by mamillary bodies. It forms the floor of third ventricle. The infundibulum and the median eminence are its named parts. The infundibulum extends downwards from the tuber cinereum to the neurohypophysis. The median eminence is between the infundibulum and the mamillary bodies. It contains capillary plexus of hypophyseal portal vessels and specialized cells called tanicytes (which presumably monitor the hormone concentration of blood).

BRAINSTEM (FIGS 58.2A AND B)

The brainstem consists of the medulla oblongata, pons and midbrain. The pons and medulla oblongata are located in the infratentorial compartment of the cranial cavity and the midbrain passes through the tentorial notch. The brainstem gives passage to the various ascending and descending tracts besides housing nuclei of third to twelfth cranial nerves.

The functional significance of the brainstem is that it houses the vital centers for the control of respiration, cardiovascular activity and alertness.

Know More ...

The term “bulb” was earlier used for medulla oblongata. Hence, one comes across terms like corticobulbar fibers and bulbar palsy, pseudobulbar palsy and bulbar poliomyelitis.

Medulla Oblongata

The medulla oblongata is cone shaped. It extends from the lower margin of pons to the upper end of the spinal cord at the level of superior border of posterior arch of atlas. It is connected to the cerebellum by means of inferior cerebellar peduncle (refer to chapter 59 for the fiber content of this peduncle).
**Location**

The medulla oblongata is located in the posterior cranial fossa.

**Relations**

i. Its anterior surface is in contact with the clivus (basisphenoid).

ii. The upper part of its posterior surface forms the floor of fourth ventricle while the lower part of the posterior surface in contact with the cerebellum.

**Subdivisions**

i. The open part is the upper half. It takes part in the formation of fourth ventricle. Its posterior wall is covered with the gray matter of the floor of fourth ventricle.

ii. The closed part is the lower half. It encloses the central canal of medulla oblongata, which is continuous above with the lower end of the fourth ventricle and below with the central canal of the spinal cord.

**Surface Features**

i. The anterior surface presents a prominent median sulcus and an anterolateral sulcus on each side. The pyramid lies between these two sulci and the olive is lateral to the anterolateral sulcus.

ii. The rootlets of the hypoglossal nerve are attached to the anterolateral sulcus between the olive and the pyramid.

iii. The posterior aspect has a posterior median sulcus and posterolateral sulcus on each side.

iv. The rootlets of the glossopharyngeal and cranial part of eleventh cranial nerves are attached to the posterolateral sulcus.

v. The abducent nerve is attached at the upper end of pyramid. The seventh and eighth cranial nerves with a small nervus intermedius are attached at the upper end of the olive at the pontomedullary junction.

**Pyramid**

Each pyramid lies between the anterior midline sulcus and anterolateral sulcus. It is related to hypoglossal rootlets laterally.

i. The pyramid is composed of bundles of corticospinal or pyramidal fibers, which connect the upper motor neurons in the motor cortex to the lower motor neurons (anterior horn cells) in the ventral horn of spinal gray matter.
ii. At the lower part of medulla oblongata, about 75 to 90 percent corticospinal fibers cross in the pyramidal decussation. The crossed and uncrossed fibers form the lateral and anterior corticospinal tracts, respectively.

**Know More ...**

The arcuate nucleus lies on the surface of the pyramid. It gives rise to anterior external arcuate fibers, which pass in front of the olive laterally to enter the inferior cerebellar peduncle. The arcuate nucleus is a collection of displaced pontine nuclei. Hence, the anterior external arcuate fibers are displaced pontocerebellar fibers.

**Olive**

The olive overlies a large inferior olivary nucleus, which lies deep in the medulla. The olive is flanked by the rootlets of hypoglossal nerve on the medial side and rootlets of the glossopharyngeal, vagus and eleventh cranial nerves on the lateral side.

**Gracile and Cuneate Tubercles**

i. The gracile and cuneate fasciculi are present on the posterior surface of the closed part of the medulla. The medially placed fasciculus gracilis (tract of Gall) ends superiorly in the gracile tubercle, which overlies the gracile nucleus. The laterally placed fasciculus cuneatus (tract of Burdach) ends in cuneate tubercle, which overlies the cuneate nucleus.

ii. The accessory cuneate nucleus (placed lateral to the cuneate tubercle) receives fibers carrying unconscious proprioception from the upper limb through the fasciculus cuneatus. The efferent fibers from this nucleus are called the posterior external arcuate fibers (cuneocerebellar tract).

**Tuberculum Cinereum**

When present, it is a raised area anterolateral to the fasciculus cuneatus. It is produced by the underlying spinal tract of the trigeminal nerve.

**Clinical insight ...**

**Herniation via Foramen Magnum**

Increased intracranial tension due to a tumor in the posterior cranial fossa favors the herniation of medulla oblongata and cerebellar tonsils into the foramen magnum. Further herniation into the vertebral canal is likely to endanger the life due to sudden compression of cardiovascular and respiratory centers in the medulla oblongata.

**Internal Structure**

The internal structure of the medulla oblongata is not uniform throughout because the position and number of nuclei and fiber tracts vary at various levels. Therefore, it is customary to study the internal structure from below upwards at three levels, at pyramidal decussation, at sensory decussation and at mid-olivary level.

**Transverse Section at the level of Pyramidal Decussation (Fig. 58.3)**

The cross section at this level is characterized mainly by the following:

*Fig. 58.3: Transverse section of medulla oblongata at the level of pyramidal decussation*
i. Central canal of medulla oblongata
ii. Gray matter surrounding the central canal
iii. Pyramidal decussation in white matter anterior to the central gray matter.

Gray Matter at Pyramidal Decussion
i. The nucleus gracilis and nucleus cuneatus are the posterior projections of the central gray matter.
ii. The lateral ends of the gray matter contain the nucleus of the spinal tract of trigeminal nerve. This nucleus extends in the upper two cervical segments of the spinal cord, where it is continuous with the substantia gelatinoa of the posterior gray horn of spinal cord.
iii. A small part of the anterior gray matter is cut off from the central gray matter by the decussating pyramidal fibers. This detached part is the junctional gray matter. It is divisible into supraspinal nucleus and accessory nucleus. The supraspinal nucleus is continuous above with hypoglossal nucleus and below with the anterior horn cells of the first spinal segment. The accessory nucleus is continuous above with the nucleus ambiguous and below with the spinal nucleus of the accessory nerve.

White Matter at Pyramidal Decussion
i. The most prominent feature is the decussation of the pyramidal or corticospinal fibers in front of the central gray matter. Majority of fibers (between 75 and 90%) cross to the opposite side to form lateral corticospinal tract. The uncrossed fibers constitute the anterior corticospinal tract.
ii. The posterior part contains fasciculus gracilis and fasciculus cuneatus.

iii. The spinal tract of trigeminal nerve is located peripheral to the corresponding nucleus and is continuous with the tract of Lissauer in the spinal cord. This tract carries pain and temperature sensations from the face.
iv. The lateral parts of medulla oblongata contain ascending and descending tracts as shown in Figure 58.3.
v. The medial longitudinal fasciculus (MLF) is continuous with the anterior intersegmental tract of the spinal cord.

Transverse Section at the Level of Sensory Decussion (Fig. 58.4)
The level of sensory decussation is higher than that of pyramidal decussion. The most prominent feature of the medulla at this level is the decussation of the internal arcuate fibers (which are the axons of the cells of the gracile and cuneate nuclei) anterior to the central gray matter. The reticular formation occupies the space between the fiber tracts and nuclear groups.

Gray Matter at Sensory Decussion
i. The nucleus gracilis and nucleus cuneatus are prominent features posterior to the central gray matter. The larger nucleus gracilis is medial to nucleus cuneatus. The accessory cuneate nucleus projects from the lateral aspect of cuneate nucleus on each side.

Know More ...
The nucleus Z at the upper pole of nucleus gracilis receives input from dorsal spinocerebellar tract carrying sensations of conscious proprioception from lower limb.

Fig. 58.4: Transverse section of medulla at the level of sensory decussion
ii. The nucleus of the spinal tract of trigeminal nerve is located anterolateral to the cuneate nucleus.

iii. The central gray matter contains the hypoglossal nuclei, dorsal nuclei of vagus and nuclei of solitary tract of both sides.

iv. The nucleus ambiguus is present between the central gray and the spinal nucleus of trigeminal nerve.

v. The inferior olivary nucleus makes its appearance at this level posterolateral to the pyramid.

White Matter at Sensory Decussation
i. The internal arcuate fibers originating in the gracile and cuneate nuclei cross in the sensory decussation in front of the central gray.

ii. The decussating internal arcuate fibers form the medial lemniscus on the opposite side.

iii. The medial lemniscus is located anterior to the central gray closer to the midline. It carries sensation of conscious proprioception, two-point discrimination, vibration and pressure.

iv. The pyramids are prominent at this level.

v. The spinal tract of the trigeminal nerve produces a surface elevation called the tuberculum cinereum.

vi. All the descending tracts are present except the corticospinal tracts and all other ascending tracts from spinal cord are present at this level.

Transverse Section at Mid-olivary Level
The mid-olive level is the open part of the medulla oblongata (Fig. 58.5). Hence, its posterior surface is covered with the gray matter of the floor of fourth ventricle.

Gray Matter at Mid-olivary Level
The inferior olivary nucleus is a large crumpled mass of gray matter on each side in the anterolateral part. It gives origin to olivo-cerebellar fibers, which exit through the medially directed hilum. The fibers cross to enter the opposite inferior cerebellar peduncle to reach the cerebellum.

i. The hypoglossal nucleus is located in the gray matter in the floor of the fourth ventricle close to the midline. The intramedullary fibers of hypoglossal nerve pass in anterior direction at first between the medial lemniscus and inferior olivary nucleus and then between the latter and the pyramid to emerge on the surface of medulla.

ii. The nucleus ambiguus is located in the reticular formation posterior to the inferior olivary nucleus. (From its embryonic position lateral to hypoglossal nucleus at the floor of fourth ventricle the nucleus ambiguous moves towards spinal nucleus of trigeminal nerve due to forces of neurobiotaxis).

iii. The dorsal motor nucleus of vagus lies lateral to the hypoglossal nucleus in the gray matter of the floor of the fourth ventricle. Its axons form the preganglionic component of the cranial outflow of parasympathetic system.

iv. The inferior salivatory nucleus is located at upper part of medulla oblongata.

v. The nucleus of tractus solitarius or solitary nucleus receives general visceral sensations as well as special visceral or taste sensations.
vi. The spinal nucleus of trigeminal nerve lies a little deeper in the medulla, medial to the inferior cerebellar peduncle.

vii. The lower ends of the vestibular and cochlear nuclei are placed in the lateral part nearer the inferior cerebellar peduncle.

viii. The nuclei of cardiovascular and respiratory centers are present in the reticular formation adjoining the nucleus of tractus solitarius and dorsal nucleus of vagus.

**White Matter at Mid-olivary Level**

The white matter of the medulla oblongata at this level is organized into distinct tracts.

i. The medial lemniscus is disposed anteroposteriorly very close to the median plane. The medial longitudinal bundle is located at the posterior end of medial lemniscus.

ii. The corticospinal fibers are contained inside the pyramids.

iii. The lateral and anterior spinothalamic tracts are positioned posterolateral to the inferior olivary nucleus.

iv. The posterior spinocerebellar tract is very close to the anterior aspect of inferior cerebellar peduncle. The anterior spinocerebellar tract is anterior to the corresponding posterior tract but close to the surface.

v. The spinal tract of trigeminal nerve along with its nucleus lies posterior to spinothalamic tracts.

**Arterial Supply of Medulla Oblongata**

i. The medullary branches of anterior spinal artery supply the medial region of the medulla oblongata, which includes the hypoglossal nucleus, medial lemniscus and the pyramid.

ii. The medullary branches of posterior inferior cerebellar artery (PICA) supply the posterolateral region of the medulla, which includes nucleus ambiguus, nucleus of tractus solitarius, vestibular nucleus, spinal nucleus and tract of trigeminal nerve, spinothalamic tracts, inferior cerebellar peduncle and descending sympathetic fibers.

iii. The posterior region, which includes the gracile and cuneate tubercles, receives supply from the branches of the posterior spinal artery.

**Clinical insight ...**

**Medial Medullary Syndrome**

This syndrome results due to deficient arterial supply to the medial region of medulla oblongata as a result of the thrombosis of anterior spinal artery.

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**Neurological Effects**

<table>
<thead>
<tr>
<th>Structure involved</th>
<th>Resultant signs and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyramid</td>
<td>Contralateral hemiplegia-UMN</td>
</tr>
<tr>
<td>Intramedullary hypoglossal nerve</td>
<td>Ipsilateral paralysis of tongue-LMN</td>
</tr>
<tr>
<td>Medial lemniscus</td>
<td>Contralateral loss of conscious proprioception, discriminative touch and vibration from the body</td>
</tr>
</tbody>
</table>

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**Lateral Medullary or Wallenberg Syndrome**

This syndrome results due to deficient arterial supply to the posterolateral region of medulla oblongata as a result of occlusion of posterior inferior cerebellar artery (PICA). Hence, this is also known as PICA syndrome.

**Neurological Effects**

<table>
<thead>
<tr>
<th>Structure involved</th>
<th>Resultant signs and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinothalamic tract</td>
<td>Contralateral loss of pain and temperature sensation from the body</td>
</tr>
<tr>
<td>Spinal tract and nucleus</td>
<td>Ipsilateral loss of pain and temperature sensation on face</td>
</tr>
<tr>
<td>Nucleus ambiguus</td>
<td>Ipsilateral paralysis of laryngeal, pharyngeal and palatal muscles resulting in hoarseness of voice, dysphagia, dysarthria and deviation of uvula opposite to the side of lesion.</td>
</tr>
<tr>
<td>Vestibular nucleus</td>
<td>Vertigo, nausea, nystagmus</td>
</tr>
<tr>
<td>Inferior cerebellar peduncle</td>
<td>Ipsilateral ataxia</td>
</tr>
<tr>
<td>Descending sympathetic fibers in reticular formation</td>
<td>Ipsilateral Horner’s syndrome</td>
</tr>
</tbody>
</table>

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**Pons**

The pons forms a bridge between the hindbrain and midbrain. It appears as a protuberance above the medulla oblongata and anterior to the cerebellum. The pons is connected to the cerebellum by middle cerebellar peduncle.

The anterior surface of the pons presents a transversely ridged appearance due to the underlying transversely
disposed ponto-cerebellar fibers. Its posterior surface is covered with gray matter and forms the upper half of the floor of the fourth ventricle.

**External Features**

i. The basilar artery is lodged in midline sulcus on the anterior surface of pons, (which is in contact with the upper part of the clivus). The other arteries in relation to this surface are superior cerebellar, anterior inferior cerebellar and labyrinthine (branches of basilar artery).

ii. The basilar artery terminates into posterior cerebral arteries at the upper margin of pons.

iii. The right and left crus cerebri, which are the parts of the midbrain, appear to emerge and diverge from the upper margin of pons.

iv. The trigeminal nerve is attached to the junction of basilar part of pons and the middle cerebellar peduncle by a large sensory root and small motor root.

v. The abducent nerve emerges near the midline at the pontomedullary junction.

vi. The facial and vestibulocochlear nerves emerge laterally in the cerebellopontine angle.

**Cerebellopontine Angle**

The cerebellopontine angle (CP angle) is a shallow triangular area, which is bounded by the lateral aspect of pons, superior part of cerebellum and the medial third of the superior margin of petrous temporal bone.

i. There are two openings at this site, internal acoustic meatus and lateral aperture of the fourth ventricle (foramen of Luschka).

ii. The angle contains facial nerve, vestibulocochlear nerve, labyrinthine artery and the protruding choroid plexus of the fourth ventricle.

**Clinical insight ...**

**Schwannoma of Eighth Cranial Nerve**

The tumor arising from the Schwann cells (Schwannoma) in the neurilemmal sheath of the eighth nerve arises in the cerebellopontine angle. It compresses the eighth nerve initially and the seventh nerve gradually. At a later stage, the tumor may compress the pons and the cerebellum. The symptoms include persistent tinnitus, deafness and vertigo (due to eighth nerve dysfunction); facial palsy (due to involvement of facial nerve) and ataxia (due to cerebellar involvement).

**Internal Structure of Pons**

The pons is subdivided into anterior or basilar part and posterior or tegmental part. The internal structure of the two parts is different.

**Basilar Part of Pons (Fig. 58.6)**

The basilar part of the pons presents uniform structure throughout the extent of pons.

i. It contains scattered pontine nuclei, which receive ipsilateral corticopontine fibers from all parts of the cerebrum. The pontine nuclei give rise to pontocerebellar fibers, which cross to the opposite side to...
reach the cerebellum through the middle cerebellar peduncle.

ii. It also contains corticospinal fibers and corticonuclear (corticobulbar) fibers.

To sum up, the longitudinal fibers in the pons are the corticospinal, corticonuclear and corticopontine. The transverse fibers in the pons are the pontocerebellar fibers.

**Tegmentum of Pons (Fig. 58.6)**
The tegmentum of pons shows different structure at its lower level and upper level.

**Tegmentum at Lower Pons**

**Gray Matter**

i. The vestibular nuclei are located in the gray matter of the floor of fourth ventricle at the lateral end. Each vestibular nucleus is divided into four parts called superior, lateral (Deiter’s), medial and inferior vestibular nuclei.

The vestibular nuclei receive sensation of balance and equilibrium brought to it by the vestibular nerve from the internal ear.

The vestibulocerebellar fibers project to the flocculonodular lobe of cerebellum. The medial longitudinal fasciculus (MLF) connects the vestibular nuclei to the cranial nerve nuclei supplying the muscles of eyeball. The lower continuation of MLF, known as anterior intersegmental tract connects the vestibular nuclei to the cranial nerve nuclei supplying the muscles of eyeball. The lower continuation of MLF, known as anterior intersegmental tract connects the vestibular nuclei to the motor neurons in the cervical spinal cord. These connections are responsible for the co-ordination between the eyes, neck and head in response to position of the body. The vestibulospinal tract arises from the lateral vestibular nucleus and terminates on the motor neurons in the spinal cord.

ii. The cochlear nuclei are related to inferior cerebellar peduncle. They consist of dorsal and ventral cochlear nuclei. The ventral and dorsal nuclei lie in respective relation to inferior cerebellar peduncle. The cochlear nerve brings auditory impulses to these nuclei from the internal ear. The cochlear nuclei project to various nuclei via efferent connections as follows. The majority of the axons of the cochlear nuclei pass in anterior direction through the reticular formation, trapezoid body and medial lemniscus to emerge on the anterior aspect of the lower margin of pons. The para-abducent neurons (inter-nuclear neurons or interneurons) are part of the abducent nucleus.

iv. The motor nucleus of the facial nerve is located deeply in the reticular formation. Its axons have an unusual course inside the pons. At first, they incline in postero-medial direction towards the medial aspect of abducent nucleus. Then, they curve round the upper pole of the abducent nucleus forming the internal genu of the facial nerve. Finally, they descend anterolateral to pass between the facial nucleus and the nucleus of spinal tract of trigeminal nerve on way out of the pons. This unusual course of the facial nerve in the pons is an example of neurobiotaxis, which is a term, used for the tendency of neurons to migrate towards major sources of stimuli in embryonic life.

v. The superior salivatory nucleus lies just above the pontomedullary junction. The preganglionic parasympathetic fibers arising from it join the nervus intermedius of the facial nerve.

vi. The spinal nucleus of trigeminal nerve lies lateral to the facial nucleus.

**White Matter at Lower Pons**

i. The lemniscal system consists of the major ascending tracts, which are disposed as a transverse band in the pons on either side of the midline. Mediolaterally, the lemnisci are the medial lemniscus, trigeminal lemniscus, spinal lemniscus and lateral lemniscus.

ii. Anterior to the lemnisci lies the trapezoid body, which is composed of crossing fibers of the cochlear nuclei.

iii. The medial longitudinal fasciculus lies in paramedian position medial to the abducent nucleus.

iv. Other ascending tracts (except the olivospinal tract and dorsal spinocerebellar tract) and descending tracts (except the corticospinal fibers), as seen in upper medulla, are present in the tegmentum of pons.

v. The reticular formation occupies tegmentum.

**Tegmentum at Upper Pons (Fig. 58.7)**
The tegmentum of the upper pons contains all the four nuclei of the trigeminal nerve.

i. The motor nucleus of the trigeminal nerve lies deep in the lateral part of the tegmentum.

ii. The principal sensory nucleus of trigeminal nerve is located lateral to the motor nucleus. It is continuous superiorly with the mesencephalic nucleus and inferiorly with the spinal nucleus.
iii. All the four lemnisci and other tracts are present except the anterior (ventral) spinocerebellar tract, which enters the superior cerebellar peduncle.

Arterial Supply of Pons
The pontine branches of the basilar artery and the pontine branches of anterior inferior cerebellar and superior cerebellar arteries, supply the pons. The paramedian penetrating arteries supply the anterior part and the peripheral circumferential arteries supply the posterolateral region of the pons.

Clinical insight...

### Anterior Inferior Cerebellar Artery (AICA) Syndrome
This is a vascular lesion involving the structures of the lateral portion of lower pons.

<table>
<thead>
<tr>
<th>Structure involved</th>
<th>Resultant signs and symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facial nucleus</td>
<td>Ipsilateral facial paralysis-LMN</td>
</tr>
<tr>
<td>Solitary nucleus</td>
<td>Ipsilateral loss of taste sense from anterior 2/3rd of tongue</td>
</tr>
<tr>
<td>Cochlear nucleus</td>
<td>Clinically asymptomatic (ipsilateral weak hearing identified only by sophisticated audiometric tests)</td>
</tr>
</tbody>
</table>

### Contd...

<table>
<thead>
<tr>
<th>Vestibular nucleus</th>
<th>Vertigo, nausea, nystagmus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal tract and nucleus of trigeminal nerve</td>
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</tr>
<tr>
<td>Spinothalamic tract</td>
<td>Contralateral loss of pain and temperature sense from the body</td>
</tr>
<tr>
<td>Descending sympathetic fibers in reticular formation</td>
<td>Ipsilateral Horner’s syndrome</td>
</tr>
</tbody>
</table>

### Pontine Hemorrhage
The rupture of arteries supplying the pons leads to intrapontine bleeding. If massive it is invariably fatal. The patient goes into coma, has pinpoint pupils and has hyperpyrexia (running very high temperature).

### Millard Gubler Syndrome
This is the lesion of pons in which abducent and facial nerves are involved along with corticospinal fibers.

### Effects of Lesion
i. Ipsilateral LMN facial paralysis (involving entire face) due to damage to facial nucleus
ii. Ipsilateral medial squint due to damage to abducent nucleus
iii. Contralateral hemiplegia.

### Midbrain
The midbrain is the shortest and the uppermost part of the brainstem. It is connected to the cerebellum by superior
cerebellar peduncle. The tubular cavity passing through the midbrain is called cerebral aqueduct.

**Parts of Midbrain**

i. The tectum is the part that lies posterior to the cerebral aqueduct. It consists of one pair of superior colliculi and one pair of inferior colliculi.

ii. The cerebral peduncles (right and left) are located anterior to the cerebral aqueduct.

**Subdivisions of Cerebral Peduncle**

i. Crus cerebri anteriorly

ii. Substantia nigra in the middle

iii. Tegmentum posteriorly.

The crus cerebri and substantia nigra are bilaterally present but the tegmentum is single and is traversed by cerebral aqueduct.

**External Features of Crus Cerebri**

The crus cerebri are thick rope-like pillars containing corticospinal and cortico pontine fibers. Superiorly, they are continuous with the internal capsule of cerebral hemisphere and inferiorly, they converge to meet each other as they reach the upper margin of pons.

i. The crus cerebri form the posterolateral boundaries of the interpeduncular fossa.

ii. The oculomotor nerve emerges into the interpeduncular fossa from the medial side of the crus on each side.

iii. The structures crossing the crus are posterior cerebral artery, superior cerebellar artery, trochlear nerve, posterior communicating artery, basal vein and the optic tract.

**External Features of Tectum**

i. The superior and inferior colliculi are separated from each other by a cruciform sulcus.

ii. The pulvinar of thalamus and the pineal gland are related superiorly to the tectum.

iii. The superior cerebellar peduncles enter the midbrain distal to the inferior colliculi.

iv. The trochlear nerves decussate in the superior medullary velum. The trochlear nerves are the only cranial nerves with posterior attachment to the brainstem and which cross to the opposite side before emerging.

v. The superior brachium, which is a raised band of fibers, connects the superior colliculus to the lateral geniculate body.

vi. The inferior brachium connects the side of the inferior colliculus to the medial geniculate body.

**Internal Structure of Midbrain**

The crus cerebri and substantia nigra have uniform structure at all levels but the tegmentum differs at the levels of superior and inferior colliculi.

**Fibers in Crus Cerebri (Fig. 58.8)**

The crus cerebri gives passage to the fibers originating in cerebral cortex. These fibers are arranged in a specific order.
Section i. The medial part of the crus cerebri contains the frontopontine fibers.

Section ii. The middle part contains corticospinal and corticonuclear (corticobulbar) fibers.

Section iii. The lateral part contains temporopontine, parietopontine and occipitopontine fibers.

Substantia Nigra
This is a band of medium-sized pigmented neurons situated between the crus cerebri and tegmentum on both sides. The substantia nigra appears dark in macroscopic sections because of the presence of melanin pigment in its neurons.

Section i. The neurons in substantia nigra are arranged in two zones. The pars compacta is adjacent to tegmentum and pars reticularis is adjacent to crus cerebri.

Section ii. The pars reticularis receives striatonigral fibers mainly from the caudate nucleus and putamen.

Section iii. The nigrostriatal fibers originate in pars compacta and terminate on the caudate nucleus and putamen. These fibers are dopaminergic. So dopamine is present in both substantia nigra and corpus striatum. The nigrostriatal fibers exert an inhibitory influence on the neurons of the striatum to bring about smooth voluntary movements.

White Matter at Lower Midbrain
The white matter of the midbrain at the level of inferior colliculus contains the tracts and reticular formation.

Section i. The most significant feature of the white matter is the presence of a large decussation of the fibers of the superior cerebellar peduncle (carrying dentatorubrothalamic fibers) in the midline. This is located at the level of the medial ends of the substantia nigra. The crossed fibers ascend to end in the red nucleus and in the nucleus ventralis lateralis of thalamus.

Section ii. The rubrospinal tracts lie in the midline in front of the cerebellar decussation, while the tectospinal tracts lie behind the decussation. The rubrospinal and tectospinal tracts begin at the level of superior colliculus from the red nucleus and the superior colliculus respectively, of the opposite side.

Section iii. The medial longitudinal fasciculus lies in front of the trochlear nucleus.

Section iv. The medial, trigeminal, spinal and lateral lemnisci form a curved band posterolateral to the substantia nigra. Some fibers of the lateral lemniscus end in the inferior colliculus and remaining fibers along with fibers originating in inferior colliculus aggregate to form the inferior brachium, which enters the medial geniculate body.

Tegmentum at the Level of Inferior Colliculi
(Fig. 58.8)

The tegmentum contains gray matter, fiber tracts and reticular formation.

Gray Matter at Lower Midbrain
The gray matter of the midbrain surrounds the cerebral aqueduct.

Section i. The nucleus of trochlear nerve is located in the ventral part of periaqueductal gray close to the midline. Its axons wind round the periaqueductal gray in posterior direction and decussate in the upper end of superior medullary velum with similar fibers of opposite side before emerging out.

Section ii. The mesencephalic nucleus of trigeminal nerve lies in lateral position in the central gray matter throughout the midbrain. The unusual feature of this nucleus is that it is the only nucleus in entire CNS that contains pseudounipolar neurons similar to those of sensory ganglia. The peripheral processes of these neurons are believed to bring proprioceptive sensations from the muscles of mastication, eyeball, face and tongue. Their central processes descend to end in motor nucleus of trigeminal nerve on both sides.

Clinical insight ...

In Parkinson’s disease, there is degeneration of the pigmented neurons in the substantia nigra, causing deficiency of dopamine in the corpus striatum. The patient experiences involuntary tremors while doing work. Levodopa, which is the precursor of dopamine, is helpful in some patients. Levodopa crosses the blood brain barrier and is concentrated in nigrostriatal system.

Tegmentum at the Level of Superior Colliculi
(Fig. 58.9)

Gray Matter at Upper Midbrain

Section i. The periaqueductal gray contains a single oculomotor complex, which lies in the midline ventral to the aqueduct.

Section ii. The oculomotor nucleus is divided into neuronal groups for the innervation of specific extraocular muscles. The Edinger-Westphal nucleus (which supplies parasympathetic innervation to the sphincter pupillae and ciliaris muscles) lies in association with the oculomotor complex. The axons from the oculomotor nuclear complex pass anteriorly through the red nucleus, the medial ends of substantia nigra and the crus cerebri to emerge in the interpeduncular fossa as oculomotor nerve.

Section iii. The mesencephalic nucleus of the trigeminal nerve is present laterally in the periaqueductal gray matter.
iv. The pretectal nucleus is present in relation to the upper part of the superior colliculus.

Red Nucleus

The red nucleus forms a prominent feature in the anterior part of the tegmentum closer to the midline at the level of superior colliculi. Its red color is due to presence of ferric iron in the neurons. Its main afferent connections are, the cerebellorubral fibers, (which originate in the emboliform, globose and dentate nuclei of the cerebellum) and the cerebrorubral fibers. Its efferent connections are the rubrospinal fibers. The red nucleus also communicates with ventralis lateral (VA) nucleus of thalamus by rubrothalamic projection. Besides, it projects to reticular formation, cranial nerve nuclei and inferior olivary nucleus. Since the red nucleus is part of the extrapyramidal system, it has a role in maintaining the tone of voluntary muscles.

White Matter at Upper Midbrain

The white matter of midbrain contains following tracts:

i. The dorsal tegmental decussation of Meynert consists of decussating tectospinal fibers from the superior colliculi. After crossing the fibers form tectospinal tract.

ii. The ventral tegmental decussation of Forel consists of decussating fibers (from the red nucleus), which after crossing form the rubrospinal tracts.

iii. The medial longitudinal fasciculus lies in close relation to the oculomotor complex.

iv. The ascending tracts consist of medial lemniscus, trigeminal lemniscus and spinal lemniscus in anterior to posterior order. The position of the ascending tracts is shifted laterally nearer the surface of the midbrain.

**Medial Longitudinal Fasciculus**

Medial longitudinal fasciculus (MLF) is a compact bundle of fibers, which retains its medial position throughout the brainstem (Fig. 58.10).
Connections

i. Superiorly, it ascends to the rostral interstitial nucleus of MLF, which is located just above the upper end of cerebral aqueduct. (Note the interstitial nucleus is in association with nucleus of Cajal and Darkshewitsch).

ii. It forms the premotor center of vertical gaze movements of the eyes through connections with nuclei of third and fourth cranial nerves.

iii. The rostral interstitial nuclei of MLF and the MLF of the two sides are connected by the posterior commissure.

iv. Inferiorly, the MLF is continuous with anterior intersegmental tract of spinal cord (fasciculus proprius). This way it connects the cranial nerve nuclei supplying muscles that move the eyeball to anterior horn cells of cervical spinal cord (which supply the neck muscles).

v. The MLF receives a large contribution of fibers from the vestibular nuclei through which it interconnects the oculomotor, trochlear, abducent, spinal accessory and nuclei of lateral lemniscus.

vi. MLF carries the axons of para-abducent nucleus to the contralateral oculomotor nucleus (for controlling the action of medial rectus muscle) and has connections with pontine paramedian reticular formation (PPRF), which is the horizontal gaze center.

Functions

MLF plays a role in co-ordination of vertical and horizontal conjugate eye movements. It is also important in coordinating the movements of eyes and head in response to vestibulocochlear stimulation.

Lesion of MLF

Internuclear ophthalmoplegia (Figs 58.11A and B) results due to unilateral damage to MLF in midbrain or pons. This interrupts the path of impulses from the horizontal gaze center in the pons to the opposite oculomotor nucleus in the midbrain. On attempted lateral gaze, there is nystagmus (jerky movements) in the abducting eye (contralateral eye) and slow or absent adduction in the affected side. The lesion of right MLF results in slow or absent adduction in right eye and nystagmus in the left eye during attempted lateral gaze to the left.

Lesion of the Vertical Gaze Center

This gives rise to defects in the up-gaze or down-gaze or both. Lesion of posterior commissure and its nuclei causes disturbances of up-gaze. The lesion of interstitial nucleus of Cajal may cause paralysis of downward gaze.

Tectum

The tectum consists of a pair of inferior colliculi and pair of superior colliculi. The colliculi are composed of neurons.

Inferior Colliculus

The inferior colliculi are a pair of ovoid masses of gray matter forming the lower part of tectum. Each inferior colliculus is a relay center in the auditory pathway.

i. The inferior colliculi of two sides are reciprocally connected to each other.

ii. They receive auditory impulses from both ears through the lateral lemniscus and the fibers from the
ipsilateral medial geniculate body via the inferior brachium.

iii. They projects on the medial geniculate bodies through the inferior brachium.

iv. The inferior colliculi are the reflex centers for responses to auditory stimuli. They are important in locating the source of sound.

Superior Colliculi
The superior colliculi are a pair of ovoid masses of gray matter located above the inferior colliculi.

i. Each superior colliculus is connected to the lateral geniculate body of its side by superior brachium.

ii. The superior colliculi receive retinotectal fibers, which travel in the optic tract, reach the lateral geniculate body but leave it in the superior brachium to finally terminate in the superior colliculus.

iii. They also receive spinotectal fibers from the spinal cord and the corticotectal fibers from occipital and temporal lobes.

iv. The tectospinal fibers cross over in the dorsal tegmental decussation in the midbrain and descend to reach the gray matter of the opposite side in the spinal cord.

v. The tectothalamic fibers end in the pulvinar of thalamus and the tectocortical fibers reach the occipital cortex.

vi. The superior colliculus connects to pretectal nucleus to supply retinotectal fibers (received from LGB).

vii. The superior colliculi are the reflex centers for the movements of the eyes and the head in response to the visual stimuli.

Pretectal Nucleus
This is a small collection of neurons closely related anteriorly to the upper end of superior colliculus. It receives retinotectal fibers from superior colliculus and projects on oculomotor nuclei of bilaterally. The pretectal nucleus is the center of direct and consensual light reflex.

(For details of light reflex refer to visual pathway in chapter 68)

Arterial Supply of Midbrain
The midbrain is supplied by posterior cerebral and superior cerebellar arteries, which are the branches of basilar artery. In addition direct branches from the basilar artery and from posterior communicating arteries are also received. These arteries give off paramedian and circumferential branches, which penetrate the midbrain.

Clinical insight ...

Weber’s Syndrome
Weber’s syndrome results due to infarction in basal region of cerebral peduncle following occlusion of a branch of posterior cerebral artery involving corticospinal fibers in crus cerebri and intra-tegmental fibers of oculomotor nerve. This causes contralateral hemiplegia and ipsilateral paralysis of extraocular and intraocular muscles supplied by oculomotor nerve (down and out eye with dilated and fixed pupil).

Benedict’s Syndrome
Benedict’s syndrome results due to lesion of the tegmentum involving red nucleus, fibers of third nerve and medial lemniscus. This syndrome consists of ipsilateral paralysis of muscles supplied by third nerve, contralateral hemianesthesia (loss of proprioception, discriminative touch and vibration sense) and involuntary movements like chorea and athetosis on the side of lesion.

Perinaud’s Syndrome
Perinaud’s syndrome is caused due to compression of the upper dorsal region of the midbrain including the superior colliculi by the pineal tumor. It presents as a combination of impaired upward or downward gaze (due to compression of vertical gaze center) and pupillary abnormality.

Herniation of Uncus
Herniation of the uncus of temporal lobe through the tentorial notch (Fig. 56.9) results in compression of midbrain and its displacement to the opposite side.

This results in following neurological deficits:

i. Compression of oculomotor nerve leading to ipsilateral dilated and fixed pupil.

ii. Shifting of the midbrain to the opposite side leading to compression of corticospinal fibers in opposite crus by the free edge of tentorium cerebelli. This leads to ipsilateral (on the side of lesion) hemiplegia due to injury to uncrossed corticospinal fibers in opposite crus cerebri.

iii. The compression of posterior cerebral artery leads to infarction of occipital lobe (homonymous hemianopia).
The cerebellum (Fig. 59.1) is located posterior to the medulla oblongata and pons and inferior to the occipital lobes of cerebrum in the posterior cranial fossa. The tentorium cerebelli intervenes between the cerebellum and the cerebrum. The cerebellum is the largest part of hindbrain. Its weight is about 150 gm.

i. Each cerebellar hemisphere is connected to the brainstem by three cerebellar peduncles.

ii. The inferior cerebellar peduncle connects the cerebellum to medulla oblongata, the middle cerebellar peduncle to the pons and superior cerebellar peduncle to the midbrain.

Cerebellar Cortex

The gray matter on the surface of the cerebellum is known as the cerebellar cortex, which is of uniform thickness. The cortex is folded in such a way that surface of cerebellum presents characteristic transverse fissures, which enclose between them leaf like areas (folia) of gray and white matter. The central core of white matter of the folium presents the pattern of a branching tree hence the name, arbor vitae cerebelli.

Intracerebellar Nuclei

The gray matter inside the cerebellum is disposed as four intracerebellar nuclei (dentate, emboliform, globose and fastigial).

Parts of Cerebellum

i. The cerebellum consists of right and left hemispheres, joined by the midline vermis, which has worm like appearance.

ii. Each hemisphere is divided into superior and inferior surfaces by the horizontal fissure. The vermis is also divided into superior and inferior vermis. The superior vermis is almost on the same plane as that of the superior surface of the cerebellum. The
Chapter

inferior vermis is situated in a depression between the inferior surfaces of the two hemispheres called vallecula.

Anatomical Lobes of Cerebellum (Fig. 59.2)
The cerebellum is divided into three lobes with the help of the deep fissures like the fissura posterolateralis and the fissura prima (Table 59.1).

i. The fissura posterolateralis on the inferior aspect, demarcates the flocculonodular lobe from the middle (posterior) lobe.

ii. The fissura prima on the superior surface demarcates the anterior lobe from the middle (posterior) lobe. These lobes and their components are given in the following Table 59.1.

<table>
<thead>
<tr>
<th>Lobe</th>
<th>Part of vermis</th>
<th>Corresponding part of hemisphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior lobe</td>
<td>Lingula</td>
<td>Ala of central lobule</td>
</tr>
<tr>
<td></td>
<td>Central lobule</td>
<td>Quadrate lobule</td>
</tr>
<tr>
<td></td>
<td>Culmen</td>
<td></td>
</tr>
<tr>
<td>Posterior lobe or middle lobe</td>
<td>Declive</td>
<td>Simple lobule</td>
</tr>
<tr>
<td></td>
<td>Folium</td>
<td>Superior semilunar lobule</td>
</tr>
<tr>
<td></td>
<td>Tuber</td>
<td>Inferior semilunar lobule</td>
</tr>
<tr>
<td></td>
<td>Pyramid</td>
<td>Biventral lobule</td>
</tr>
<tr>
<td></td>
<td>Uvula</td>
<td>Tonsil</td>
</tr>
<tr>
<td>Flocculonodular lobe</td>
<td>Nodule</td>
<td>Flocculus</td>
</tr>
</tbody>
</table>

Functional Lobes of Cerebellum
Based on connections and functions the cerebellum is divisible into three lobes, which do not exactly coincide with the anatomical lobes.

Archicerebellum
The archicerebellum or vestibulocerebellum is phylogenetically the oldest part. It consists of flocculonodular lobe and the lingula. It receives predominantly vestibulocerebellar fibers from all vestibular nuclei (except lateral vestibular nucleus of Deiter’s) and also direct fibers of the vestibular nerve. The archicerebellum projects to the vestibular nuclei (cerebellovestibular projection) either directly or via the fastigial nucleus. The archipallium also connects to the reticular formation of the brainstem via fastigial nucleus. The anterior vermis projects directly to the lateral vestibular nucleus.

Functions

i. The connections with the superior, inferior and medial vestibular nuclei influence the cranial nerve nuclei supplying the muscles that move the eyeball via the medial longitudinal fasciculus. This is the basis of controlling eye movements during movements of head.

ii. The connections with spinal cord via lateral vestibulospinal tract arising in lateral vestibular nucleus and via reticulospinal tracts help in control of trunk muscles and maintenance of equilibrium.

Paleocerebellum
The paleocerebellum or spinocerebellum consists of anterior lobe without lingula but with pyramid and uvula. It corresponds to paravermal zone of cerebellar hemisphere. It receives impulses mainly from the spinal cord via the spinocerebellar and cuneocerebellar (posterior external arcuate fibers) tracts. The paleocerebellum projects on the globose and emboliform nuclei. The efferent fibers from these nuclei pass to the brainstem centers (red nucleus, reticular formation and tegmentum of midbrain. The tracts arising from these centers (rubrospinal, reticulospinal and central tegmental) influence the anterior horn cells of the spinal cord.

Function
The paleocerebellum is responsible for maintenance of muscle tone and equilibrium.

Neocerebellum
The neocerebellum or cerebrocerebellum consists of the middle (posterior) lobe without the pyramid and uvula. It receives corticopontocerebellar fibers from the opposite cerebrum, olivocerebellar and tectocerebellar fibers from the brainstem. The neocerebellum projects on the dentate
nucleus. The efferent fibers from this nucleus end on the red nucleus and the ventralis lateral (VA) nucleus of the thalamus. The dentato-thalamocortical projection controls the lower motor neurons through the corticospinal, corticonuclear and cortico-olivary tracts.

**Function**

The neocerebellum is responsible for the smooth performance of highly skilled voluntary movements.

**Cerebellar Peduncles**

1. The inferior cerebellar peduncle or restiform body connects the cerebellum to the medulla oblongata. It is composed of a large number of afferent fibers and a few efferent fibers as listed below:
   i. Dorsal or posterior spinocerebellar tract
   ii. Cuneocerebellar tract or posterior external arcuate fibers
   iii. Olivocerebellar fibers
   iv. Vestibulocerebellar fibers
   v. Anterior external arcuate fibers
   vi. Striae medullaris
   vii. Reticulocerebellar fibers
   viii. Cerebellovestibular fibers
   ix. Cerebelloreticular fibers.
2. The middle cerebellar peduncle or brachium pontis connects the cerebellum to the pons and consists of pontocerebellar fibers only. These fibers arise in the pontine nuclei and reach the cerebellum of the opposite side.
3. The superior cerebellar peduncle or brachium conjunctivum connects the cerebellum to the midbrain. It is composed of both afferent and efferent fibers as listed below:
   i. Anterior (ventral) spinocerebellar tract
   ii. Tectocerebellar fibers
   iii. Trigeminocerebellar fibers
   iv. Dentatothalamic and dentatorubral fibers.

**Histology of Cerebellar Cortex**

There are three layers in the cerebellar cortex.

i. The molecular layer underlies the pia mater. It contains dense ramifications of dendrites of Purkinje cells and the parallel fibers, which are the axons of granule cells. The neurons present in this layer are the basket cells and stellate cells.

ii. The middle layer contains a single row of Purkinje cells, which are large flask-shaped cells. The dendrites of the Purkinje cells enter the molecular layer, where they synapse with parallel fibers of granule cells, stellate cells, basket cells and with the climbing fibers (olivocerebellar fibers). The axons of the Purkinje cells project to the intracerebellar nuclei.

iii. The granule cell layer is present between Purkinje cell layer and the white matter. It is composed of granule cells, Golgi cells and cerebellar glomeruli. The dendrites of the granule cells end in claw-like endings in the cerebellar glomeruli, where they synapse with the rosette of the mossy fibers and with the axons and dendrites of Golgi cells.

**Neurons of Cerebellar Cortex**

The neuronal connections of the cerebellar cortex are given in Figure 59.3. The excitatory climbing fiber (olivocerebellar fiber) makes synaptic contacts with the dendrites of one Purkinje cell in the molecular layer. The mossy fibers (consisting mainly of pontocerebellar, spinocerebellar and vestibulocerebellar fibers) branch profusely within the granular layer of the cortex. Each branch of the mossy fiber terminates in an expanded end called rosette, which forms a complex synapse (cerebellar glomerulus) with the dendrites of the granule cells. The mossy fibers are excitatory to the granule cells. The granule cells in turn excite Purkinje cells, basket cells, stellate cells and Golgi cells via parallel fibers. Thus, it is obvious that the granule cells are the only excitatory neurons. The stellate, basket and Golgi cells are inhibitory interneurons. The Purkinje cells are inhibitory to the neurons in intracerebellar nuclei. The Purkinje cells are the only output neurons in the cerebellar cortex (the other four cells remain confined to the cortex). They are excited by climbing fibers and parallel fibers.

**Cerebellar Nuclei**

The cerebellar nuclei or deep cerebellar nuclei (Fig. 59.4) are described as the output neurons of the cerebellum.
They consist of four nuclei per hemisphere. From lateral to medial side they are the dentate nucleus, emboliformis, globosus and the fastigial or roof nucleus. The deep nuclei receive axons of the Purkinje cells (inhibitory). In addition, they receive collaterals from the climbing and mossy fibers (excitatory).

i. The fastigial nuclei are the smallest and belong to the archicerebellum. They receive axons of the Purkinje cells of the vermal cortex and flocculonodular lobe. The efferents from these nuclei form the cerebellarvestibular and cerebelloreticular fibers, which leave through the inferior cerebellar peduncle.

ii. The emboliform and globus (nucleus interpositus) nuclei belong to the paleocerebellum. They receive axons of the Purkinje cells of the paravermal cortex. The efferents from these nuclei form the cerebellarvestibular and cerebelloreticular fibers, which leave through the inferior cerebellar peduncle. These fibers influence the spinal cord through the rubrospinal tracts.

iii. The dentate nucleus belongs to the neocerebellum and receives axons of the Purkinje cells of the lateral parts of the hemisphere. The axons of the dentate nucleus form the dentatorubrothalamic tract. The dentatorubrothalamic fibers decussate in the midbrain at the level of inferior colliculus to cross to the opposite side. Some of the crossed fibers terminate into the red nucleus and into the intermediate nucleus of thalamus. Some fibers descend in the brainstem to end on inferior olivary nuclei and reticular formation.

**Arterial Supply**

The cerebellum receives blood from three pairs of cerebellar arteries.

i. The superior cerebellar artery (a branch of basilar artery) supplies the superior surface of the cerebellum.

ii. The anterior inferior cerebellar artery (AICA) is a branch of basilar artery and supplies the anterior part of inferior surface.

iii. The posterior inferior cerebellar artery (PICA) is a branch of vertebral artery and supplies the posterior part of inferior surface of cerebellum.

**Summary of Functions of Cerebellum**

i. The cerebellum plays a role in precise coordination of the voluntary movements of the body by controlling the strength, duration and force of contraction.

ii. It is responsible for the maintenance of tone of the skeletal muscles and of equilibrium of the body.

iii. The cerebellum acts as a regulatory system that modifies motor acts initiated by cerebral cortex.

These functions are dependent on the information received regarding muscle activities from the voluntary muscles (via spinocerebellar and olivocerebellar tracts), from cerebral cortex (via pontocerebellar fibers) and regarding balance from vestibular nerve (via vestibulocerebellar fibers). The information reaches the Purkinje cells via climbing fibers and mossy fibers, which exert excitatory influence. The axons of Purkinje cells project to the intracerebellar nuclei. They exert inhibitory influence. The output from the intracerebellar nuclei reaches the cerebral cortex indirectly via thalamus and directly to tectum, red nucleus, tegmentum of midbrain, reticular formation, inferior olivary nuclei and vestibular nuclei through which it influences lower motor neurons.

**Clinical insight ...**

1. The dysfunction of cerebellar hemispheres produces typical signs and symptoms (described as cerebellar syndrome), which manifest on the side of the lesion.
   a. Generalized muscular hypotonia
   b. Intention tremor
   c. Dysmetria or loss of control over the voluntary act as for example, when reaching the finger to the nose, the finger overshoots the nose.
   d. Adiadochokinesis or inability to perform rapidly alternating opposite movements like pronation-supination
   e. Speech defect like dysarthria and thick monotonous speech.

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Contd...
The fourth ventricle is the cavity of the hindbrain hence it is enclosed by the medulla oblongata and pons in front and the cerebellum behind. It is located posterior to the posterior surfaces of the pons and upper half of medulla oblongata and anterior to the cerebellum. The fourth ventricle is lined by the ependyma and contains cerebrospinal fluid and choroid plexuses. At its upper end the ventricle is continuous with the cerebral aqueduct. At its lower end, it is continuous with the central canal of the closed part of medulla oblongata.

**Features**

The fourth ventricle presents roof or posterior wall, floor or anterior wall and lateral walls. It has three apertures, two lateral recesses and three dorsal recesses in the roof.

### Lateral Recesses

The cavity extends laterally on each side as the lateral recess, which passes between the inferior cerebellar peduncle and the peduncle of the flocculus. Each recess reaches up to the flocculus, where it opens into the subarachnoid space by the lateral aperture.

### Roof (Fig. 59.7)

The roof of the fourth ventricle is tent-shaped. The upper and the lower parts of the roof meet at the apex, which projects in the white core of the cerebellum as the median dorsal recess.

i. The upper half of the roof is formed by the converging superior cerebellar peduncles and by the superior medullary velum.

ii. The lower part of the roof is mainly formed by the tela choroidea of the fourth ventricle. The tela choroidea consists of the ependyma and a double fold of pia mater. The inferior medullary velum is present on each side in anterior relation to the cerebellar tonsil, where it becomes continuous with the white matter of the cerebellum. The peduncle of the flocculus is the upper thickened margin of the inferior medullary

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**vi. Jerky nystagmus in horizontal plane due to defective postural fixation of conjugate gaze.**

**vii. Swaying (falling) towards the side of lesion on standing with feet close together.**

2. Medulloblastoma is a highly malignant tumor of childhood. It arises from the granule cells of the cerebellar vermis. There is disturbance in equilibrium causing truncal ataxia. The child walks in a peculiar broad based gait. There is difficulty in holding the head steady. When the tumor enlarges it may project into the cavity of the fourth ventricle (Fig. 59.5).

3. The rise in intracranial pressure due to, for example, the posterior fossa tumor may displace the cerebellar tonsils downward in to the foramen magnum, where the tonsils get impacted causing compression of the medulla oblongata.
velum. Below the tela choroidea the roof presents a big midline aperture called foramen of Magendie, through which ventricular cavity communicates with cisterna magna.

Recesses in the Roof
There are three recesses in the roof:
i. The median dorsal recess extends into the white matter of the cerebellum and lies just superior to the nodule.

ii. The right and left lateral dorsal recesses project into the white matter of cerebellum lateral to the nodule but above the inferior medullary velum. The right and left lateral recesses extend laterally between the inferior cerebellar peduncle and peduncle of flocculus to reach the flocculus and open into the subarachnoid space at the cerebellopontine angle by a lateral aperture called foramen of Luschka.

Choroid Plexuses of Fourth Ventricle (Fig. 59.7)
The tela choroidea of the roof is vascularized to form choroid plexuses. A branch of posterior inferior cerebellar artery supplies the choroid plexus on each side. The right and left plexuses protrude into the cavity as vertical limbs (separated by foramen Magendie) and then extend on either side as horizontal limb into the lateral recesses. Thus, the plexus presents a T-shaped appearance. The lateral end of horizontal limb of the plexus projects through the lateral aperture at cerebellopontine angle. And the lower ends of the vertical limbs project through the median aperture in to the cerebello-medullary cistern.

Lateral Walls
The upper part of each lateral wall is formed by superior cerebellar peduncles and the lower part is formed on each side by the inferior cerebellar peduncle and also by the gracile and cuneate tubercles.

Floor (Rhomboid Fossa)
The floor of the fourth ventricle is diamond-shaped. It is covered by a thick layer of gray matter, which contains the nuclei of some of the cranial nerves. The ependyma covers the gray matter of the floor.

Subdivisions (Fig. 59.8)
i. The floor is divisible into the upper pontine and lower medullary parts by the striae medullaris, (which are the aberrant pontocerebellar fibres that originate in arcuate nuclei and reach the inferior cerebellar peduncle via the floor of the fourth ventricle).

ii. The floor is divided into right and left halves by a median sulcus.

iii. Just lateral to the median sulcus there is a longitudinal elevation of gray matter called the medial eminence, which is limited laterally by the sulcus limitans.

iv. The region lateral to the sulcus limitans is called vestibular area since it overlies vestibular nuclei. The vestibular area occupies both pontine and medullary parts of the floor. It extends into the lateral recess, where it is continuous with the auditory (acoustic) tubercle. This tubercle overlies the dorsal cochlear nucleus and forms anterior boundary of foramen of Luschka.

Features of Pontine Part
i. The facial colliculus is a small swelling in the lower part of the medial eminence. It indicates the position of the subjacent abducent nucleus but is produced by the recurving fibers (internal genu) of the facial nerve around the abducent nucleus.

ii. The superior fovea is the depression of the sulcus limitans lateral to the facial colliculus.

iii. Above the superior fovea the floor presents a small bluish area called locus coerules, which overlies the pigmented neurons of pontine reticular formation. These pigmented neurons constitute substantia ferruginea.
Features of Medullary Part

i. The inferior fovea is an inverted V-shaped area at the lower end of sulcus terminalis.

ii. The hypoglossal triangle lies medial to the inferior fovea. It overlies the hypoglossal nucleus.

iii. The vagal triangle is the area lying inferolateral to the hypoglossal triangle and below the inferior fovea. It overlies the dorsal nucleus of vagus.

iv. The funiculus separans is a ridge covered with thickened ependyma. It intervenes between the vagal triangle and the area postrema.

v. The area postrema lies between the funiculus separans and the gracile tubercle. It contains neurons. It has a specialized ependymal covering composed of tanycytes. There is no blood brain barrier here.

vi. The calamus scriptorius is the lowest part of the floor of fourth ventricle. It is so called because of its resemblance to a pen nib. It is overlapped by the obex, which is the meeting point of the right and left taenia (coincides with inferior angle of fourth ventricle). The taenia indicates the site of attachment of the tela choroidea to the inferolateral border of the ventricular floor.

Clinical insight ...

Ependymoma

The tumor of the fourth ventricle is called ependymoma, which arises from proliferation of ependymal cells. This tumor causes obstruction to the flow of CSF leading to internal hydrocephalus.
DIENCEPHALON

Subdivisions

The diencephalon is subdivided into five parts:
1. Thalamus (dorsal thalamus)
2. Epithalamus
3. Hypothalamus
4. Subthalamus (ventral thalamus)
5. Metathalamus (lateral and medial geniculate bodies).

Thalamus

The thalamus is a large mass of gray matter inside the cerebral hemisphere (Fig. 60.1). The right and left halves of the thalamus are completely separate except for the interthalamic adhesion. It receives all the sensory information from the body through the lemnisci or ascending tracts. It processes the sensory input for onward transmission to the sensory areas of the cerebral cortex via the thalamic radiations.

Parts of Thalamus (Fig. 60.2)

i. The anterior narrow end is called the anterior tubercle, which forms the posterior boundary of the interventricular foramen.
ii. The posterior expanded end is called the pulvinar, which lies just above and lateral to the superior colliculus of midbrain. The pulvinar of the two sides are separate from each other and overhang the tectum of the midbrain.
iii. Below the pulvinar and lateral to the superior colliculus, the lateral and medial geniculate bodies are closely related to the thalamus.

Medial Surface of Thalamus

i. The medial surface is covered with ependyma as it forms the greater part of lateral wall of the third ventricle.
ii. The interthalamic adhesion is composed of gray matter. It connects a small area on the medial surfaces...
of the two sides though there is no structural continuity between the two sides.

iii. This surface is demarcated from that of hypothalamus by the hypothalamic sulcus.

Lateral Surface of Thalamus
This surface is related to the posterior limb of the internal capsule (Fig. 63.4A).

Superior Surface of Thalamus
i. The fornix lies in close contact with this surface and subdivides it into lateral and medial parts. The lateral part forms the floor of the central part of lateral ventricle hence it is covered with ependyma. The medial part is covered with the tela choroidea of the third ventricle.

ii. The choroid fissure is the slit bounded by superior surface of the thalamus and the inferior surface of the fornix (Fig. 60.2).

iii. The stria medullaris thalami courses along the junction of the superior and medial surfaces.

Inferior Surface of Thalamus
This surface is continuous with the hypothalamus, subthalamus and the tegmentum of the midbrain from before backwards.

Structure of Thalamus
i. The thalamic gray matter is divisible into three main groups of nuclei by a Y-shaped internal medullary lamina. In addition, three nonspecific groups of nuclei are present in the thalamus. Thus, thalamus consists of a total of six groups of nuclear masses.

Main Nuclear Groups (Fig. 60.3)
There are three main groups:

i. Anterior
ii. Medial or Dorsomedial (DM)
iii. Lateral

Subdivisions of Lateral Group
The lateral group is further subdivided into ventral and dorsal (lateral) parts. The ventral part consists of three nuclei from before backwards, ventralis anterior (VA), ventral lateral (VL) and ventralis posterior (VP).

Subdivisions of Ventralis Posterior
i. The ventralis posterior is further subdivided into ventralis posterolateralis (VPL) and ventralis posteromedialis (VPM).

ii. The dorsal (lateral) part consists of three nuclei from before backward, Lateral Dorsal (LD), Lateral Posterior (LP) and Pulvinar (P).

Minor Groups (Nonspecific thalamic nuclei)
The minor groups of thalamic nuclei are the intralaminar nuclei, midline nuclei and the reticular thalamic nuclei.
i. The intralaminar nuclei are present in the substance of internal medullary lamina. They consist of Centromedian nucleus (CM) and parafascicular nucleus (PF).

ii. The Midline Nuclei (MLN) are present between the medial dorsal group and the ependymal wall of the third ventricle.

iii. The Reticular Thalamic Nuclei (RTN) are located between the external medullary lamina and the posterior limb of internal capsule.

**Connections of Anterior Nucleus**

i. The anterior nucleus receives the mamillothalamic tract from the mamillary body and the projection fibers (fornix) from the hippocampus.

ii. It projects to the cingulate gyrus via the anterior thalamic radiation.

iii. The anterior nucleus and its connections are part of the Papez circuit (Fig. 64.6) that plays a role in the emotional behavior and recent memory.

**Connections of Dorsomedial Group**

i. The Dorsomedial (DM) group receives fibers mainly from the prefrontal cortex. In addition it receives fibers from the amygdaloid body, hypothalamus, corpus striatum and the piriform cortex.

ii. The major projection from the DM is to the prefrontal cortex.

iii. The DM group plays an important role in emotion and behavior. It is regarded as an integrating center of somatic and visceral impulses. Its damage may lead to decrease in anxiety, tension, aggression and temporary amnesia (personality changes similar to those seen in prefrontal lobotomy).

**Connections of Ventralis Anterior Nucleus**

i. The ventralis anterior (VA) nucleus receives afferents from globus pallidus, deep cerebellar nuclei and substantia nigra.

ii. It projects to the striatum and sensory cortex and motor cortex of cerebrum.

iii. The VA nucleus plays a central role in transmission of the cortical recruiting response.

**Connections of Ventralis Lateral Nucleus**

i. The ventralis lateral (VL) nucleus receives afferents from the cerebellar nuclei, red nucleus, globus pallidus and substantia nigra.

ii. It projects to the motor and premotor cortex.

iii. The VL nucleus has an important role in regulation of voluntary movements and maintenance of muscle tone. It is an integrating center for inputs from cerebellum, striatum and cerebral cortex. Surgical ablation of this nucleus is sometimes used in the treatment of Parkinson’s tremor.

**Connections of Ventralis Posterolateralis Nucleus**

i. The Ventralis Posterolateralis (VPL) nucleus receives afferents from medial lemniscus, spinal lemniscus and parietal lobe.

ii. It projects to the postcentral gyrus through the superior thalamic radiation.

iii. It is a relay station (third order neurons) for sensations of touch, pain, temperature and proprioceptive sensations from the contralateral body except the face.

**Connections of Ventralis Posteromedialis**

i. The Ventralis Posteromedialis (VPM) receives sensations from the trigeminal lemniscus, solitary nucleus and the parietal lobe.

ii. It projects to the postcentral gyrus through the superior thalamic radiation.

iii. The VPM is a relay station (third order neurons) for the touch, pain, temperature and proprioceptive sensations from the contralateral face and for taste.

**Connections of Lateral Dorsal Nucleus**

i. The Lateral Dorsal (LD) nucleus receives afferents from the pretectum, superior colliculus, other thalamic nuclei, cingulate gyrus, posterior parahippocampal cortex and hippocampus.

ii. It projects to the cingulate gyrus, precuneus and parahippocampal gyrus.

**Connections of Lateral Posterior Nucleus**

i. The Lateral Posterior (LP) nucleus receives afferents from the superior colliculi and parietal lobe.

ii. It projects to the superior and inferior parietal lobules, cingulate gyrus and parahippocampal gyrus.

**Connections of Pulvinar**

i. The pulvinar receives afferents from the superior colliculi, lateral and medial geniculate bodies and amygdaloid bodies.

ii. It has reciprocal connections with the occipital cortex, parietal cortex, temporal cortex and prefrontal and orbitofrontal cortex.

iii. The function of the pulvinar is to integrate the visual, somatic sensory and auditory inputs.

**Connections of Minor Thalamic Nuclei**

i. The centromedian and parafascicular nuclei are part of ascending reticular activating system since they receive large input from the reticular formation. Besides this, they receive afferents from the corpus striatum, cerebellum, other thalamic nuclei, amygdaloid nucleus...
Vertebral Column and Spinal Cord, Cranial Cavity and Brain

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and hypothalamus. They project on the striatum, and through it, establish diffuse connections with the entire cortex.

ii. The reticular thalamic nuclei do not project to the cortex but receive input from the cortex and other thalamic nuclei. They are probably concerned with regulation of intrathalamic activity.

Thalamic Radiations
There are four thalamic radiations—anterior, superior, inferior and posterior. The thalamus establishes to and fro connections with the cerebral cortex via the thalamic radiations, which pass through the internal capsule.

i. The anterior thalamic radiation connects the frontal lobe to the dorsomedial (DM), VA, VL group of nuclei and the anterior nuclei. It also contains reciprocal frontothalamic fibers. It passes through the anterior limb of internal capsule.

ii. The superior thalamic radiation connects the VPM and VPL nuclei to the postcentral gyrus (parietal lobe). It contains reciprocal parietothalamic fibers and corticothalamic fibers for other thalamic nuclei. It passes through the posterior limb of internal capsule.

iii. The inferior thalamic radiation passes through the sublentiform part of internal capsule and connects the medial geniculate body to the temporal lobe. It also contains temporothalamic fibers and corticothalamic fibers for other thalamic nuclei.

iv. The posterior thalamic radiation passes through the retrolentiform part of internal capsule and connects the lateral geniculate body to the occipital lobe. It contains reciprocal fibers and corticothalamic fibers for other thalamic nuclei.

Arterial Supply
The branches of posterior communicating, posterior cerebral and basilar arteries supply the thalamus.

Functions
i. The thalamus is a relay station of fine sensations whereas crude sensations (pain and temperature) are perceived in the thalamus.

ii. It maintains the state of wakefulness and alertness through the connections of the intralaminar nuclei to the ascending activating reticular system on one hand and cerebral cortex on the other hand via the striatum.

iii. It regulates the motor activities by linking cerebellum and globus pallidus to the motor and premotor cortex.

Thalamic Syndrome
The thalamic syndrome is the disturbance of the sensory functions of the thalamus, usually due to vascular lesion. The threshold for touch, pain and temperature sensations is reduced on the opposite side of the lesion. Therefore, the patient experiences perverted, exaggerated and exceptionally disagreeable sensations. There is emotional instability with spontaneous crying and laughing.

Epithalamus (Fig. 60.5)
The epithalamus is located at the posterior end of the roof and lateral wall of the third ventricle.

Components of Epithalamus
i. Pineal gland
ii. Habenular nuclei
iii. Habenular commissure
iv. Posterior commissure.

Pineal Gland
The pineal gland (epiphysis cerebri) is located just below the splenium of corpus callosum in a depression between the superior colliculi. It is attached to the roof the third ventricle by pineal stalk, which contains superior and inferior laminae separated by the pineal recess of the third ventricle. The superior lamina gives passage to the habenular commissure and the inferior lamina to the posterior commissure.

Nerve Supply of Pineal Gland
The nervus conarii consists of postganglionic sympathetic fibers, which run subendothelially in the wall of the straight sinus and enter the pineal gland to supply the pinealocytes.

Brain Sand (corpora arenacea)
The aggregations of calcium and magnesium phosphates and carbonates form the corpora arenacea or brain sand.
from the early age. The presence of the brain sand in the midline is detectable on radiographs. The displacement of the gland to one side of the midline is indicative of space occupying lesion in the cranium.

**Habenular Nucleus**
The habenular nucleus is located in the habenular triangle, which is bounded superomedially by stria medullaris thalami, inferiorly by superior colliculus and laterally by pulvinar. The habenular nucleus receives afferent connections through the stria medullaris thalami from neurons in the septal area, basal nucleus of Meynert in the basal forebrain and preoptic hypothalamus. The fascicle retroflexus or habenulo-interpeduncular tract (composed of efferent fibers from habenular nucleus) projects to the brainstem reticular formation via the interpeduncular nucleus (located in the midbrain). The habenular nucleus is responsible for integration of olfactory and autonomic functions hence it is part of the limbic system.

**Habenular Commissure**
The habenular commissure communicates the septal areas of the cerebral hemispheres. It is located in the superior lamina of pineal recess. It is formed by a few fibers of stria medullaris thalami that pass through the superior lamina of the pineal stalk to reach the habenular nucleus and through it to the septal area of the opposite side.

**Posterior Commissure**
This commissure connects the pretectal nuclei, interstitial nuclei of posterior commissure, interstitial nucleus of Cajal, nucleus of Darksheitsch and rostral interstitial nuclei of medial longitudinal fasciculus of the two sides. It is located in the inferior lamina of pineal recess. The pinealomas may compress the vertical gaze center located here and present as Perinard's syndrome.

**Hypothalamus (Fig. 60.4)**
The hypothalamus is a small mass of gray matter. It is the chief center that maintains the internal milieu of the body. It is present in the floor and lower lateral walls of the third ventricle. Superiorly, it is continuous with the thalamus at the hypothalamic sulcus. It extends from the lamina terminalis to the caudal margin of mamillary bodies, where it is continuous with the tegmentum of midbrain. The hypothalamus controls the endocrine glands, autonomic nervous system and the limbic system. It is regarded as the biological clock of the body.

**Visible Part of Hypothalamus**
Some part of the hypothalamus is visible at the base of the brain in the interpeduncular fossa behind the optic chiasma. It includes the gray matter of tuber cinereum and mamillary bodies. The infundibulum or pituitary stalk is attached to the median eminence just behind the optic chiasma.

**Arterial Supply**
The circle of Willis provides ample blood supply as it is in close relation to the hypothalamus.

**Subdivisions**
Each half of the hypothalamus is subdivided in medial and lateral zones by the passage of fornix (which passes through the hypothalamus to reach the mamillary bodies).

**Nuclei in Medial Zone**
The gray matter in this zone is divided into anterior, tuberal and posterior regions.

1. The anterior region is composed of suprachiasmatic, paraventricular, supraoptic, preoptic and anterior nuclei.
   i. The paraventricular and supraoptic nuclei contain neurosecretory neurons, which secrete ADH and oxytocin. The axons of these neurons form hypothalamo-hypophyseal tract, which projects to the neurohypophysis. The neurosecretory granules are stored in the nerve terminals of these axons (the dilated axon terminals are called Herring bodies) in the neurohypophysis. Lesion of these nuclei, e.g. by a tumor or trauma causes diabetes insipidus which is characterized by polyuria (excess of urination) and polydipsia (excessive thirst).
   ii. The anterior nucleus exerts control over parasympathetic system.
i. The preoptic nucleus regulates the release of gonadotropic hormones from the adenohypophysis. It is the only nucleus of the hypothalamus that is sexually dimorphic.

2. The tuberal region contains the arcuate or infundibular nucleus located in tuber cinereum (besides ventromedial and dorsomedial nuclei). The arcuate nucleus contains neurons that produce hypothalamic-releasing and release inhibiting factors. The axons of these neurons constitute tuberohypophyseal tract, which terminates on hypophyseal portal vessels in the median eminence. Thus, it influences the release or release inhibition of the hormones of the adenohypophysis.

3. The posterior region contains the mamillary nuclei and a posterior nucleus. The mamillary nuclei receive input from the hippocampus through the anterior column of fornix and project to the anterior nucleus of thalamus. The posterior nucleus exerts control over sympathetic system.

Nuclei in Lateral Zone
This zone contains a nucleus composed of diffuse neurons (satiety center), which on stimulation induces eating. The lesions of this nucleus cause anorexia and starvation.

Afferent Connections of Hypothalamus
i. The medial forebrain bundle connects the hypothalamus to nuclei in the limbic system, the nuclei in septal area and to the primary olfactory cortex (uncus and anterior end of parahippocampal gyrus).

ii. The stria terminalis connects it to the amygdaloid complex.

iii. The fornix connects the mammillary nuclei to the hippocampus.

iv. The median forebrain bundle is the connecting link with the brainstem nuclei like tegmental nuclei, raphe nuclei and locus ceruleus of reticular formation.

v. It is connected to autonomic neurons in brainstem and spinal cord by dorsal longitudinal fasciculus.

vi. The periventricular system of fibers on the medial surface of thalamus transmits to the hypothalamus emotional and affective information from the prefrontal cortex (via the mediodorsal nucleus of thalamus).

Efferent Connections
i. The hypothalamus controls the adenohypophysis by hypothalamo-hypophyseal portal vessels and the neurohypophysis by hypothalamo-hypophyseal neural tracts.

ii. The control of autonomic nervous system is exerted via the dorsal longitudinal fasciculus, which connects to the craniosacral outflow (parasympathetic neurons) and thoracolumbar outflow (sympathetic neurons). Similar control is also provided by mamillotegmental tract that projects to autonomic neurons via reticular formation.

Summary of Hypothalamic Functions
i. The anterior hypothalamus has an excitatory effect on the parasympathetic neurons whereas posterior hypothalamus has similar effect on sympathetic neurons.

ii. The anterior hypothalamus helps in temperature regulation.

iii. The water balance of the body is maintained by action of ADH secreted in supraoptic and paraventricular nuclei.

iv. The food intake is regulated by hypothalamic nucleus in the tuberal region, which lies dorsal to the tuber cinereum. It is called ventromedial nucleus. It inhibits the urge to eat and hence called satiety center. Bilateral destruction results in hyperphagia and obesity.

v. The hypothalamus is aptly described as master orchestrator of endocrine system of the body through its control of anterior pituitary.

vi. The oxytocin secreted by hypothalamus causes contraction of smooth muscle of uterus and myoepithelial cells of the lactiferous ducts of mammary glands.

Clinical insight...
The hypothalamus may be affected by inflammation, neoplasm or vascular deficiency. It may be compressed by hydrocephalus of third ventricle. Its lesion causes widespread disturbances in homeostatic and behavioral functions (obesity, sexual disorders, hypothermia or hyperthermia, diabetes insipidus, disturbances in sleep and emotional disturbances).

Subthalamus
The subthalamus is a very complex region. It is situated ventral to the thalamus and lateral to the hypothalamus overlying the inferior part of the internal capsule. It lies superior to the substantia nigra and red nucleus. The subthalamus contains gray matter and fiber tracts.

Gray Matter and Fiber Tracts in Subthalamus
i. The subthalamic nucleus of Luys has reciprocal connections with the globus pallidus through the fasciculus sub-thalamicus.

Know More...
Contd...

**Zona incerta** is a thin sheet of gray matter between the thalamus and subthalamic nucleus.

**Field H1 of Forel** is the area between the zona incerta and thalamus. Fasciculus lenticularis, ansa lenticularis and dentato-rubro-thalamic tracts meet here to form thalamic fasciculus.

**Field H2 of Forel** is the area between the zona incerta and subthalamic nucleus and is traversed by fasciculus lenticularis.

**Field H of Forel** or prerubral field lies below and medial to the zona incerta. The fasciculus lenticularis and ansa lenticularis are assembled here.

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**Clinical insight ...**

**Lesion of Subthalamic Nucleus**

The lesion of the subthalamic nucleus produces hemiballismus in the opposite side. The involuntary and violent movements (of throwing or flailing type) affecting usually the proximal parts of the upper limbs are the characteristic features of this condition.

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**Metathalamus**

The lateral geniculate body is described with optic pathway in chapter 68 and the medial geniculate body with auditory pathway in chapter 72.

**Third Ventricle**

The third ventricle is the cavity bounded by the thalamus and hypothalamus (Fig. 60.2). It is a narrow slit-like cavity lined with ependyma. The third ventricle communicates with the lateral ventricles through the interventricular foramina and with the fourth ventricle through the cerebral aqueduct. It is visible radiologically in CT scan and MRI as a narrow midline space.

**Boundaries (Fig. 60.5)**

**Roof**

A layer of ependyma stretching across the two thalami forms the roof. The ependyma of the roof comes in contact with the vascular pia mater (tela choroidea) in two places and they invaginate as linear choroid plexuses in the cavity of the ventricle. The choroid plexuses of the third ventricle are supplied by anterior and posterior choroidal arteries. The internal cerebral veins pass posteriorly lying within the tela choroidea.

**Anterior Wall**

The anterior wall of the third ventricle is formed by the lamina terminalis, which stretches between the optic chiasma and the rostrum of the corpus callosum. The anterior commissure lies in the superior part of the lamina terminalis. The anterior column of fornix lies behind the lamina terminalis on each side. The interventricular foramen of Monro is located between the anterior column of fornix and the anterior tubercle of thalamus. This foramen is a communication between the third ventricle and the lateral ventricle of each side. The choroid plexuses of the third ventricle are continuous with those of lateral ventricles through the interventricular foramen. Hypertrophy of the choroid plexus may block the interventricular foramen with resultant accumulation of CSF in the lateral ventricles. The unilateral hydrocephalus of the lateral ventricle may compress the opposite hemisphere thus shifting the midline structures towards the opposite side.

**Lateral Wall**

The lateral wall of the third ventricle is traversed by hypothalamic sulcus, which extends from the interventricular foramen to the cerebral aqueduct. The hypothalamic sulcus demarcates the thalamus above and the hypothalamus below. The medial surfaces of the two thalami often fuse with each other at a localized interthalamic adhesion, which lies above the hypothalamic sulcus.

**Floor**

The floor of the third ventricle is formed by the optic chiasma, infundibulum, tuber cinereum, mamillary bodies, posterior perforated substance and the upper end of the tegmentum of midbrain.
Posterior Wall
The posterior wall consists of the pineal gland, posterior commissure, habenular commissure and cerebral aqueduct.

Recesses (Fig. 60.5)
The recesses of the third ventricle are the prolongations of its cavity. There are four recesses:

i. The infundibular recess is a funnel-shaped extension in the infundibulum of the pituitary.
ii. The optic recess is an angular diverticulum just above the optic chiasma at the junction of anterior wall and the floor.
iii. The pineal recess projects in the stalk of the pineal gland.
iv. The suprapineal recess is a diverticulum of the roof of the ventricle.
ANATOMY OF CEREBRUM

The cerebrum is the largest part of the brain. It has an ovoid shape. It consists of two incompletely separated cerebral hemispheres.

Cerebral Hemisphere
The outer surface of the cerebral hemisphere is covered with cortex, which is highly folded due to the presence of sulci and gyri. It is estimated that the surface area of human cortex is 2200 sq cm and it is composed of about ten thousand million neurons. The core of the hemisphere consists of white matter containing a group of nuclei called basal ganglia. The cavity inside each hemisphere is called the lateral ventricle. The longitudinal fissure of cerebrum intervenes between the medial surfaces of the right and left hemispheres. At the bottom of the fissure lies the corpus callosum, which is a connecting bond between the hemispheres. The contents of the longitudinal fissure are, falx cerebri and the accompanying arachnoid mater, pia mater covering the medial surfaces of the hemispheres, anterior cerebral vessels and the indusium griseum on the superior surface of corpus callosum.

External Features (Figs 61.1 and 61.2)
The cerebral hemisphere has three poles, three surfaces and three borders.

Frontal Pole
The frontal pole is the pointed anterior extremity of the cerebral hemisphere. A point at the junction of the root of nose and the medial end of superciliary arch indicates its position on the surface.

Occipital Pole
The occipital pole is the pointed posterior extremity of the cerebral hemisphere. A point superolateral to the external occipital protuberance indicates its position on the surface.

Temporal Pole
The temporal pole is the anterior end of the temporal lobe. It is located in the middle cranial fossa under cover the lesser wing of sphenoid.

Surfaces of Cerebral Hemisphere
The surfaces are, superolateral, medial (or vertical) and inferior. The right and left medial surfaces enclose the longitudinal fissure. The inferior surface is subdivided into orbital and tentorial surfaces by the stem of the lateral sulcus.

Fig. 61.1: Superolateral surface of left cerebral hemisphere showing poles, borders and demarcation of lobes
Borders of Cerebral Hemisphere

i. The superomedial border lies between the medial and superolateral surfaces. It is indicated on the surface by a paramedian line from a point just superolateral to inion to a point just superolateral to nasion.

ii. The inferolateral border lies between the superolateral and inferior surfaces. Its anterior part separating orbital surface from the superolateral surface is called the superciliary border. The point, where stem of the lateral sulcus cuts this border and divides into three rami corresponds to the pterion on the surface.

iii. The inferomedial border intervenes between the medial and inferior surfaces. It is subdivided into three parts. The medial orbital border intervenes between the orbital and medial surfaces of frontal lobe. The medial occipital border intervenes between the tentorial surface and medial surface of occipital lobe and the inferomedial border proper or the hippocampal border lies between the previous two. The uncus and parahippocampal gyrus form the hippocampal border.

Lobes of Cerebrum

There are four lobes namely, frontal, parietal, occipital and temporal, which are very well demarcated on the superolateral surface (Fig. 61.1).

Cerebral Sulci and Gyri (Fig. 61.3A)

The cerebral cortex is composed of neurons and neuroglia with minimum fibers. It shows numerous elevations and depressions to increase the surface area greatly. The elevations are called gyri and depressions are known as sulci. The pattern of the sulci and gyri is not constant and may differ in right and left hemispheres of the same brain.

Lateral Sulcus or Sylvian Fissure

The deep lateral sulcus is located on the inferior and superolateral surfaces. It consists of a stem and three rami. The stem begins at the base of the brain in the vallecula and extends laterally to cut the inferolateral border. On reaching the superolateral surface, it divides into three rami (Fig. 61.3B). The posterior ramus of the lateral sulcus is long and continues backwards in the parietal lobe. It can be marked on the surface by drawing a 7 cm long line from the pterion to the parietaleminence. The anterior and ascending rami are short. They encroach on the inferior frontal gyrus. The insula or island of Reil and the limen insulae are in the floor of the lateral sulcus. The parts of cerebral hemisphere surrounding the lateral sulcus on the superolateral surface are called opercula since they cover the insula.

Contents of Lateral Sulcus

The lateral sulcus contains free margin of lesser wing of sphenoid, sphenoparietal sinus, middle cerebral artery...
and its cortical branches in addition to deep and superficial middle cerebral veins.

**Central Sulcus or Fissure of Rolando**
This sulcus is an important landmark for demarcating the sensory and motor cortex on the superolateral surface. It begins at the superomedial border slightly (1 cm) behind the midpoint of a line joining occipital and frontal poles. It passes downward, forward and laterally at an angle of 70° to the median plane. Its lower end lies slightly above the posterior ramus of lateral sulcus.

**Surface Marking**
Take a point about 1 cm behind the midpoint of the line joining the nasion and inion. Draw another line from this point at an angle of 70° directed downward, forward and laterally up to a point 5 cm above preauricular point.

**Parieto-occipital Sulcus**
This sulcus lies on the medial surface mainly but cuts the superomedial margin about 4 cm in front of the occipital pole to appear for a short distance on the superolateral surface.

**Demarcation of Lobes on Superolateral Surface (Fig. 61.1)**
With the help of the lateral, central and parieto-occipital sulci, the preoccipital notch and two imaginary lines, it is possible to divide the superolateral surface of the cerebrum in four lobes. The central sulcus is prolonged till it touches the posterior ramus of lateral sulcus. An imaginary vertical line is drawn from the point of parieto-occipital sulcus on the superomedial border to the preoccipital notch on the inferolateral margin (preoccipital notch lies about 5 cm in front of the occipital pole). The posterior ramus of the lateral sulcus is extended to touch the vertical line.

i. The frontal lobe lies in front of the central sulcus and above the posterior ramus of lateral sulcus.

ii. The parietal lobe is bounded in front by central sulcus, behind by the vertical imaginary line, above by superomedial border and below by posterior ramus of lateral sulcus and its backward extension.

iii. The occipital lobe lies behind the vertical imaginary line

iv. The temporal lobe lies below the posterior ramus of the lateral sulcus and its extension. It is limited behind by the lower part of the vertical line.

**Sulci and Gyri on Superolateral Surface (Fig. 61.3A)**

**Frontal Lobe**

i. The precentral sulcus runs parallel to and one finger-breath in front of the central sulcus. The cortex between precentral and central sulci is known as precentral gyrus.

ii. In front of precentral sulcus, the frontal lobe presents superior and inferior frontal sulci, which run horizontally forwards. These two sulci subdivide the frontal
Insula (Island of Reil)

The word insula means hidden. The insula is the submerged part of the cerebral cortex in the depths of the stem and posterior ramus of the lateral sulcus. It forms the floor of the lateral sulcus. It is surrounded by the circular sulcus except at its apex. The surface of the insula is marked by a number of sulci and gyri. The middle cerebral blood vessels lie on its surface. The insular cortex is continuous with the anterior perforated substance at the limen insulae or gyrus ambiens, which forms the apex of the insula. On its internal aspect, the insular cortex is very close to the lateral surface of the lentiform nucleus, the structures intervening between the two, being, extreme capsule, claustrum and the external capsule. There is considerable uncertainty about the function of insula. It is assumed that parainsular cortex bears the gustatory area.

Sulci and Gyri on Medial Surface (Fig. 61.4)

i. The cingulate gyrus lies between the cingulate sulcus and the callosal sulcus lying just above the corpus callosum.

ii. The paracentral lobule is located around the central sulcus. It is continuous with both the precentral and postcentral gyri across the superomedial border.

iii. The medial frontal gyrus is the large anterior part of the medial surface of the frontal lobe.
iv. The paraterminal gyrus lies in front of the lamina terminalis and parolfactory gyrus lies in front of the paraterminal gyrus. The anterior and posterior parolfactory sulci bound the parolfactory gyrus.

v. The parieto-occipital sulcus lies on the posterior part of the medial surface. It begins on the superomedial border about 5 cm anterior to the occipital pole and descends anteriorly to meet the calcarine fissure below and behind the splenium. This sulcus demarcates the parietal and occipital lobes on the medial surface.

vi. The calcarine sulcus starts near the occipital pole and extends forward lying a little above the medial occipital border. It ends by joining the parieto-occipital sulcus. It is very deep and projects in the posterior horn of lateral ventricle as calcar avis.

vii. The precuneus is the quadrilateral area in front of the parieto-occipital sulcus and the upturned end of the cingulate sulcus. It forms the medial surface of the parietal lobe.

viii. The cuneus is a triangular area of cortex bounded by the superomedial border, parieto-occipital sulcus and the calcarine sulcus. It forms the medial surface of the occipital lobe.

**Sulci and Gyri on Inferior Surface (Fig. 61.2)**

i. The orbital surface presents the olfactory sulcus, close to the medial margin. The olfactory bulb and tract lie in this sulcus. Gyrus rectus is the area medial to the olfactory sulcus. The remaining orbital surface is divided into anterior, posterior, medial and lateral orbital gyri by an H-shaped orbital sulcus.

ii. The tentorial surface presents the collateral sulcus, which projects in the inferior horn of the lateral ventricle as the collateral eminence. It is a long sulcus that begins near the occipital pole and runs forward almost parallel to the calcarine sulcus. It reaches as forward as the rhinal sulcus, which demarcates the uncus on the medial surface of the temporal lobe from the temporal pole. The lingual gyrus lies between the collateral and calcarine sulci. The parahippocampal gyrus lies medial to the collateral sulcus. It is continuous anteriorly with the uncus and posteriorly with the cingulate gyrus through the isthmus, which winds round the splenium and forms a connecting link between the medial and inferior surfaces.

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**Know More ...**

**Types of Sulci**

There are four main types of sulci on the cerebral hemisphere.

i. Limiting sulcus separates the areas of cortex, which differ in structure and functions, e.g. the central sulcus.

ii. Axial sulcus develops in the long axis of a rapidly growing cortical area. The posterior part of the calcarine sulcus, which is a mere fold in the center of the visual cortex, is the example of the axial sulcus.

iii. Complete sulcus is the one that reaches the wall of the ventricle to produce an elevation there. There are two examples of this type. The posterior part of the calcarine sulcus produces calcar avis in the posterior horn and the collateral sulcus produces collateral eminence in the inferior horn of the lateral ventricle.

iv. Secondary sulcus is the one that depends on other factors for its formation. Examples of the secondary sulci are the lateral sulcus and the parieto-occipital sulcus. The submerging of insula is responsible for the formation of lateral sulcus and the backward growth of corpus callosum is responsible for the formation of parieto-occipital sulcus.
Functional Areas of Cerebral Cortex

Different areas of cerebral cortex perform different functions. The functional areas are classified according to Brodmann in terms of numbers.

Motor Areas (Figs 61.5 and 61.6)

The primary motor area or area 4 occupies the entire precentral gyrus including the anterior part of the paracentral lobule on the medial surface of the hemisphere (Fig. 61.6). Histologically, it is characterized by presence of giant pyramidal cells of Betz in the inner pyramidal layer (fifth layer) of the cerebrum. The pyramidal cells that give origin to the corticospinal and corticonuclear (corticobulbar) fibers are known as upper motor neurons. Majority of corticospinal fibers ends on the anterior horn cells of spinal cord indirectly via internuncial neurons. The corticonuclear fibers end on the cranial nerve nuclei in the brainstem. The motor area controls the voluntary movements of the opposite half of the body.

Motor Homunculus (Fig. 61.7)

i. The body is represented upside down in the motor area. The sequence from below upwards, is pharynx, larynx, tongue, lips, face, neck, fingers with hand, wrist, elbow, shoulder, trunk, and hip in the precentral gyrus. The leg and perineum are present in the paracentral lobule on the medial surface. The extent of the cortical area for the movements depends on the skill of movements. Thus, in the upper limb the hand has larger representation and among fingers the thumb has the largest representation. The representation of the human body in proportion to the area of the motor cortex is known as motor homunculus, means “the little man inside.”

Fig. 61.5: Functional areas of Brodmann on superolateral surface of left cerebral hemisphere

Fig. 61.6: Functional areas of Brodmann on medial surface of left cerebral hemisphere
ii. Premotor cortex or area 6 is located in front of the precentral gyrus. It occupies the posterior parts of the superior, middle and inferior frontal gyri and extends on the corresponding part of medial surface of the frontal lobe. The neurons in this area give origin to corticospinal and corticonuclear fibers, which descend along with the similar fibers of the motor cortex. This area is responsible for the performance of skillful acts, which are learnt through repetitive efforts.

iii. Frontal eye field or area 8 lies in front of the premotor area in the middle frontal gyrus. It is connected to the visual cortex of the same side and of the opposite side. It is projected to the superior colliculi and pontine gaze center in the reticular formation and other oculomotor related nuclei in the brainstem. It is necessary for the conjugate movements of the eyes (stimulation causes movements of both eyes to the opposite side). Lesion in this area results in difficulty in voluntarily moving the eyes to the opposite side. So, the eyes move towards the side of lesion.

iv. Prefrontal cortex (areas 9, 10, 11 and 12) occupies the anterior part of frontal lobe (area 12 is largely present on orbital surface of frontal lobe). It is regarded as the association cortex. It has numerous connections with cortex of the other three lobes. There are to and fro connections with dorsomedial thalamic nucleus. Lesion in prefrontal cortex results in personality change due to impaired capacity in abstract thinking, judgment, foresight and tactfulness.

v. Motor speech area of Broca (area 44, 45) occupies the opercular and triangular portions of the inferior frontal gyrus of the dominant hemisphere. Description of motor speech area is given with cortical speech areas (vide infra).

Sensory Areas (Figs 61.5 and 61.6)

i. Primary sensory area occupies the postcentral gyrus and extends in the posterior part of the paracentral lobule. The Brodmann areas 3,1,2 are arranged in anteroposterior order in these gyri. The sensory cortex is granular in type since it contains more granule cells and less pyramidal cells. It receives profuse thalamocortical connections from the nuclei VPM and VPL of thalamus. The contralateral body is represented upside down in the sensory cortex (sensory homunculus). Injury to sensory cortex results in altered or impaired sensations and not loss of sensations in the opposite half of body.

ii. Sensory association area (5 and 7) is located in superior parietal lobule on the superolateral surface.

iii. Visual or striate area (area 17) includes the calcarine sulcus, cuneus and lingual gyrus in the occipital lobe. The visual cortex is very thin hence, it is possible to see the stria of Gennari with unaided eye on sectioning of the cortex in the calcarine sulcus. The stria consists of the thick outer band of Baillarger in the fourth or inner granular layer of the cortex. The visual cortex receives input via optic radiation, which brings impulses from the temporal half of ipsilateral retina and nasal half of contralateral retina. Thus, the left half of field of vision is represented in right visual area and right half is represented in left visual area. The macula lutea of retina (area of highest visual acuity) is represented in occipital pole.

iv. The visual association cortex or parastriate and peristriate cortex (area 18 and 19) surround the striate cortex. The association areas help in interpretation of visual impulses in the light of past experiences. Areas 18 and 19 form the occipital eye field. The corticotectal fibers originate in both the visual and visual
association areas and terminate on the superior colliculi.

v. Primary acoustic or auditory cortex (area 41 and 42) lies in superior temporal gyrus. It is concealed from view because it occupies the anterior transverse temporal gyri (Heschl’s gyri) on the superior aspect of the superior temporal gyrus. The acoustic cortex receives auditory radiations from medial geniculate bodies of both sides.

vi. Acoustic association area 22 lies posteriorly on the lateral aspect of the superior temporal gyrus. The association areas are essential for the interpretation of the sound impulses in the light of past experiences. Part of area 22 is included in Wernicke’s speech area.

vii. The entorhinal or olfactory area 28 is located in uncus, which is the anteromedial part of parahippocampal gyrus. It is bounded by rhinal sulcus laterally and anterior perforated substance medially.

viii. The gustatory area (area 49) is located in parietal operculum (posteroinferior part of postcentral gyrus). For more information refer to gustatory pathways in chapter 47.

Cortical Speech Areas

The cortical areas of speech are present on the dominant hemisphere. So, in a right-handed person the left cerebral hemisphere is responsible for language function. The dominant hemisphere is referred to as the verbal or talking hemisphere. There are two types of speech areas, motor and sensory. The motor speech center is located in front of the central sulcus while the sensory speech centers are located behind the central sulcus. All the cortical speech centers receive arterial blood from the middle cerebral artery.

Motor Speech Area

The motor speech area or Broca’s area is located in the inferior frontal gyrus. It corresponds to Brodmann’s areas 44 and 45 in the dominant hemisphere. It is connected to the motor area controlling the movements of the vocal cords in the precentral gyrus. It is also connected to the sensory speech areas by arcuate fasciculus (a bundle of association fibers). The Broca’s area is responsible for spoken speech (rhythm of speech).

Sensory Speech Areas

There are three areas for sensory speech.

i. Part of area 22 located on the posterior part of superior temporal gyrus.

ii. The angular gyrus (area 39) on inferior parietal lobule.

iii. The supramarginal gyrus (area 40) on the inferior parietal lobule.

This area is important in comprehension of received speech and selection of words to express ideas. Area 22 comprehends spoken language and recognizes familiar sounds. Area 39 is responsible for visual speech or reading and area 40 is responsible for recognition of and naming of the objects by touch and proprioception. All these areas are interconnected and connected to the motor speech area by the arcuate fasciculus.

Clinical insight ...

Aphasia means disturbance in the ability to speak or comprehend or write or read the words.

i. The lesion of Broca’s area causes motor aphasia (expressive or nonfluent aphasia). It is characterized by distorted and hesitant speech even though the peripheral speech apparatus is normal. However, the comprehension is preserved.

ii. The lesion of area 22 produces word deafness (fluent aphasia), in which the patient speaks without understanding what is spoken.

iii. The lesion of area 39 produces word blindness in which there is reading difficulty (alexia) and writing difficulty (agraphia). In addition the patient experiences right-left confusion, finger agnosia (inability to select or name own or another’s finger) and dyscalculia.

iv. The lesion of area 40 causes tactile agnosia (inability to name objects by touch).

v. The lesion in the arcuate fasciculus results in conduction aphasia, where repetition of spoken language is extremely difficult though comprehension is intact and speech is fluent.

vi. Lesion of both sensory and motor speech areas results in global aphasia in which the patient neither can speak nor can understand spoken speech.
BLOOD SUPPLY OF BRAIN

The brain is richly supplied with blood through the vertebralbasilar and internal carotid arteries. The oxygen consumption of the neural tissue is very high (25% of the oxygen that is breathed in is cerebrally used). Acute arrest of circulation produces loss of consciousness in about seven seconds. The cerebrovascular accidents (CVA) due to infarction, hemorrhage and embolism result in stroke, in which the entire half of the body or a limb or one half of the face is suddenly paralyzed. The persons in whom there is narrowing of cerebral arteries (due to hypertension, atherosclerosis and diabetes) are more prone to stroke. The common causes of cerebral hemorrhage are aneurysm of major arteries, small arteriolar aneurysms due to hypertension and arteriovenous malformations. Therefore, the blood supply of the cerebral cortex and the internal capsule assumes a great importance.

The brain is supplied by right and left internal carotid arteries and right and left vertebral arteries.

Intracranial Course of Internal Carotid Artery

The intracranial course of the artery is subdivided into intrapetrous, intracavernous and supraclinoid parts.

Intrapetrous Part

The internal carotid artery (ICA) ascends in the carotid canal and enters the middle cranial fossa through the upper opening of the foramen lacerum.

Intracavernous Part

From foramen lacerum the artery courses forwards in the floor of the cavernous sinus, where it is in close relation to the abducent nerve.

Supraclinoid Part

After the artery pierces the dural roof of the cavernous sinus it bends sharply backwards and upwards to terminate at the vallecula of cerebrum into middle and anterior cerebral arteries.

Carotid Siphon

The internal carotid artery shows multiple bends, which produce S-shaped shadow called the carotid siphon on an angiogram. The carotid siphon helps in damping down its pulsations in the cranial cavity.

The aneurysm of ICA may compress the central part of optic chiasma and produce bitemporal hemianopia. Trauma to the ICA in cavernous sinus leads to the formation of arteriovenous fistula causing pulsating exophthalmos.

Branches

i. The intrapetrous part gives origin to superior and inferior carotico-tympanic branches, which enter the middle ear.

ii. The intracavernous part gives branches to the trigeminal ganglion, hypophyseal branches to the pituitary and the meningeal branches.

iii. The branches of supraclinoid part (Fig. 62.1) are, ophthalmic artery, posterior communicating artery, anterior choroidal artery and the terminal branches (anterior and middle cerebral arteries).

(Note: ICA gives direct branches to the genu of internal capsule)

Vertebrobasilar Arteries (Fig. 62.1)

i. The right and left vertebral arteries unite with each other at the lower margin of pons to form the basilar artery.
The branches intracranial part of vertebral artery supply not only the hindbrain but also the spinal cord (for description of vertebral artery refer chapter 53).

The basilar artery runs on the median sulcus on the ventral surface of pons and divides into right and left posterior cerebral arteries at upper margin of pons. Its bilateral branches include superior cerebellar, pontine, anterior inferior cerebellar (AICA) and labyrinthine. In 83 percent of cases, labyrinthine artery originates from the anterior inferior cerebellar artery for which reason AICA is termed as cerebellolabyrinthine artery.

**Circle of Willis (circulus arteriosus)**

The arterial circle at the base of the brain is an anastomosis between the internal carotid and the vertebrobasilar system of arteries. It is polygonal in shape and is located in the interpeduncular cistern.

**Formation (Fig. 62.1)**

i. The anterior communicating artery (which connects the right and left anterior cerebral arteries) forms anterior part of the circle of Willis.
ii. The anterior cerebral artery forms the anterolateral part on each side.
iii. The lateral part is formed by the termination of internal carotid artery on each side.
iv. The circle is completed posteriorly by the bifurcation of basilar artery into the right and left posterior cerebral arteries.
v. Posterolaterally, the posterior communicating artery is the connecting link between the internal carotid and posterior cerebral arteries. (Note: The middle cerebral artery does not take part in to the formation of the circle).

**Functional Importance**

This arterial circle equalizes the pressure of the blood flow to the two sides of the brain, as it is the main collateral channel.

**Know More ...**

**Variations**

The variations are very common in the circle of Willis. One of the arteries may be underdeveloped or absent. The hemodynamic balance of the circle is disturbed by such variations. The posterior communicating artery enlarges to compensate for the absent or the unusually small proximal segment of posterior cerebral artery. Similarly the anterior communicating artery enlarges to compensate for the absent or unusually small anterior cerebral artery. Sometimes the anterior communicating channel may be double.

**Berry Aneurysm (Figs 62.2 and 62.3A)**

The berry aneurysm is a localized dilatation on one of the arteries of the circle of Willis due to congenital muscular weakness. The most common sites of berry aneurysm are the junction of anterior cerebral and anterior communicating arteries and at the bifurcation of internal carotid arteries. Rupture of berry aneurysm may cause life-threatening subarachnoid hemorrhage.

**Clinical insight ...**

**Carotid Angiogram**

The carotid angiography is performed by direct needle puncture into the carotid arteries to inject radio-opaque dye. Figure 62.2 depicts the branches of internal carotid arteries and berry aneurysm on anterior communicating artery.

**Branches of Circle of Willis (Fig. 62.1)**

The central branches of the circle of Willis supply of the interior of the hemisphere and hence penetrate the base of the brain at specific points. There are six groups of central branches as follows:

i. Anteromedian
ii. Right and left anterolateral
Blood Supply of Brain

Chapter

iii. Posteromedian
iv. Right and left posterolateral

Distribution of Central Branches

1. Anteromedian branches arise from the anterior communicating and anterior cerebral arteries. They perforate the lamina terminalis to supply the anterior hypothalamus.

2. The right and left anterolateral or striate branches originate mainly from the middle cerebral artery of the corresponding side. They pierce the anterior perforated substance. These striate arteries are divided into lateral and medial groups. The medial striate branches arise from both middle cerebral and anterior cerebral arteries. The lateral striate branches arise from the middle cerebral artery.
   i. A large medial striate artery called recurrent artery of Heubner takes origin from the anterior cerebral artery. It enters the medial part of the anterior perforated substance to supply the head of caudate nucleus, part of putamen, anterior limb of the internal capsule including the genu.
   ii. The lateral striate arteries (lenticulostriate) ascend in the external capsule to pierce the lateral surface of the lentiform nucleus. They pass through this nucleus and the internal capsule in lateral to medial direction to end in the caudate nucleus (one of the lateral striate arteries, which is usually the longest, was termed by Charcot as artery of cerebral hemorrhage). The structures supplied by the lateral striate arteries are, part of anterior limb of internal capsule, part of posterior limb of internal capsule, caudate nucleus, putamen and part of globus pallidus.

Clinical insight ...

Occlusion of Striate Arteries

i. Occlusion of lenticulostriate arteries results in loss of blood supply to internal capsule leading to contralateral spastic hemiplegia, paralysis of lower half of face and altered sensorium.

ii. One of the named lateral striate arteries is very long and is called deep optic artery. It supplies the optic radiation. The occlusion of this artery results in homonymous hemianopia.

iii. Charcot Bouchard Aneurysms (Fig. 62.3B) are the microaneurysms of the lenticulostriate arteries in the presence of long-standing hypertension. Their rupture results in cerebral hemorrhage.

3. Posteromedian central arteries originate from posterior communicating and posterior cerebral arteries. They are divided into two groups.
   i. The rostral arteries pierce the hypophysis, infundibulum and tuberal region of hypothalamus. A few of these, called thalamoperforating arteries supply the thalamus.
ii. The caudal arteries pierce the posterior perforated substance to supply the mamillary bodies, subthalamus and thalamus.

4. The right and left posterolateral central branches are called thalamogeniculate arteries. They are the branches of posterior cerebral arteries. They pierce the cerebral peduncle and lateral geniculate body to supply the caudal half of thalamus, geniculate bodies and most of the lateral nuclear mass of thalamus.

**Choroidal Arteries**

The anterior and posterior choroidal arteries are regarded as central arteries since they supply the structures inside the cerebral hemispheres.

i. The anterior choroidal artery is a branch of the internal carotid artery. From its origin the artery passes backwards along the edge of the optic tract and crosses it twice, hence it is called the satellite artery of the optic tract. Then it enters the inferior horn of lateral ventricle through the choroid fissure to supply the choroid plexus. In addition it supplies the optic tract, amygdaloid complex, tail of caudate nucleus, globus pallidus, hippocampus and posterior limb of internal capsule including its retrolentiform and sublentiform parts. The anterior choroidal artery is prone to thrombosis due to its small caliber and long subarachnoid course. Its thrombosis may result in contralateral hemianesthesia, hemiparesis and hemianopia accompanied by loss of recent memory.

ii. The posterior choroidal artery is a branch of the posterior cerebral artery in the region of the splenium. There are three posterior choroidal arteries, one medial and two lateral. The medial posterior choroidal artery supplies the tectum, choroid plexus of third ventricle and thalamus. The lateral posterior choroidal arteries enter the choroid fissure and supply the choroid plexus of the central part and inferior horn of the lateral ventricle. These arteries supply the pulvinar, lateral geniculate bodies and fornix. Clinical evidence suggests that posterior choroidal arteries supply the hippocampus.

**Blood Supply of Cerebral Cortex**

The cortical branches of the anterior, middle and posterior cerebral arteries supply blood to the cerebral cortex (Figs 62.4 to 62.6).

**Anterior Cerebral Artery**

This artery arises from the internal carotid artery below the anterior perforated substance and lateral to the optic chiasma. It crosses the optic chiasma to reach the longitudinal fissure. At the anterior end of the longitudinal fissure the anterior communicating artery connects the right and left anterior cerebral arteries. Inside the longitudinal fissure, the anterior cerebral artery winds round the genu and then run posteriorly on the superior aspect of the body of corpus callosum.

**Distribution**

i. The orbital branches supply the medial half of orbital surface of the frontal lobe (olfactory bulb, olfactory gyrus and medial olfactory gyrus).

ii. The frontal branches supply the medial surface of the frontal and the parietal lobes including the paracentral lobule, cingulate gyrus, and corpus callosum.

iii. The parietal branches supply the precuneus.
Blood Supply of Brain

Chapter

Area of Supply
The anterior cerebral artery supplies the medial part of orbital surface of frontal lobe and the medial surfaces of frontal and parietal lobes. It also supplies one to two cm of the superolateral surface (of the frontal and parietal lobes) adjacent to superomedial border. The functional areas that receive blood from anterior cerebral artery are the motor and sensory areas for lower limb and perineum.

Middle Cerebral Artery
It is one of the terminal branches of the internal carotid artery. It turns laterally on the anterior perforated substance to enter the stem of the lateral sulcus, where it divides into four to five cortical branches on the surface of insula.

Distribution
i. The orbital branches supply the lateral half of orbital surface of frontal lobe.
ii. The frontal branches supply the superolateral surface of frontal lobe (precentral, middle and inferior frontal gyri) excluding the area supplied by anterior cerebral artery.
iii. The parietal branches supply the postcentral gyrus, inferior parietal lobule and superior parietal lobule excluding the area supplied by the anterior cerebral artery.
iv. The temporal branches supply the lateral surface of the temporal lobe excluding the inferior temporal gyrus but including the temporal pole. The functional areas that receive blood from the middle cerebral artery are, the motor and sensory areas (upper limb, trunk and face), premotor area, frontal eye field, auditory area and the speech centers in the dominant hemisphere.

Posterior Cerebral Artery
The right and left posterior cerebral arteries are the terminal branches of basilar artery. Each passes laterally around the crus cerebri of the midbrain, where it receives the posterior communicating artery. It continues along the lateral aspect of the midbrain and enters the supratentorial compartment through the tentorial notch. Then it courses on the tentorial surface of temporal lobe lying on the parahippocampal gyrus.

Distribution
i. The posterior temporal branches supply to the inferior surface of temporal lobe, uncus, and occipitotemporal and lingual gyri. They also send twigs to inferior temporal gyrus excluding the temporal pole.
ii. The calcaine and parieto-occipital branches supply the medial surface of the occipital lobe, which includes the cuneus. These cortical branches send twigs to superolateral surface of the occipital lobe. The visual cortex is the important functional area supplied by the posterior cerebral artery. The occipital pole receives blood from the anastomosis between the branches of posterior cerebral and middle cerebral arteries. Therefore, in the occlusion of the posterior cerebral artery there is macular sparing.

Clinical insight ...

Effects of Occlusion of Anterior Cerebral Artery
The loss of cortical supply to paracentral lobule results in contralateral spastic monoplegia (lower limb), altered sensorium in lower limb and urinary incontinence. There may be gradual changes in personality due to damage to orbital cortex of prefrontal lobe.

Clinical insight ...

Effects of Occlusion of Middle Cerebral Artery
The loss of cortical supply to precentral gyrus results in contralateral spastic paralysis of trunk, upper limb and lower part of face with altered sensorium and conjugate deviation of the eyes to the side of the lesion (due to involvement of posterior part of middle frontal gyrus). There will be global aphasia (if dominant hemisphere is affected). Loss of blood supply to prefrontal lobe results in gradual changes in personality.

Clinical insight ...

Effects of Occlusion of Posterior Cerebral Artery
The right and left posterior cerebral arteries are the terminal branches of basilar artery. Each passes laterally around the crus cerebri of the midbrain, where it receives the posterior communicating artery. It continues along the lateral aspect of the midbrain and enters the supratentorial compartment through the tentorial notch. Then it courses on the tentorial surface of temporal lobe lying on the parahippocampal gyrus.
Cerebral Angiography (Fig. 62.2)

i. The carotid angiography is performed by direct needle puncture of the internal carotid arteries.

ii. The right vertebral artery is approached by passing a catheter in succession through the following arteries - femoral, external iliac, common iliac, abdominal aorta, thoracic aorta, arch of aorta, brachiocephalic and right subclavian.

iii. The left vertebral artery is approached through the same route except that after the arch of aorta the catheter passes in to the left subclavian artery.

The contrast material is injected under general anesthesia and serial films are taken.

Venous Drainage of Cerebrum

The veins of the cerebrum are divided into external (superficial) and internal (deep) sets. The veins of the superficial set drain the surface of the cerebrum while those of deep set drain the interior of the cerebrum.

External or Superficial Veins of Cerebrum

i. The superior cerebral veins, about eight to ten in number, drain the superolateral and medial surfaces of the cerebrum. They empty into the superior sagittal sinus against the flow of blood in the sinus. Tear of the superior cerebral vein results in subdural hemorrhage.

ii. The superficial middle cerebral vein begins on the superolateral surface and enters the posterior ramus and the stem of the lateral sulcus. On reaching the inferior surface it terminates into the cavernous sinus. (The superficial middle cerebral vein is connected to the superior sagittal sinus by a superior anastomotic vein of Trolard. It is connected to the transverse sinus by inferior anastomotic vein of Labbe).

iii. The deep middle cerebral vein receives veins from the insula in the depths of the lateral sulcus and runs medially to reach the base of the brain at the vallecula. It takes part in the formation of basal vein.

iv. The anterior cerebral vein accompanies the anterior cerebral artery. It reaches vallecula at the base of the brain, where it terminates by uniting with the deep middle cerebral vein and striate veins to form the basal vein. (Note: striate veins come out through the anterior perforated substance).

v. The basal vein runs posteriorly along with the optic tract and crosses the crus cerebri to open into the great cerebral vein under the splenium. It receives tributaries from the interpeduncular fossa, inferior horn of lateral ventricle, parahippocampal gyrus and midbrain.

vi. The inferior cerebral veins drain the orbital and tentorial surfaces. Those of the orbital surface join the superior cerebral veins. Those on the tentorial surface open into basal vein and the transverse sinus.

Deep Veins of Cerebrum (Fig. 62.7)

i. The thalamostriate vein travels in the floor of the lateral ventricle between the thalamus and the caudate nucleus up to the level of the interventricular foramen. It drains the corpus striatum, internal capsule, thalamus, fornix and septum pellucidum.

ii. The choroidal vein spirals along the entire choroid plexus of the lateral ventricle. It receives veins from the hippocampus, fornix, and corpus callosum on its way to the interventricular foramen.

iii. The internal cerebral vein is formed on each side at the level of the interventricular foramen by the union of
thalamostriate and choroidal veins. The right and left internal cerebral veins run backwards in the tela cho- 
roidea of the third ventricle and unite with each other below the splenium to form the great cerebral vein. 
iv. The great cerebral vein of Galen is a very short vein. It is located in the cisterna ambiens under the sple- 
nium. Its main tributaries are the right and left basal veins. It also receives veins from cerebellum, pineal gland and tectum. It emerges from beneath the sple- 
nium to open into the anterior end of the straight sinus. The site of its junction with the straight sinus is marked by a sinusoidal plexus, which regulates the blood flow from the great cerebral vein into the straight sinus.
The interior of each cerebral hemisphere consists of a core of white matter, which is composed of myelinated nerve fibers. The fibers of white matter are classified into three types, association, commissural and projection.

**Association Fibers (Fig. 63.1)**
The association fibers connect different parts of the cerebral cortex of the same hemisphere to each other. The short association fibers connect the adjacent gyri to each other. The long association fibers connect the gyri located at a distance from each other.

**Examples of Long Association Fibers**
1. The cingulum (girdle shaped) is located within the cingulate gyrus. It extends from the paraterminal gyrus to the uncus. The cingulum is part of the Papez circuit of the limbic system.
2. The uncinate fasciculus (arcuate fasciculus) is a curved fiber bundle. It connects the inferior frontal gyrus and the orbital gyri of the frontal lobe to the cortex of the temporal lobe. Thus, it connects the sensory and motor speech areas to each other in the dominant hemisphere.
3. The superior longitudinal fasciculus is a long bundle that begins in the frontal lobe and arches back via the parietal lobe to the occipital lobe from where it turns into the temporal lobe. Thus, it connects the occipital lobe to the frontal eye field.
4. The inferior longitudinal fasciculus connects the occipital lobe to the temporal lobe.

**Commissural Fibers**
The commissural fibers cross the midline and connect the identical parts of the two hemispheres.

**Examples of Commissural Fibers**
1. The anterior commissure connects the right and left temporal lobes. It is of the shape of a cupid’s bow. It crosses the midline in the upper part of the lamina terminalis anterior to the columns of fornix. Its fibers divide into anterior and posterior bundles. The anterior bundle connects the anterior perforated substance and the olfactory tracts of the two sides. The posterior bundle at first passes through the head of the caudate nucleus and then inclines posteriorly in the lentiform nucleus to enter the middle and inferior gyri of the temporal lobe.
2. The posterior and habenular commissures are part of epithalamus and are located in the posterior part of the roof of third ventricle.
iii. The hippocampal commissure connects the hippocampus of the two sides to each other.

iv. The corpus callosum is the largest commissure of the brain.

**Corpus Callosum (Fig. 58.2B)**

This is located in the floor of the longitudinal fissure. It is of the shape of an arch.

**Parts**

The corpus callosum consists of four parts. Its anterior end is called the genu, the central part is the trunk and the posterior bulbous part forms the splenium. The fourth part is the rostrum, which is the prolongation from the genu to the upper end of lamina terminalis.

**Relations**

i. The superior aspect of the corpus callosum is covered with indusium griseum, in which medial and lateral longitudinal striae are embedded. The indusium griseum is the rudimentary grey matter.

ii. Transverse fissure is located between the splenium and the superior colliculi and pineal gland. It gives passage to the tela choroidea of third and lateral ventricles. The posterior choroidal arteries enter the fissure and the internal cerebral veins leave it and unite to form the great cerebral vein beneath the splenium.

iii. The anterior and superior aspects of the corpus callosum are in close relation to the anterior cerebral vessels.

iv. The inferior aspect of the corpus callosum gives attachment to the septum pellucidum anteriorly and the fornix posteriorly.

v. The rostrum and genu form the boundaries of the anterior horn and the trunk forms the roof of the central part of the lateral ventricle.

**Connections of Corpus Callosum (Fig. 63.2)**

The fibers of the corpus callosum interconnect the corresponding parts of the right and left hemispheres.

i. The fibers passing through the rostrum connect the orbital surfaces of the frontal lobes.

ii. The fibers passing through the genu interconnect the two frontal lobes by means of a fork-like bundle of fibers called forceps minor.

iii. The fibers passing through the splenium interconnect the occipital lobes by means of a fork like bundle of fibers called forceps major. The forceps major bulges into the medial wall of the posterior horn of lateral ventricle to give rise to an elevation called the bulb.

**Arterial Supply**

The rostrum, genu and body of corpus callosum receive bilateral branches from anterior cerebral artery. The splenium receives branches from the posterior cerebral arteries.

**Clinical insight ...**

**Split Brain Syndrome**

The transection of corpus callosum (commissurotomy) causes split brain syndrome. The nondominant hemisphere (right) is dissociated from the dominant hemisphere (left). The patient is unable to match an object held in one hand with that in the other, when blindfolded and is unable to correctly name objects placed in the left hand (anomia).

**Projection Fibers**

The projection fibers connect the cerebral cortex to other regions of central nervous system by corticopetal or ascending and corticofugal or descending fibers.
Examples of Projection Fibers

i. The corona radiata (Fig. 63.3) is a mass of white matter composed of the projection fibers, which converge from the cerebral cortex to the internal capsule and fan out from the internal capsule towards the cortex.

ii. The internal capsule transmits the projection fibers like corticospinal, corticonuclear and corticopontine fibers. These fibers arise in the cerebral cortex and terminate on the lower neurons (like anterior horn cells, cranial nerve nuclei in brainstem and pontine nuclei). The internal capsule also gives passage to thalamic radiations (comprising to and fro connections between cerebral cortex and thalamic nuclei).

iii. The fornix is composed of projection fibers, which take origin from the hippocampus. The fibers in the fornix are connected to the neurons of the mamillary body.

Internal Capsule (Figs 63.4A and B)

The internal capsule is a curved and compact mass of projection fibers situated deep inside the hemisphere. All projection fibers of the cerebrum are concentrated in the internal capsule. Therefore, a small lesion in it can cause widespread paralysis and sensory loss in the opposite side.

Parts

The internal capsule consists of five parts:
1. Anterior limb
2. Genu
3. Posterior limb
4. Sublentiform part
5. Retrolentiform part

Relations

i. Superiorly, the fibers in the internal capsule fan out to become the corona radiata.

ii. Inferiorly, the descending fibers pass through the crus cerebri and the thalamic radiations connect with the thalamus.
iii. Laterally, the lentiform nucleus fits into the concavity of the internal capsule.
iv. Medially, the head of the caudate nucleus is related to the anterior limb and the thalamus is in relation to the posterior limb.

**Fiber Composition**

**Anterior Limb**

i. The frontopontine fibers are descending fibers. They originate in frontal lobe and terminate on nuclei pontis.

ii. The anterior thalamic radiation consists of to and fro connections from the dorsal medial (DM) nucleus to the prefrontal cortex, from the ventralis anterior (VA) nucleus to the premotor area, from VL nucleus to the motor area and from the anterior nuclei to the cingulate gyrus.

**Genu**

i. The genu contains corticonuclear fibers, which arise in area 4 (precentral cortex) and terminate on the motor nuclei of the cranial nerves in the brainstem.

ii. A few fibers of the superior thalamic radiation containing ascending fibers from the nuclei VPM and VPL of the thalamus and parietothalamic fibers to the same nuclei pass through the genu.

**Posterior Limb**

i. The descending fibers include the corticospinal fibers arising mainly from the precentral gyrus. They are located in discrete bundles more towards the anterior part of the posterior limb. From anteroposterior direction the arrangement of fibers is as follows, upper limb, trunk and lower limb.

ii. The other descending fibers are the corticocubral, corticoreticular and frontopontine.

iii. The superior thalamic radiation consists of projections from the VPL and VPM nuclei to the postcentral gyrus. This radiation also contains ascending fibers from other thalamic nuclei (pulvinar) and the descending fibers from the parietal cortex to the same thalamic nuclei and other nuclei of thalamus including pulvinar (parietothalamic fibers).

**Sublentiform Part**

i. The descending fibers include the parietopontine and temporopontine fibers to the pons.

ii. The inferior thalamic radiations mainly consist of auditory radiation from the medial geniculate body to the anterior transverse gyri and superior temporal gyrus. The temporothalamic fibers are also present.

**Retrolentiform Part**

i. The descending fibers are the parietopontine, occipitopontine and occipitotectal fibers.

ii. The posterior thalamic radiations consist of the optic radiation from the lateral geniculate body to the visual cortex in the occipital lobe. The other ascending fibers in posterior thalamic radiation are thalamocortical projection from other thalamic nuclei including the pulvinar. The reciprocal corticothalamic fibers are also present.

**Arterial Supply (Fig. 63.5)**

i. The upper part of the anterior limb receives blood from the striate branches of middle cerebral artery and its lower part from the recurrent branch of anterior cerebral artery.

ii. The upper part of the genu receives blood from the striate branches of middle cerebral artery and the lower part from the direct branches of internal carotid and recurrent branch of anterior cerebral arteries.

iii. The upper part of the posterior limb receives arterial supply from the striate branches (lenticulo-striate) of middle cerebral artery and its lower part by anterior choroidal artery.

iv. The retrolentiform and sublentiform parts receive branches from the anterior choroidal artery.

**Clinical insight ...**

**Effects of Lesions of Internal Capsule**

i. The microaneurysms (Charcot-Bouchard) usually develop in the intracerebral arterioles of lenticulo-striate branches of middle cerebral arteries especially in the presence of...
To summarize, the pyramidal fibers form the bulk of projection fibers in the white matter (corona radiata and internal capsule). Hence, the pyramidal tract is described in detail below.

**Pyramidal Tract (Fig. 55.14)**

The pyramidal tract constitutes the motor pathway, which controls the voluntary movements of the body. It consists of corticonuclear fibers and corticospinal fibers. The function of the pyramidal tract is to influence the lower motor neurons in the brainstem and spinal cord to regulate the voluntary movements in the opposite half of the body. The pyramidal tract is composed of two types of fibers, corticonuclear for controlling neurons in cranial nerve nuclei in brainstem and corticospinal fibers controlling anterior horn cells in spinal cord.

**Origin**

i. The corticonuclear fibers originate as the axons of the pyramidal cells of the motor and premotor cortex, pass through the corona radiata and genu of the internal capsule to terminate on the various cranial nerve nuclei in the brainstem.

ii. The corticospinal fibers originate in following parts of the cerebral cortex, giant pyramidal cells or Betz’s cells in the primary motor area 4 (precentral gyrus and corresponding part of paracentral lobule) and pyramidal cells of premotor area 6 (posterior parts of superior, middle and inferior frontal gyri and corresponding area extending on medial surface of frontal lobe). The corticospinal fibers are the axons of these pyramidal cells. The cell bodies of these neurons and their axons together comprise the upper motor neurons. The axons of the upper motor neurons extend from the cerebrum to the anterior horn cells (lower motor neurons) at various levels of spinal cord.

**Course of Corticospinal Fibers (Fig. 55.14)**

i. The corticospinal fibers originate in motor and premotor cortex and pass through corona radiata.

ii. They aggregate towards the anterior two-thirds of the posterior limb of the internal capsule, where fibers form discrete bundles. The bundle for head and neck is placed most anteriorly followed by upper limb, trunk and the lower limb.

iii. From the internal capsule the corticospinal fibers descend through the middle two-thirds of the crus cerebri of midbrain, where they are in close approximation with the oculomotor nerve.

iv. In their further descent the corticospinal fibers enter the ventral or basilar part of the pons, where they break up into smaller fascicles and interface with crossing pontocerebellar fibers and pontine nuclei. In the pons the fibers are in close relation to the abducent and a little laterally to the facial nerve.

v. As soon as the corticospinal fibers enter the medulla oblongata the scattered fascicles aggregate to form pyramids on the ventral surface of medulla oblongata.

vi. At the level of pyramidal decussation of medulla oblongata about 70 to 90 percent of fibers cross over to the opposite side to form lateral corticospinal tract on each side. This tract extends through the entire length of the spinal cord and terminates directly or indirectly on the anterior horn cells.

vii. The uncrossed fibers continue downwards as anterior corticospinal tracts and at different levels of spinal cord cross to the opposite side via the anterior commissure of spinal cord to terminate like the lateral corticospinal tract. The anterior corticospinal tract extends up to the midthoracic level of the cord.

**Comparative Features of UMN and LMN Lesions**

See Table 63.1

**Table 63.1: Difference between UMN and LMN lesions**

<table>
<thead>
<tr>
<th>Sign</th>
<th>Upper motor neuron (for example—lesion of internal capsule due to cerebral hemorrhage)</th>
<th>Lower motor neuron (for example—lesion of anterior horn cells due to poliomyelitis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of paralysis</td>
<td>Spastic</td>
<td>Flaccid</td>
</tr>
</tbody>
</table>

Contd...
**Clinical insight ...**

**Plantar Response**
It is elicited as follows. The outer aspect of the sole (S1 dermatome) is firmly stroked with a blunt point (e.g. a key). The normal plantar response is the flexion of the metatarsophalangeal joint of great toe and flexion of closing together of other toes. The Babinski sign consists of extension of great toe and the fanning out of other toes. This occurs in upper motor neuron lesion (UMN). The Babinski sign is positive in newborn and infants due to incomplete myelination of corticospinal fibers.

**Effects of Lesions at Different Levels of Pyramidal Tract**

i. The cortical lesions are produced due to thrombosis in middle cerebral artery or anterior cerebral artery. This may cause contralateral localized paralysis, for example of face or one limb and this may be accompanied by altered sensorium, convulsions, aphasia and abnormality of higher functions.

ii. Vascular lesions of internal capsule are very common, especially in hypertensive patients. Small lesion of posterior limb of internal capsule results in contralateral hemiplegia with upper motor neuron type of facial palsy (contralateral paralysis of lower face) due to crowding of fibers in internal capsule.

iii. In the midbrain, the lesion of corticospinal fibers is accompanied by lesion of oculomotor nerve resulting in a combined UMN and LMN lesions. There is contralateral hemiplegia due to lesion of corticospinal fibers and ipsilateral LMN paralysis of extraocular muscles due to oculomotor lesion (Weber’s syndrome).

iv. In the pons various combinations of UMN and LMN lesions occur. Contralateral hemiplegia is accompanied by either the abducent nerve palsy or facial nerve palsy or both.

v. In the medulla oblongata the thrombosis of anterior spinal artery leads to medial medullary syndrome in which there is contralateral hemiplegia accompanied by ipsilateral hypoglossal nerve palsy and contralateral loss of conscious proprioception in the body. The thrombosis of PICA results in lateral medullary syndrome, which produces symptoms corresponding to involvement of posterolateral structures in the medulla oblongata.

vi. In lesions of spinal cord the corticospinal tracts are involved. These tracts are crossed hence their lesion produces ipsilateral UMN paralysis (on the same side of the lesion). If the anterior horn cells and lateral corticospinal tracts show degeneration there is combined UMN and LMN paralysis.
LATERAL VENTRICLE

The lateral ventricle is the ependyma-lined cavity inside each cerebral hemisphere. It contains choroid plexus and CSF. Each lateral ventricle communicates with the third ventricle through the interventricular foramen of Monro. The lateral ventricle is roughly a C-shaped cavity with an extension from the back of the C (Fig. 64.1).

Subdivisions (Fig. 64.2)

The ventricle consists of:

i. The central part, which lies into the parietal lobe.

ii. The anterior horn, which extends into the frontal lobe from the level of interventricular foramen.

iii. The inferior horn, which extends into the temporal lobe.

iv. The posterior horn, which extends into the occipital lobe.

Central Part

The central part extends from the interventricular foramen to the splenium of corpus callosum. It presents medial wall, roof and floor.

- The medial wall (Fig. 60.2) decreases in height in anteroposterior direction. The septum pellucidum and the fornix below it form the anterior part of the medial wall but the fornix alone is present in the posterior part. The septum pellucidum (septum lucidum) consists of right and left laminae, which connect the fornix and the corpus callosum. Its two laminae may be separated by a cavity, which is known as the fifth ventricle. This septum contains a few septal nuclei.

- The trunk of the corpus callosum forms the roof.

- The floor consists of six structures (Fig. 60.2). From lateral to medial they are, the body of caudate nucleus, thalamostriate vein, stria terminalis, a narrow strip of superior surface of thalamus, the choroid plexus and the fornix. At the posterior end, the floor has a triangular area called...
the collateral trigone, where the inferior and posterior horns diverge from the central part of the ventricle.

**Anterior Horn**

The anterior horn has roof, floor, anterior wall medial wall and lateral wall.

i. The roof is formed by the trunk of the corpus callosum.

ii. The anterior wall is formed by the genu of the corpus callosum.

iii. The medial wall is formed by the septum pellucidum.

iv. The floor consists mainly of the head of caudate nucleus laterally and the rostrum of the corpus callosum medially.

v. The lateral wall contains the head of the caudate nucleus.

(Note that the head of the caudate nucleus is related to the lateral wall and the floor).

**Inferior Horn (Fig. 64.3A)**

The anterior end of the inferior horn reaches very close to the uncus in the temporal lobe. The inferior horn has roof, lateral wall and floor.

i. The roof contains the tail of caudate nucleus and stria terminalis, which enter the roof from the central part of the lateral ventricle. The tail of the caudate nucleus joins the amygdaloid nucleus and the stria terminalis begins in the same nucleus, which overlies the tip of the inferior horn in the uncus.

ii. The tapetum forms the lateral wall, which is closely related to the looping fibers (Meyer’s loop) of the optic radiations. Enlarged inferior horn may compress these fibers giving rise to visual field defect known as contralateral upper homonymous quadrantanopia.

iii. The floor shows the bulge of the hippocampus covered by a white sheet called alveus and the fimbria medially. The collateral eminence is produced by the collateral sulcus laterally.

**Posterior Horn (Fig. 64.3B)**

The posterior horn may be asymmetrical in adults or sometimes absent. It has roof, medial wall and lateral wall.

i. The roof and the lateral walls are formed by the tapetum.

ii. The medial wall is invaginated by the forceps major, which produces the bulb of posterior horn above and by the calcarine sulcus, which gives rise to the calcar avis below.

**Choroid Fissure**

The choroid fissure is the space through which a vascular sheet of piamater enters the lateral ventricle. The ependyma and tela choroidea come in direct contact with each other in this space. The ependyma-covered tela choroidea forms the choroid plexus of the lateral ventricle. The choroid fissure is a C-shaped gap having upper and lower parts.

i. The upper part of the choroid fissure is related to the central part of the lateral ventricle. It is bounded by fornix above and superior surface of thalamus below (Fig. 60.2).
ii. The lower part of the choroid fissure is related to the inferior horn of the lateral ventricle. It is bounded by the fimbria below and the structures in the roof of the inferior horn above (Fig. 64.3A).

**Choroid Plexus**
The tela choroidea enters the transverse fissure to reach the superior surface of the thalamus. Here, it comes in direct contact with the ependyma of the roof of the third ventricle and at the choroid fissure with the ependyma of the lateral ventricle. The choroid plexuses thus formed, project through the roof of third ventricle and through the choroid fissure of lateral ventricle. Anterior and posterior choroidal arteries supply choroid plexuses of both the ventricles. The choroid plexuses are present in central part and inferior horn since the choroid fissure is confined to these parts of the lateral ventricle. The anterior and posterior horns are devoid of choroid plexuses.

**Radiological Visualization**
Pneumoencephalography and ventriculography are the older methods of visualizing the lateral ventricles. They are almost replaced by MRI and CT scans nowadays.

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### Clinical insight ...

#### Hydrocephalus
The hydrocephalus is accumulation of CSF in lateral ventricle, usually due to blockage of interventricular foramen of Monro.

#### Intraventricular Hemorrhage
The caudate nucleus is intimately related to the anterior horn, the central part and the inferior horn of the lateral ventricle. The hemorrhage in the caudate nucleus (usually due to hypertension) may break in to the cavity of the lateral ventricle and cause fatal intraventricular bleeding.

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**Fig. 64.4:** Coronal section of brain passing through anterior perforated substance (Note the continuity of gray matter of anterior perforated substance with gray matter of basal ganglia).

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### BASAL GANGLIA
The basal ganglia or the basal nuclei are the collections of gray matter situated inside the cerebral hemisphere. The basal ganglia belong to the extrapyramidal system and their lesion results in movement disorders in the body.

#### Component Nuclei (Fig. 64.4)
Broadly, the basal ganglia consist of four nuclei:
1. Caudate nucleus
2. Lentiform nucleus
3. Claustrum
4. Amygdaloid nucleus.

The lentiform nucleus consists of the lateral part called putamen and the medial part called the globus pallidus. The structure and functions of the putamen and globus pallidus are different.

#### Corpus Striatum
The corpus striatum includes the caudate nucleus and the lentiform nucleus.

#### Striatum
The caudate nucleus and the putamen of the lentiform nucleus are similar in structure and connections. Therefore together, they are called the striatum.

#### Pallidum
The globus pallidus is known as the pallidum.
(Note: The main receiving station of the corpus striatum is the striatum but its main output station is the pallidum).

#### Caudate Nucleus (Fig. 64.2)
This is a comma-shaped nucleus having three parts, the head, body and tail.

i. The head bulges into the lateral part of the floor and the lateral wall of the anterior horn. It is related laterally to the anterior limb of the internal capsule, which separates it from the lentiform nucleus. Below the head, a band of gray matter connects the caudate nucleus with the putamen of lentiform nucleus. This band of gray matter is continuous with the anterior perforated substance through aggregations of gray and white matter called substantia innominata. This is the only place, where the surface gray matter is continuous with the intracerebral gray matter.

ii. The body extends backward from the head at the level of interventricular foramen and lies in the floor of the central part of the lateral ventricle. The thalamostriate vein and stria terminalis lie in the groove between the body of caudate nucleus and the thalamus.

iii. The tail continues forwards and downwards in the roof of the inferior horn of the lateral ventricle along with
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stria terminalis and ends in the amygdaloid nucleus at the tip of the inferior horn.

Lentiform Nucleus

The lentiform nucleus has the shape of a biconvex lens.

Relations

It has a highly convex medial surface and a lateral surface.

1. The structures intervening between the lateral surface and the insular cortex are, external capsule, claustrum and the extreme capsule (from medial to lateral side). A few of the lateral striate arteries pierce the lateral surface and pass through the substance of lentiform nucleus.

2. The medial surface is intimately related to the anterior limb of internal capsule anteriorly and the posterior limb of internal capsule posteriorly (the genu being in contact with the apex). Inferiorly, the lentiform nucleus is connected by a band of gray matter to the head of the caudate nucleus and is continuous with the anterior perforated substance. Its inferior aspect is deeply grooved by fibers of anterior commissure.

Subdivisions

A vertical line of white matter called external medullary lamina divides the lentiform nucleus into larger lateral part called putamen and smaller medial part called globus pallidus.

The putamen is darker in color compared to globus pallidus, which is pale. The globus pallidus is also called pallidum because of its pale color (pallidum means pale). It is further divided into outer and inner segments by internal medullary lamina of white matter. The globus pallidus is the only output nucleus of corpus striatum.

Afferent Connections of Striatum

1. The corticostriate fibers from the sensory and motor cortices are excitatory and cholinergic.

2. Thalamostriate fibers from the centromedian nucleus, midline and intralaminar nuclei and the nucleus dorsalis medialis of the thalamus are considered to be excitatory.

3. Nigrostriate fibers from the substantia nigra are dopaminergic and inhibitory to the striatum.

Efferent Connections of Striatum

Major output is striatopallidal fibers, which terminate in globus pallidus.

Afferent Connections of Pallidum

The pallidum receives fibers from the striatum, substantia nigra and the subthalamic nucleus.

Efferent Connections of Pallidum

The pallidofugal fibers form four separate bundles.

1. Fasciculus lenticalaris arises from the inner segment of the globus pallidus and enters the subthalamic region.

2. Ansa lenticularis arises from both the inner and outer segments of the globus pallidus and enters the subthalamic region, where it meets the dentato-rubro-thalamic fibers and the fasciculus lenticularis. The union of the three tracts is called the fasciculus thalamicus, which terminates in the ventralis anterior (VA), ventralis lateral (VL) and centromedian nuclei of thalamus.

3. Fasciculus subthalamicus consists of reciprocal connections between the globus pallidus and nucleus subthalamicus.

4. Descending pallidotegmental fibers terminate in red nucleus, midbrain reticular formation and inferior olivary nucleus. Through these connections, the corpus striatum exerts influence on the lower motor neurons.

Functions of Corpus Striatum

1. The corpus striatum mediate the enormous number of automatic activities involved in normal motor functions. For example, the maintenance of erect posture when sitting or standing requires coordinated contraction of many muscles. This co-ordination is under subconscious control and is mediated by the extrapyramidal system.

2. The corpus striatum provides the crucial physiological link between the “idea of movement” and the “motor execution of that idea.” Their influence on the motor action is indirect as they affect the motor regions of the cerebral cortex before motor commands are sent to the brainstem and spinal cord.

Clinical insight ...

1. Lesions in the corpus striatum cause disturbances in the initiation and cessation of a motor event. This results into various kinds of abnormal movements.

2. Parkinson’s disease is associated with degeneration of neurons of substantia nigra with resultant depletion of dopamine in corpus striatum. This gives rise to increased muscle tone with slow and abnormal movements. The characteristic features of this disease are, cogwheel rigidity and resting tremor (pill-rolling tremor). Mask-like facies with no emotional response and shuffling gait are the other characteristic features.

3. Huntington’s chorea is an autosomal dominant disorder associated with severe degeneration of neurons in caudate nucleus and putamen. It is accompanied by gyral atrophy in frontal and temporal lobes. It leads to movements, which are brisk, jerky and purposeless.
Clastrum
This is a small strip of gray matter between the lentiform nucleus and the insular cortex.

Amygdaloid Nucleus
It is located in the temporal lobe deep to the uncus. The amygdaloid nucleus has complex chemical connections with the limbic system and hence functionally, it belongs to the limbic system.

LIMBIC SYSTEM
The limbic system is the structural basis of the behavioral and emotional expression of the individual. The limbic system plays a role in feeling, feeding, fighting and fleeing activities. It is responsible for emotions necessary for sexual functions. It integrates the olfactory, visceral and somatic impulses through the hypothalamus. In addition to the above functions, the limbic system is an integral part of the processes involved in recent memory. The term limbus means a ring. The limbic structures are disposed along the edge of the cerebral hemisphere like a ring.

Constituents of Limbic System
i. Cortical gray matter
ii. Subcortical gray matter
iii. Interconnecting fiber tracts.

Cortical Gray Matter
i. Limbic lobe (cingulate gyrus, isthmus, parahippocampal gyrus and uncus) and orbitofrontal cortex.
ii. Hippocampal formation (hippocampus, dentate gyrus, gyrus fasciolaris and indusium griseum).
iii. Since the cortical areas included in the limbic system are not totally agreed upon many authorities include entorhinal area (anterior part of parahippocampal gyrus and uncus), septal area (which includes paraterminal and parolfactory gyri) and piriform lobe under this heading.

Subcortical Gray Matter
i. Dorso medial (mediadorsal) nucleus of thalamus, which has reciprocal connections with entorhinal area, hypothalamus, prefrontal cortex and amygdaloid nucleus. It plays a role in affective behavior.
ii. Anterior nucleus of thalamus, (part of Papez circuit)
iii. Amygdaloid complex
iv. Hypothalamus including mamillary bodies
v. Septal nuclei
vi. Interpeduncular nucleus
vii. Habenular nuclei
viii. Midbrain tegmental nuclei.

Interconnecting Fiber Tracts
The fibers tracts of limbic system include fornix, mamillothalamic tract (Vicq d’Azyr), stria terminalis, stria medullaris thalami, median forebrain bundle, diagonal band of Broca, cingulum and fasciculus retroflexus.

Amygdaloid Nucleus (Fig. 64.4)
The amygdaloid nucleus is an almond-shaped collection of subcortical nuclear mass lying inside the uncus at the tip of the inferior horn of the lateral ventricle. It is continuous with the tail of caudate nucleus. Due to the wide-ranging connections of the amygdala, it occupies the central place in human being’s emotional processing and hence functionally, it is an integral part of the limbic system.

Subcortical Connections of Amygdala
i. The stria terminalis originates in the amygdala and passes backwards in the roof of the inferior horn and then forwards in the floor of the central part of the lateral ventricle. It divides into three parts at the level of interventricular foramen. The supracommissural part ends in septal nuclei and septal area (paraterminal gyrus). The commissural part joins the anterior commissure to reach the opposite amygdaloid complex. The subcommissural part ends in preoptic and anterior nuclei of hypothalamus and anterior perforated substance.
ii. The ventral amygdalofugal fibers terminate in septal area, anterior perforated substance, mediadorsal nucleus of thalamus, hypothalamic nuclei and basal nucleus of Meynert. There is connection with the midbrain and the corpus striatum also.

Contd...
resembling fragments of voluntary movements and progressive mental deterioration.
iv. Sydenham’s chorea or St Vitus’ dance occurs as a result of minute hemorrhages and capillary emboli in the corpus striatum. The abnormal movements similar to Huntington chorea are the cardinal sign of this disease.
v. In hepatolenticular degeneration or Wilson’s disease, there is defect in copper metabolism. The involvement of lentiform nucleus causes tremor, rigidity and impairment of voluntary movements. The liver is also affected. Deposition of copper in cornea gives rise to characteristic Kayser-Fleischer ring.
Cortical Connections of Amygdala
The amygdala is in connection with the entorhinal cortex, hippocampal formation, temporal and occipital cortices and the frontal, cingulate and insular cortices.

Hippocampal Formation
This consists of hippocampus, dentate gyrus, indusium griseum and the longitudinal striae.

i. The hippocampus (Fig. 64.5) is part of cerebral cortex that resembles sea horse in appearance in its coronal section. It is also described as ram’s horn or Ammon’s horn. It forms a curved elevation in the floor of the inferior horn of lateral ventricle. Its anterior expanded end presents shallow grooves, which give it the appearance of the paw hence called pes hippocampi. The hippocampus consists of three-layered cortex. The axons of the pyramidal neurons of the hippocampus form a white sheet called alveus that covers the ventricular aspect of the hippocampus under the ependyma. The alveus continues as the fimbriae, which continue backward as the crus of the fornix. The hippocampus receives connections from entorhinal area, septal area and cingulate gyrus. The structural layers of hippocampus (called cornu ammonis) is divided into three sectors (CA1, CA2 and CA3 - CA stands for cornu ammonis), as shown in Figure 64.5. The pathologists recognize CA1 sector as Sommer’s sector. The large pyramidal cells of this sector are very sensitive to hypoxia.

ii. The fornix forms the efferent pathway of hippocampus. It is a prominent bundle of projection fibers located on the medial surface of the cerebral hemisphere. It consists of a posterior part called crus, body and the anterior part called column. The crus is the continuation of fimbria. The two crura are united with each other by hippocampal commissure through which the right and left hippocampi are joined. The body of the fornix is the continuation of the crus. It is connected to the corpus callosum by septum pellucidum. The body lies in contact with the superior surface of the thalamus and forms the superior boundary of the choroid fissure of the central part of the lateral ventricle. The anterior end of the body divides into right and left columns. Each column forms the anterior boundary of the interventricular foramen. The column divides into precommisural and postcommisural fibers. The precommisural fibers terminate in septal areas including the basal nucleus of Meynert, amygdaloid complex and anterior thalamus while the postcommisural fibers pass through the hypothalamus to terminate in the mamillary bodies from where the mamillothalamic tract connects it to anterior nucleus of thalamus.

Vestigial Part of Hippocampal Formation
This includes the indusium griseum, gyrus fasciolaris, dentate gyrus and longitudinal striae. The indusium griseum is continuous anteriorly with the paraterminal gyrus while posteriorly, it is continuous with gyrus fasciolaris and through it with the dentate gyrus, which is a longitudinal strip of gray matter in association with the hippocampus. The lateral margin of the dentate gyrus is fused with the hippocampus and its free medial margin is crenated giving it the appearance of teeth. Anteriorly the dentate gyrus ends in a tail, which runs across the inferior surface of uncus and terminates into it.

Papez Circuit (Fig. 64.6)
It is a circular pathway that interconnects certain important structures in limbic system. It contains the following stations, the hippocampus projecting via the fornix to mamillary nucleus, the mamillary nucleus projecting via the mamillothalamic tract to the anterior nucleus of thalamus, anterior nucleus of thalamus projecting to the cingulate gyrus and the cingulate gyrus projecting via the cingulum back to the hippocampus.

Functional Importance of Hippocampus
It plays important role in learning and recent memory and in the control of emotional behavior (It has been proved that hippocampus has no olfactory function).
**Limbic Lobe**

The limbic lobe consists of septal area, cingulate gyrus, isthmus and parahippocampal gyrus.

i. The septal area includes septum pellucidum and the paraterminal and subcallosal (parolfactory) gyri on the medial surface of the hemisphere. The septal nuclei are the sparse gray matter in the septum pellucidum and the subcortical gray matter in the septal region. The basal nucleus of Meynert is included in septal nuclei since it is located in substantia innominata of basal forebrain between the globus pallidus and anterior perforated substance. The basal nucleus of Meynert projects via cholinergic fibers to the amygdala and the entire neocortex. It shows degeneration in Alzheimer’s disease. The septal area has reciprocal connections with the hypothalamus via the median forebrain bundle and it projects via the stria medularis thalami to the habenular nucleus.

ii. The cingulate gyrus lies on the medial surface of the hemisphere starting below the rostrum of the corpus callosum. It follows the curve of the corpus callosum and continues round the splenium on the inferior surface to merge with the parahippocampal gyrus through the narrow isthmus. This gyrus receives afferent connections from the anterior nucleus of thalamus (part of Papez circuit) and also from amygdaloid body. It projects via the cingulum to the parahippocampal gyrus and hippocampal formation. Lesions in the cingulate gyrus result in akinesia, mutism, apathy and indifference to pain.

iii. The parahippocampal gyrus is present on the inferior surface of the hemisphere lying medial to the collateral and rhinal sulci. Anteriorly, the parahippocampal gyrus is continuous with the uncus. The anterior part of the parahippocampal gyrus including the uncus is called the entorhinal area (area 28). Its main afferent connection is lateral olfactory stria. So, the anterior part of parahippocampal gyrus belongs to olfactory system (paleocortex). The hippocampal formation part of the gyrus is archicortex and the remaining part is neocortex.

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**CEREBROSPINAL FLUID**

The cerebrospinal fluid (CSF) is a clear, colorless, acellular fluid contained in the subarachnoid spaces, the ventricles of the brain and the central canal of the spinal cord. The CSF supports and cushions the brain and spinal cord against concussive injuries and removes metabolic waste products. Examination of CSF is necessary in the diagnosis of diseases like meningitis, for which the sample is obtained usually by lumbar puncture. In some cases, cisternal puncture is performed to obtain the CSF.

### Site of Production

The choroid plexuses in the ventricles of brain secrete the CSF.

### Characteristic Features of CSF

i. Daily production is around 1500 ml and the total volume of CSF is 140 to 150 ml. This indicates that entire volume of CSF is replaced several times a day.

ii. The normal pressure in supine position in lumbar subarachnoid space is 50 to 200 mm of water and in sitting position 200 to 250 mm of water.

iii. Its specific gravity ranges from 1.003 to 1.008

iv. Glucose level is half of that of blood (40 – 60 mg %).

v. Protein content is very low compared to plasma proteins (20 – 40 mg %).
Circulation of CSF (Fig. 64.7)

The CSF flows from the ventricles to the subarachnoid space by passing successively through the lateral ventricles, interventricular foramina of Monro, third ventricle, cerebral aqueduct, fourth ventricle and through the lateral and median foramina in the roof of fourth ventricle into the subarachnoid space. The CSF in cranial subarachnoid space is continuous with spinal subarachnoid space. The movement of CSF is assisted by pulsations of the arteries in the subarachnoid space. The CSF leaves the subarachnoid space mainly through the arachnoid villi and granulations projecting into the superior sagittal sinus and adjacent lacunae.

Blood Brain Barrier

The blood brain barrier includes the tissues intervening between the blood in the capillaries and the neural tissue. There are tight junctions between the endothelial cells of the capillaries. So, the barrier consists of endothelial cells with tight junctions, continuous basement membrane of the capillaries and the perivascular feet of the astrocytes. The blood brain barrier protects the neural tissue from circulating toxic substances in the blood. It allows selective transport of substances and thereby provides the optimal microenvironment for the neurons. There are certain areas of brain, where blood brain barrier is not present, the examples of which are, the median eminence of hypothalamus, the pituitary, choroid plexus, pineal gland and area postrema of fourth ventricle. The breakdown of blood brain barrier occurs following brain damage due to ischemia or infection, which results in the entry of ions, fluid and proteins in the extracellular space. In newborn children, the blood brain barrier is not well developed. In neonatal jaundice, the bile pigments pass through the barrier and damage the basal ganglia producing kernicterus.
The autonomic nervous system is concerned with the nerve supply of the smooth muscles, cardiac muscle and the glands of the body. Like the somatic system it consists of efferent and afferent components. However, there is a basic difference in the somatic and autonomic efferent paths. In somatic system the axons of lower motor neurons in the spinal cord and brainstem directly supply the voluntary muscle. In the case of the autonomic system, the axons of preganglionic neurons in the spinal cord and the brainstem terminate in the ganglia outside the central nervous system and the axons of neurons in these ganglia (postganglionic fibers) supply the target structures.

Subdivisions of Efferent Component

It is broadly divided into, sympathetic or thoracolumbar outflow and parasympathetic or craniosacral outflow. In general, most organs receive both sympathetic and parasympathetic innervation. The actions of the two systems appear to be antagonistic but are mutually complimentary. The sympathetic stimulation is increased in stress situations hence it is required for fight, fright and flight responses, which result in increased heart rate and blood pressure. The parasympathetic stimulation causes reduction in heart rate and blood pressure and increase in digestion and absorption of food. Some examples of only sympathetic supply are the blood vessels, dilator pupillae, sweat glands and arrector pili muscles. Some examples of only parasympathetic supply are ciliaris and sphincter pupillae muscles of eyeball, majority of exocrine glands with the exception of the sweat glands.

Neurotransmitters at Sympathetic Synapses

The preganglionic sympathetic fibers are cholinergic. The postganglionic sympathetic fibers are adrenergic with the exception of sweat glands, which are supplied by cholinergic fibers.

Neurotransmitter at Parasympathetic Synapses

Both preganglionic and postganglionic fibers are cholinergic.

Thoracolumbar Outflow (Fig. 65.1)

i. The preganglionic neurons of the sympathetic division are located in the intermediolateral column of all the thoracic and upper two lumbar segments of spinal cord. Therefore, it is evident that the sympathetic part in CNS is confined to the fourteen segments of spinal cord. The preganglionic fibers (axons of preganglionic neurons) leave the spinal cord via the corresponding ventral roots. They are further carried from the spinal nerve by white rami communicantes (called white because they are myelinated) to the sympathetic chain, which is paravertebral in position. It is very important to understand that the number of white rami communicantes is equivalent to the number of spinal segments containing preganglionic sympathetic neurons. So the number of white rami communicantes is fourteen only and they connect the spinal cord to the sympathetic chain.

ii. The postganglionic neurons are located in two places, in the ganglia of sympathetic chains and in the collateral ganglia. The preganglionic fibers terminate on them and
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their axons become the postganglionic fibers, which supply the effector organs.

Sympathetic Chains or Trunks

The sympathetic chains are two ganglionated nerve trunks, which are paravertebral in location and extend from the base of cranium to the coccyx. The sympathetic ganglia contain the postganglionic neurons. The upper end each trunk continues as internal carotid nerve, which forms sympathetic plexus around the internal carotid artery. At the lower end, the two chains join in front of the first piece of coccyx to form ganglion impar. Each trunk bears three cervical ganglia (superior, middle and inferior) eleven or twelve thoracic, four or five lumbar and four or five sacral ganglia.

Collateral Ganglia

The collateral ganglia are prevertebral in position and are located in the abdomen in front of the vertebral column. They include coeliac ganglion, aorticorenal, superior and inferior mesenteric ganglia.

Modes of Termination of the Preganglionic Fibers

i. Some preganglionic fibers synapse in the cells of the corresponding sympathetic ganglia. A few fibers from the upper thoracic segments of spinal cord ascend in the sympathetic chain to synapse in the cervical ganglia.

ii. A few fibers from the lower thoracic segments and upper two lumbar segments of spinal cord travel caudally in the sympathetic chain to synapse in the lumbar or sacral sympathetic ganglia.

iii. Some preganglionic fibers pass through the thoracic sympathetic ganglia without relay. These myelinated preganglionic fibers leave the sympathetic trunk as the greater, lesser and least splanchnic nerves. The splanchnic nerves are composed of long preganglionic fibers. They terminate on the prevertebral ganglia and the suprarenal medulla.

Postganglionic Sympathetic Fibers

i. The postganglionic fibers join back to the corresponding spinal nerve by gray rami communicantes. The sympathetic chain is connected to each spinal nerve by a gray ramus communicans. Hence, there are 31 pairs of gray rami corresponding to the total number of spinal nerves. In this way sudomotor, vasomotor and pilomotor fibers are ensured in the territory of supply of each spinal nerve. The postganglionic fibers from thoracic ganglia supply the neck and thoracic viscera. The dilator pupillae muscle in the eyeball is unique in receiving its sympathetic innervation through a long route. The postganglionic fibers from thoracic ganglia supply thoracic viscera.

ii. The postganglionic fibers from the collateral ganglia take part in plexuses, which supply the abdominal viscera. The postganglionic fibers from lumbar and sacral ganglia also form plexuses for abdominal and pelvic viscera.

Craniosacral Outflow (Fig. 65.2)

The preganglionic neurons are located in the four cranial nerve nuclei (vide infra) in the brainstem and in the intermediomedial column of second to fourth sacral segments of spinal cord. The postganglionic neurons are located in peripheral parasympathetic ganglia.

Cranial Outflow

i. Edinger-Westphall nucleus in the midbrain is part of oculomotor nucleus. The axons of this nucleus pass through the oculomotor nerve as preganglionic fibers and terminate on ciliary ganglion in the orbit. The
postganglionic fibers from the ciliary ganglion supply ciliaris and sphincter pupillae muscles.

ii. Superior salivatory nucleus in the pons sends its axons in the nervus intermedius of facial nerve. The postganglionic fibers for lacrimal gland leave in greater petrosal branch of the facial nerve. The union of greater petrosal and deep petrosal nerves in the foramen lacerum forms the nerve of pterygoid canal (Vidian nerve) that carries the postganglionic fibers to the pterygopalatine ganglion. After the synapse in the ganglion the postganglionic fibers are carried to the lacrimal gland in the zygomatic branch of the maxillary nerve. The postganglionic fibers for submandibular and sublingual salivary glands leave in the chorda tympani branch of facial nerve. The chorda tympani nerve takes these fibers to the submandibular ganglion via the lingual nerve. After the synapse the postganglionic fibers directly supply the submandibular and sublingual salivary glands.

iii. Inferior salivatory nucleus in the upper medulla oblongata sends preganglionic fibers through the glossopharyngeal nerve. The tympanic branch of the ninth nerve takes these fibers to the middle ear where they form tympanic plexus. The lesser petrosal nerve arising from the tympanic plexus enters the infratemporal fossa to terminate on the otic ganglion. The postganglionic fibers join the auriculotemporal nerve, which takes them to the parotid gland.

iv. Dorsal nucleus of vagus sends preganglionic fibers through the vagus nerve. These fibers leave the vagus in its various branches to reach the intramural ganglia, where they synapse. The intramural ganglia are located within or adjacent to the visceral organs. The short postganglionic fibers innervate viscera of thorax and abdomen as far as the junction of right two-thirds and left one-third of transverse colon (derivatives of foregut and midgut).

**Sacral Outflow**

The preganglionic neurons in the second to fourth sacral segments of spinal cord leave along with the ventral roots of the second to fourth sacral nerves and separate out to form the pelvic splanchnic nerves or nervi erigentis. These nerves unite with the sympathetic plexuses in the pelvis and terminate on the intramural ganglia for synapse. The postganglionic fibers supply the pelvic viscera (detrusor muscle of urinary bladder and smooth muscle of genital organs) including the digestive tract beyond the territory of the vagus nerve.

**Visceral Afferent Fibers**

The general visceral afferent fibers travel to the CNS along with the sympathetic nerves or parasympathetic nerves. These fibers carry visceral pain sensations and sensations for the autonomic reflexes. The afferent fibers accompanying the sympathetic nerves reach the spinal nerve in the white ramus communicantes of T1 to L2 levels and reach the cell bodies in the spinal ganglion. The dorsal roots of the spinal nerves carry the sensations to CNS. General visceral afferents in the parasympathetic system follow the preganglionic and postganglionic fibers back to the brainstem and sacral spinal cord. Those carried in the facial, glossopharyngeal and vagus nerves have their cell bodies in corresponding sensory ganglia. The sacral fibers have their cell bodies in spinal ganglia S2 to S4.
CASE 1
A 35-year-old man developed sudden and acute pain in the lumbar region after lifting a heavy suitcase. The pain radiated down to the outer side of his left leg. MRI of the vertebral column showed prolapse of the disc in the posterolateral direction between L4 and L5 vertebrae.

Questions and Solutions
1. Which nerve is compressed if there is disc prolapse between L4 and L5 vertebrae?
   Fifth lumbar nerve is compressed.

2. In which area will there be sensory loss in disc prolapse at this level?
   The sensory loss will include L5 dermatome (lateral aspect of leg, middle part of dorsum of foot and second to fourth toes).

3. Which muscle of the leg is tested to ascertain the compression of L5?
   The extensor hallucis longus is tested.

4. What is the difference between the spinal nerve root and the spinal nerve?
   The spinal nerve roots (ventral and dorsal) are the filaments by which spinal nerves are attached to the spinal cord. The spinal nerve is formed by the union of ventral and dorsal nerve roots.

5. If the disc prolapse occurs in the midline in posterior direction at the level of L4/L5, which structure is compressed?
   Cauda equina is compressed.

6. Name the parts of the intervertebral disc giving the histological structure of its peripheral part.
   The disc consists of inner nucleus pulposus and outer annulus fibrosus. The latter is made of white fibrocartilage.

7. Give the development of the disc.
   The nucleus pulposus develops from notochord and the annulus fibrosus from the mesoderm of sclerotome.

8. Which ligaments are closely related to the intervertebral discs?
   The anterior longitudinal and the posterior longitudinal ligaments are closely related to the disc.

9. Describe the above mentioned ligaments.
   i. The anterior longitudinal ligament is present on the anterior surfaces of the vertebral bodies and the discs. It extends from the sacrum to the anterior tubercle of atlas, from where it continues upwards as anterior atlanto-occipital membrane.
   ii. The posterior longitudinal ligament is located inside the vertebral canal. It is attached to the posterior surfaces of the discs and adjacent margins of the vertebral bodies. It is not attached to the posterior surfaces of the bodies because the basivertebral veins emerge from the vertebral bodies on this aspect and empty into the internal vertebral venous plexus. This ligament extends from the sacrum to the lower margin of the posterior surface of the body of axis. It is continued upwards as the membrana tectoria, which passes through the foramen magnum to attach to the basilar part of occipital bone near the margin of the foramen magnum.
CASE 2

A 37-year-old high jump athlete fell on his head with a great impact. His neck was acutely flexed. He had tingling in his fingertips. Later he had tingling in his toes. He was taken to the hospital. The radiograph of cervical vertebrae showed fracture of C7 vertebral arch.

Questions and Solutions

1. Which funiculus of the spinal cord is compressed by the fractured fragments?
   Posterior funiculus is compressed.

2. Which tracts are present in this funiculus?
   The tract of Gall or fasciculus gracilis is located medially and tract of Burdach or fasciculus cuneatus laterally.

3. What is the reason for tingling in fingertips?
   The irritation of tract of Gall (carrying tactile discrimination sensations from upper limb) is responsible for tingling in fingertips.

4. What is the reason for tingling in toes?
   The irritation of tract of Burdach (carrying tactile discrimination sensations from lower limb) is responsible for tingling in toes.

5. Which artery supplies the affected funiculus?
   Posterior spinal artery supplies the posterior funiculus.

6. Trace the affected tracts from the first order neurons to sensory cortex.
   Dorsal root ganglia → Rootlets of dorsal roots → Posterior funiculi → fasciculus cuneatus and gracilis → Cuneate and gracile nuclei in medulla oblongata → Internal arcuate fibers → Sensory decussation → Medial lemniscus → Nucleus VPL of thalamus → Thalamic radiations → Area 3, 1 and 2 in postcentral gyrus in parietal lobe.

CASE 3

A person came to the hospital for a combination of motor and sensory symptoms. After neurological examination, he was diagnosed to have subacute combined degeneration of spinal cord. This disease is due to vitamin $B_{12}$ deficiency.

Questions and Solutions

1. Which anemia is associated with $B_{12}$ deficiency?
   Pernicious anemia.

2. How is $B_{12}$ deficiency related to this condition?
   Intrinsic factor of Castle secreted by parietal cells of fundic glands of stomach helps in absorption of $B_{12}$ from the small intestine. Therefore, if there is no $B_{12}$ in diet or if fundic glands are not secreting the intrinsic factor, it leads to folic acid deficiency. This results in delayed DNA synthesis in megaloblasts. The net result is megaloblastic or microcytic anemia.

3. Draw a cross section of the spinal cord to show the gray matter and tracts in thoracic region.
   Refer to figure 55.10.

4. Name the major tracts that undergo demyelination in this disease.
   The posterior column tracts, spinocerebellar tracts and lateral corticospinal tracts undergo degeneration on both sides (usually in lumbosacral region).

5. Give the clinical effects of the loss of function in these tracts.
   i. Bilateral loss of position and vibratory sensations below the level of lesion due to lesion of posterior column tracts.
   ii. Ataxia on walking due to lesion of spinocerebellar tracts.
   iii. Spastic paraplegia (UMN) due to lesion of corticospinal tracts.

6. What are the positional changes in the developing spinal cord?
   During third month of intrauterine life the length of the cord coincides with the length of the vertebral column. At birth the lower end of the spinal cord coincides with the lower margin of L3 vertebra. In adult, the lower end of the cord ends at lower margin of L1 vertebra.

7. Briefly describe the arterial supply of spinal cord.
   There are three longitudinal arterial channels on the surface of the spinal cord formed as follows. The two posterior spinal arteries and one anterior spinal artery (branches of vertebral arteries) are replenished.
at intervals by radicular arteries derived from the segmental arteries. The radicular artery on left side derived from lower posterior intercostal artery is especially large and takes the major share in supply of the lower part of the spinal cord. It is called arteria radicularis magna (artery of Adamkiewicz). The central branches of the anterior spinal artery supply the anterior two thirds of the cross sectional area and those of posterior spinal artery supply the posterior horns and posterior columns.

8. Write short note on cauda equina.

Cauda equina consists of a leash of spinal nerve roots (resembling the tail of a horse) arising from the conus medullaris. It is located in the dilated part of the subarachnoid space known as lumbar cistern from L2 vertebra to S2 vertebra. It is composed of dorsal and ventral roots of lumbar, sacral and coccygeal nerves surrounding the filum terminale. The filum terminale, 5th sacral nerve and coccygeal nerve pierce the dural sac to traverse the epidural space in the sacral canal. The lumbar cistern (in which cauda equina floats in CSF) is approached for drawing CSF sample or to inject anesthetic solution between spines of third and fourth lumbar vertebrae. A site above this may injure the spinal cord. The nerves of the cauda equina are less likely to injure or if injured are capable of regeneration.

CASE 4

A patient was brought to the hospital with sudden onset of vertigo and nystagmus. The attending physician noted that the patient had dysphagia, dysarthria and hoarseness of voice. On examination, it was found that the laryngeal and palatine muscles on left side were paralyzed. There was loss of pain and temperature on left half of face and loss of pain and temperature on the body below the neck on the right side. The patient had unsteady gait. The above signs and symptoms are indicative of a vascular lesion in the brainstem.

Questions

1. Name the parts of the brainstem and identify the syndrome.

The brainstem consists of midbrain, pons and medulla oblongata from above downwards. This is a vascular lesion of medulla called lateral medullary syndrome.

2. Which artery is occluded in this syndrome and what is it a branch of?

Left posterior inferior cerebellar artery is occluded. It is a branch of left vertebral artery.

3. Give reason for loss of pain and temperature on the left side of face.

Loss of pain and temperature sensation on face on left side is due to lesion of left spinal tract of trigeminal nerve, which is an uncrossed tract.

4. Give reason for loss of pain and temperature sensations below the neck on the right side.

The lateral spinothalamic tract carries sensation of pain and temperature from the body below the neck. Since this is a crossed tract the lesion of left side in medulla will cause effect below the neck on right side.

5. Explain the paralysis of laryngeal, pharyngeal and palatine muscles.

Lesion of nucleus ambiguus results in paralysis of above muscles (the vagus and cranial accessory nerves arise from the nucleus ambiguus)

CASE 5

An elderly woman with the history of hypertension developed paralysis of the left half of the body with increased muscle tone and increased tendon reflexes. The Babinski response was positive on the left side. There was altered sensation on the left half of the body. On CT scan a small lesion was noted deep inside the white matter of right cerebral hemisphere.

Questions and Solutions

1. Which deeply located structure containing aggregation of sensory and motor fibers is affected?

The internal capsule is affected.

2. Is the paralysis in this case of UMN or LMN type? Give reasons in support of your answer.

It is upper motor neuron type of paralysis. The typical features of this type are, increased muscle tone, increased tendon reflexes and positive Babinski response.
3. Name the parts of the structure affected and the lesion of specific fibers in it, which caused paralysis in opposite half of body.

The internal capsule consists of five parts, anterior limb, genu, posterior limb, sublentiform part and retro lentiform part.

The lesion involved the corticospinal fibers, which are crowded in the anterior part of the posterior limb of internal capsule.

4. Classify white matter of the cerebrum giving examples.

The white matter of cerebrum is classified into three types, association, commissural and projection fibers. The association fibers remain confined to the same hemisphere as they connect different parts of the same hemisphere, example—cingulum. The commissural fibers connect the identical parts of the two hemispheres, example—corpus callosum. The projection fibers connect the cerebral cortex to other parts of CNS, example—corticospinal and corticonuclear fibers.

5. Which arteries are called arteries of cerebral hemorrhage?

Lateral striate (lenticulostriate) branches of middle cerebral artery.

CASE 6

A 68-year-old patient complained of difficulty in walking and altered sensation in his right lower limb. He also complained of urinary incontinence. On examination, Babinski response was positive on right side, there was motor weakness and impaired sensation in the right lower limb.

Questions and Solutions

1. Name the cerebral gyrus that is affected.

The lesion is in the left paracentral lobule.

2. On which surface of cerebral hemisphere is the affected gyrus located?

The paracentral lobule is located on medial surface of cerebral hemisphere.

3. Describe with the help of a diagram of motor homunculus.

Refer to chapter 61 and figure 61.7.

4. Occlusion of which artery is responsible the lesion in the above gyrus?

Occlusion of left anterior cerebral artery will cause infarction in the paracentral lobule.

5. Describe the origin and course of this artery.

Refer to chapter 62 on blood supply of brain.

6. What is Heubner’s artery a branch of? Give the area of its supply.

Heubner’s artery is the central branch of anterior cerebral artery. It is also described as medial striate artery. It pierces the anterior perforated substance to enter the hemisphere and supply the corpus striatum, anterior limb and part of genu of internal capsule.

CASE 7

A 10-year-old girl was brought to the hospital with complaints of difficulty in holding her head and trunk erect. While walking she kept her legs apart (due to fear of falling). CT scan of head showed a midline tumor in posterior cranial fossa and dilatation of fourth ventricle. Subsequently, the tumor was diagnosed as medulloblastoma, which is a malignant growth of vermis of cerebellum.

Questions and Solutions

1. Name the main parts of cerebellum.

Right and left hemispheres connected by midline vermis.

2. Draw a labeled diagram of sagittal section of fourth ventricle to show its relations to cerebellar vermis and cerebellar peduncles.

Refer to figure 59.6.

3. Name the apertures in the roof of fourth ventricles.

The median aperture is called foramen of Magendie and the lateral apertures are called foramina of Luschka.

4. What is the function of these foramina?

The foramen of Magendie opens into cerebellomedullary cistern of subarchnoid space. The foramina of Luschka are located at the end of lateral recesses near the flocculus of cerebellum open in the subarchnoid space at cerebellopontine angle (cisterna pontis).
These are the only points where CSF from ventricular cavities escapes into the subarachnoid space.

5. **What is the effect of blockage of these foramina by medulloblastoma?**
The blockage of foramina causes obstruction to the escape of CSF into subarachnoid space leading to accumulation and its dilatation.

6. **What is the name for dilated ventricle or ventricles in the brain?**
Hydrocephalus.

7. **Name the sites of production of CSF.**
Choroid plexuses of lateral ventricles, third ventricle and fourth ventricle produce CSF.

8. **Which is the site of drainage of CSF into the blood circulation?**
The subarachnoid space at the superolateral surface of cerebrum comes in contact with the superior sagittal sinus. At their junctional site, the arachnoid villi (fine finger like processes of arachnoid mater) perforate the dura mater to gain entry into the venous sinus. These villi have special cells which absorb the CSF into the blood. As age advances the arachnoid villi grow in size to form arachnoid granulations (Pacchionian bodies). They project into the venous lacunae of the superior sagittal sinus. Due to their large size they produce impressions on the inner surface of parietal bones on either side of the groove for superior sagittal sinus.

9. **Describe the choroidal arteries.**
There are two choroidal arteries—anterior and posterior.
1. The anterior choroidal artery is a branch of the internal carotid artery. From its origin, the artery passes backwards along the edge of the optic tract and crosses it twice, hence it is called the satellite artery of the optic tract. Then it enters the inferior horn of lateral ventricle through the choroid fissure to supply the choroid plexus. In addition it supplies the optic tract, amygdaloid complex, tail of caudate nucleus, globus pallidus, hippocampus and posterior limb of internal capsule including its retrolentiform and sublentiform parts. The anterior choroidal artery is prone to thrombosis due to its small caliber and long subarachnoid course.

Its thrombosis may result in contralateral hemianesthesia, hemiparesis and hemianopia and loss of recent memory.
ii. The posterior choroidal artery is a branch of the posterior cerebral artery in the region of the splenium. There are three posterior choroidal arteries, one medial and two lateral. The medial posterior choroidal artery supplies the tectum, choroid plexus of third ventricle and thalamus. The lateral posterior choroidal arteries enter the choroid fissure and supply the choroid plexus of the central part and inferior horn of the lateral ventricle. These arteries supply the pulvinar, lateral geniculate bodies and fornix.

**CASE 8**
A patient presented with a red, swollen and painful right eye accompanied with high temperature. On examination, it was observed that intraorbital muscles in affected eye could not be tested because the movements of the eye were painful. The pupil in the right eye was fixed and dilated. CT scan showed thrombosis in cavernous sinus on right side.

**Questions and Solutions**

1. **What is the location of the cavernous sinus?**
The cavernous sinus is located in the middle cranial fossa on either side of the body of the sphenoid.

2. **Draw a diagram to show the nerves in relation to the cavernous sinus**
Refer to figure 56.6.

3. **Name the dural venous sinuses, which are the tributaries of the cavernous sinus and which are the draining channels.**
Sphenoparietal sinus and middle meningeal vein (sinus) are the tributaries. The superior and inferior petrosal sinuses are the draining channels.

4. **Name the cerebral vein, which is a direct tributary of the cavernous sinus.**
Superficial middle cerebral vein is the direct tributary of the sinus.

5. **Dilated and fixed pupil is suggestive of involvement of which cranial nerve?**
Dilated and fixed pupil is suggestive of involvement of parasympathetic fibers in the oculomotor nerve.
CASE 9

Neurological examination of a patient revealed following abnormal findings:

i. Deviation of tongue to left side on protrusion.
ii. Loss of vibration sense and sense of conscious proprioception from right half of body.
iii. Spastic hemiplegia on right side of body.

Questions and Solutions

1. Name the syndrome and the artery occluded.
   This is medial medullary syndrome (in which the medial region of the medulla oblongata including hypoglossal nucleus, pyramid and medial lemniscus) are affected.
   Occlusion of left anterior spinal artery is responsible for the signs.

2. Explain why the tongue deviates to left on protrusion.
   Lesion of left hypoglossal nucleus or intramedullary part of left hypoglossal nerve results in lower motor neuron paralysis of left half of tongue. Since the left genioglossus is paralyzed, on protrusion of tongue, tip of tongue deviates to the left due to overaction of right muscle.

3. Name the structure involved to cause spastic paralysis of right half of body.
   The lesion of crossed corticospinal fibres in the left pyramid causes spastic paralysis in right half.

4. Sensory deficit on right side is due to injury to which structure?
   Medial lemniscus of left side.

CASE 10

On neurological examination of a 50-year-old diabetic lady, it was noted that she had weakness in the left half of the body. Examination of the eyes revealed dilated and fixed pupil, ptosis and laterally deviated right eye.

Questions and Solutions

1. Identify the site of lesion giving reasons.
   Hemiplegia on left side and dilated and fixed pupil, ptosis and lateral deviation of the right eye confirm the lesion of right oculomotor nerve and corticospinal fibers in right crus cerebri. Therefore, the lesion is in the midbrain on right side at the level of superior colliculus.

2. Name the syndrome.
   This is a Weber’s syndrome.

3. Give reason for weakness for left half of body.
   The lesion of right crus cerebri affects corticospinal fibers contained in it, which control the opposite half of the body.

4. Which paralysis is expected if the lesion involves crus in midbrain?
   UMN paralysis on contralateral side.

5. Describe the pyramidal tract from origin to termination.
   Refer to chapter 63.
1. The supramarginal gyrus is located in
   a. Superior temporal gyrus
   b. Inferior parietal lobule
   c. Inferior frontal gyrus
   d. Superior frontal gyrus.

2. What is incorrect about cuneus?
   a. Is triangular in shape
   b. Present on medial surface of occipital lobe
   c. Stria of Gennari is visible on its cut surface
   d. Is located anterior to parieto-occipital sulcus.

3. Which part of cerebellum tends to herniate through foramen magnum?
   a. Lingula
   b. Flocculus
   c. Tonsil
   d. Nodule

4. In occlusion of anterior spinal artery which of the following in the spinal cord is not affected?
   a. Lateral corticospinal tract
   b. Dorsal spinocerebellar tracts
   c. Ventral spinocerebellar tract
   d. Tract of Gall and Burdach.

5. The paracentral lobule is supplied by
   a. Middle cerebral artery
   b. Anterior cerebral artery
   c. Both anterior and middle cerebral arteries
   d. Heubner’s artery

6. The second order neurons of posterior column tracts carrying sensations from hand are located in
   a. Nucleus gracilis
   b. Nucleus cuneatus
   c. Nucleus of spinal tract of trigeminal nucleus
   d. Accessory cuneate nucleus.

7. Which of the following is not a branch of internal carotid artery?
   a. Posterior communicating
   b. Posterior choroidal
   c. Anterior cerebral
   d. Anterior choroidal

8. The following cells are derived from neural crest except:
   a. Dorsal root ganglion
   b. Sympathetic ganglion
   c. Dorsal nucleus of vagus
   d. Parasympathetic ganglion.

9. Following is the modification of pia mater
   a. Ependyma
   b. Septum pellucidum
   c. Linea splendens
   d. Posterior median septum.

10. Rathke’s pouch is derived from
    a. Endoderm of embryonic pharynx
    b. Notochord
    c. Ectoderm of floor of stomodeum
    d. Ectoderm of roof of stomodeum.

11. Which cranial nerve decussates in superior medullary velum?
    a. Oculomotor
    b. Trochlear
    c. Trigeminal
    d. Abducent.

12. The temporal pole of the cerebrum receives blood from
    a. Anterior cerebral artery
    b. Internal cerebral artery
    c. Middle cerebral artery
    d. Posterior cerebral artery.

13. Which of the following is the most laterally located intracerebellar nucleus?
    a. Dentate
    b. Fastigius
    c. Emboliform
    d. Globose.

14. The spinothalamic tracts terminate on the following thalamic nucleus
    a. VPM
    b. Pulvinar
    c. Ventral lateral
    d. VPL
15. An infant with hydrocephalus was diagnosed to have the blocked outlet passage from third ventricle. The blocked passage is:
   a. Central canal of medulla oblongata
   b. Foramen of Monro
   c. Aqueduct of Sylvius
   d. Foramen of Magendie

16. All the following structures are seen in interpeduncular fossa except:
   a. Posterior perforated substance
   b. Optic chiasma
   c. Mamillary bodies
   d. Tuber cinereum.

17. The axons of Purkinje cells terminate on
   a. Granule cells
   b. Glomeruli
   c. Dentate nucleus
   d. Red nucleus.

18. Which of the following is an example of association fibers?
   a. Corona radiata
   b. Tapetum
   c. Forceps minor
   d. Arcuate fasciculus.

19. During difficult childbirth an infant’s head is compressed due to which a tear of the attached inferior margin of falx cerebri is feared. Which of the following is likely to be injured?
   a. Straight sinus
   b. Inferior sagittal sinus
   c. Great cerebral vein
   d. Occipital sinus

20. Uncus is supplied by following artery:
   a. Anterior choroidal
   b. Anterior cerebral
   c. Posterior cerebral
   d. Middle cerebral

21. What is true about cerebellum?
   a. Fissura posterolateralis is the first to develop
   b. Nodule is the most anterior part of vermis
   c. Globose nucleus is known as roof nucleus
   d. Flocculonodular lobe receives main connections from spinal cord.

22. If the blood accumulates between outer layer of dura mater and cranial bone, the hemorrhage is known as:
   a. Subdural
   b. Subarachnoid
   c. Epidural
   d. Subaponeurotic.

23. All the following are parts of gustatory pathway except:
   a. VPL nucleus
   b. Geniculate ganglion
   c. Nucleus of tractus solitarius
   d. Parietal operculum (area 43).

24. Which part of brain occupies the tentorial notch?
   a. Pons
   b. Temporal lobe
   c. Midbrain
   d. Thalamus.

25. Third order neurons in pain pathway from face are located in:
   a. Nucleus VPL
   b. Nucleus VPM
   c. Chief sensory nucleus of CN V
   d. Mesencephalic nucleus of CN V.

**KEY TO SINGLE BEST RESPONSE MCQs**
1-b, 2-d, 3-c, 4-d, 5-b, 6-b, 7-b, 8-c, 9-c, 10-d, 11-b, 12-c, 13-a, 14-d, 15-c, 16-b, 17-c, 18-d, 19-a, 20-c, 21-a, 22-c, 23-a, 24-c, 25-b.
SECTION 6

CRANIAL NERVES
The olfactory nerves are the first pair of cranial nerves. They begin in the olfactory mucosa of the nasal cavity, which consists of bipolar olfactory receptor cells (first order neurons of the olfactory path). The unique feature of these neurons is that they develop from the surface ectoderm and not the neuroectoderm. The axons of the bipolar cells collect together to form (about twenty) bundles of each olfactory nerve. They pass through the cribriform plate of the ethmoid to enter the anterior cranial fossa, where they terminate into the olfactory bulb. The bundles of olfactory nerve are surrounded by the meninges at the cribriform plate. This provides a communication between the subarachnoid space and the lymphatics of the nasal cavity and a route for the infection from the nasal cavity to the meninges.

Olfactory Bulb (Fig. 67.1)
This is situated in the anterior cranial fossa, below the olfactory sulcus on the orbital surface of the frontal lobe of cerebrum. The main neurons of the olfactory bulb are the mitral and tufted cells with which the fibers in the olfactory nerve make synaptic contacts. These neurons are the second order neurons in the olfactory path.

Olfactory Tract
The axons of the mitral and tufted neurons form the olfactory tract on each side. The olfactory tract runs backwards and widens in olfactory trigone at the anterior perforated substance. The lateral and medial olfactory striae extend from the angles of this trigone on either side of the anterior perforated substance. The medial olfactory stria is covered with a thin sheet of gray matter called medial olfactory gyrus. It terminates into paraterminal gyrus in front of the lamina terminalis. The lateral olfactory stria is covered with a thin layer of gray matter called lateral olfactory gyrus. It terminates into the primary olfactory cortex.
Olfactory Cortex

The primary olfactory cortex consists of anterior perforated substance, lateral olfactory gyrus, gyrus ambiens and part of amygdaloid body. From the primary cortex, the fibers are projected to the secondary olfactory cortex constituted by entorhinal area (area 28). This area includes the uncus and the adjacent anterior part of parahippocampal gyrus of the temporal lobe. The sense of smell is perceived in both primary and secondary olfactory cortices.

Know More ...

Nervi Terminalis

This is variously described as zero cranial nerve or thirteenth cranial nerve or mysterious nerve. Its existence in man is doubtful. It is postulated that it may be an additional chemosensory path for olfaction. It is also postulated that this nerve contains fibers belonging to Luteinizing Hormone Releasing Hormone (LHRH) carrying neurons and associated ganglia. Thus, it might be a remnant of embryonic migrating path of these neurons from the olfactory placode to the hypothalamus.
The visual or optic pathway conveys visual impulses from the retina to the visual cortex in the occipital lobe of the cerebrum. The visual impulse is generated in the rod and cone cells of the retina (Fig. 68.1A). These photoreceptor cells act as transducers converting light signals into electrical signals. These signals are processed in the bipolar cells (first order neurons) and then in the ganglion cells (second order neurons). The axons of the ganglion cells collect to form the optic nerve. The optic nerves unite to form optic chiasma, where decussation of nasal fibers takes place. The optic tract begins from the optic chiasma. It terminates on the Lateral Geniculate Body (LGB). The neurons of lateral geniculate body are third order neurons. They give origin to the optic radiation, which terminates on the visual cortex.

Fig. 68.1A: Microscopic structure of retina.
[Note the path of light ray (yellow arrow) and of visual impulse (green arrow)]
Cranial Nerves

Optic Nerve (Fig. 68.1B)
The optic nerve emerges from the retina at the optic disc and is composed of axons of the ganglion cells of retina. It is about four centimeter in length. Being an extension of central nervous system the axons of optic nerve are myelinated by oligodendroglia and hence the optic nerve is unable to regenerate on injury.

Coverings
Developmentally, the optic nerve is the extension of the diencephalon and hence it is covered with three meninges, like the brain. The subarachnoid space extends around the optic nerve inside the orbit. Therefore, rise in the intracranial tension slows the venous return from the central vein of the retina causing papilledema.

Parts
The optic nerve is subdivided into intra-orbital, canalicular and intracranial parts.

i. The intraorbital part, about 2.5 cm long, is surrounded by the extraocular muscles. The central retinal artery enters the substance of optic nerve on its inferomedial aspect 1.2 cm behind the eyeball. The optic nerve is crossed superiorly by three structures (nasociliary nerve, ophthalmic artery and superior ophthalmic vein) from lateral to medial side.

ii. The canalicular part passing through the optic canal is about half centimeter in length. Here, it is very closely related to the ophthalmic artery.

iii. The intracranial part is one centimeter in length. Above it is related to the gyrus rectus of the inferior surface of the frontal lobe, olfactory tract and anterior cerebral artery. Below it rests on the tuberculum sellae and the diaphragma sellae.

Arterial Supply

i. The central artery of retina supplies the intraorbital part.

ii. The branches of ophthalmic artery supply the canalicular part.

iii. The superior hypophyseal artery supplies the intracranial part.

Arrangement of Nerve Fibers
The fibers that arise from the four quadrants of the retina are arranged in the same relative positions in the optic nerve. The papillomacular fibers occupy the lateral part of the optic nerve nearer the eyeball but shift to the central part behind the point of entry of the central vessels.

Relation of Field of Vision to Retinal Quadrants (Fig. 68.2)

i. The temporal hemi-retina receives image input from the nasal visual field.

ii. The nasal hemi-retina receives image input from the temporal visual field.

iii. The upper retinal quadrants receive images from the lower visual field while the lower retinal quadrants receive images from the upper visual field.

Optic Chiasma (Fig. 68.2)
The optic chiasma is a midline structure in the middle cranial fossa.

It is formed by the fibers of the right and left optic nerves. The nasal or medial fibers (originating in nasal halves of the retinae) decussate in the central part of the chiasma. The temporal or lateral fibers (originating from the lateral half of retina) do not decussate in the chiasma (but form its lateral part). The macular fibers cross in the posteroinferior margin of the chiasma.

Know More ...

One peculiar feature that is observed regarding inferonasal fibers is that after crossing they project for a distance of about 4 mm in the adjacent optic nerve (of opposite side) before turning back posteriorly in the chiasma. This bend of nasal fibers is known as Willibrand’s knee. However, the existence of this loop is not universally accepted.
Optic Nerve and Visual Pathway

Chapter

Relations of Optic Chiasma (Fig. 56.6)

i. Superiorly, the chiasma is related to the floor of the third ventricle.

ii. Laterally, it is related to the bifurcation of internal carotid artery and the anterior perforated substance.

iii. Anteriorly, the lamina terminalis extends from the optic chiasma to the paraterminal gyrus. The anterior communicating artery is related to the anterior surface of optic chiasma.

iv. The pituitary gland is its posteroinferior relation.

The optic chiasma is usually compressed as a result of pathology of the pituitary gland producing typical defects in the visual field.

Arterial Supply

The optic chiasma receives ample supply from the branches of anterior cerebral, internal carotid, posterior communicating and middle cerebral arteries.

Optic Tract (Fig. 68.2)

It begins at the posterolateral end of optic chiasma. It is composed of ipsilateral temporal fibers and contralateral nasal fibers. Each optic tract courses backwards along the antero-lateral boundary of the interpeduncular fossa and crosses the cerebral peduncle. The majority of its fibers end in the lateral geniculate body and a few in the superior colliculus via superior brachium.

Arterial Supply

The optic tract receives twigs from the anterior choroidal, middle cerebral and posterior communicating arteries. The anterior choroidal artery crosses the tract twice hence it is called the satellite artery of the optic tract.

Lateral Geniculate Body

This is a thalamic relay station for visual impulses. It receives fibers from ipsilateral temporal retina and contralateral nasal retina. The lateral geniculate body (LGB) contains the third order neurons in the visual path. The neurons are arranged in six laminae. The contralateral fibers terminate on neurons of layers 1, 4 and 6 and ipsilateral fibers on neurons in layers 2, 3 and 5 (Fig. 68.2 inset). A few retinotectal fibers involved in visual reflexes leave the lateral geniculate body without interruption via the superior brachium to the pretectal nucleus and superior colliculi (Fig. 68.4). The axons of the neurons in LGB form the geniculo-calcine tract or optic radiation, which terminates into the visual cortex. (The medial part of LGB receives fibers from the upper half of retina and its lateral part receives fibers from the lower half of the retina. The peripheral part of retina is represented in the anterior part while the macular fibers terminate in larger central and posterior area.)

Arterial Supply

The central branches of posterior cerebral and of posterior choroidal arteries supply the lateral geniculate body.

Optic Radiation (Fig. 68.2)

The optic radiation extends from lateral geniculate body to visual cortex. To reach the visual cortex it passes through the retro-lentiform part of the internal capsule.

i. The upper fibers of the optic radiation sweep directly backwards and end in the cuneus in the upper lip of the calcarine sulcus. These fibers carry impulses from the superior retinal quadrants, representing inferior visual field.

ii. The lower fibers of the optic radiation form a loop (Meyer’s loop) by first turning anteriorly into the temporal lobe. This loop is in close relation to the inferior horn Fig. 64.3A of the lateral ventricle. After this the fibers turn posteriorly to terminate in the cuneus in the lower lip of the calcarine sulcus. These fibers carry impulses from the inferior retinal quadrants representing superior visual fields.
Arterial Supply

i. The perforating branches of anterior choroidal artery supply the looping fibers of optic radiation inside the temporal lobe.

ii. The deep optic artery (central branch of middle cerebral artery) supplies the posterior part of radiation inside the occipital lobe.

iii. The terminal part of the radiation near the visual cortex receives supply from perforating cortical branches from the calcarine branch of posterior cerebral artery and from the middle cerebral artery.

Visual Cortex (Fig. 61.6)

The visual cortex is also known as the striate cortex (area 17). The area includes cuneus and lingual gyri and the calcarine sulcus. The visual cortex receives impulses from the retinal halves of the same side (opposite half of field of vision) via the visual pathway. The upper quadrants of retina are projected on the upper lip of the calcarine sulcus and the lower quadrants on the lower lip. The macula is represented in the occipital pole.

Arterial Supply

The calcarine branches of the posterior cerebral artery supply the major part of the visual cortex. A small area near the occipital pole receives twigs from the middle cerebral artery.

Clinical insight (Fig. 68.3)...

Lesions of Visual Pathway

The symptoms and signs vary depending on the site of the lesion in the visual pathway.

Lesion of Optic Nerve (Fig. 68.3A)

The lesion of optic nerve results in optic atrophy and eventually in ipsilateral total blindness (anopia).

Lesion of Optic Chiasma

i. Compression of central portion of chiasma by, e.g., an expanding pituitary tumor results in bitemporal hemianopia. In this defect the patient is able to see the objects placed in the nasal halves of the visual fields only. There is loss of peripheral vision and retention of central vision in both eyes (tunnel vision) as shown in Figure 68.3B.

ii. If the optic chiasma is compressed at its lateral angle on one side only it causes ipsilateral nasal hemianopia. Bilateral lesion of lateral angles of optic chiasma results in binasal hemianopia, e.g., in bilateral internal carotid artery calcification (Fig. 68.3C).

Contd...
Lesion of Optic Tract
Lesion of the right optic tract results in left homonymous hemianopia and vice versa. The pupillary light reflex is absent in the blind half of each retina (Fig. 68.3D).

Lesion of Lateral Geniculate Body
The destruction of the right LGB results in left homonymous hemianopia and vice versa. The pupillary light reflex is retained as the fibers for superior colliculus have already gone out of the tract.

Lesion of Optic Radiation
i. The lesion of the lower fibers including the looping fibers (Meyer’s loop) results in the contralateral superior homonymous quadrantic hemianopia (Fig. 68.3E). The temporal lobe pathology may be the cause of lesion in Meyer’s loop.
ii. The lesion of the upper part of the optic radiations (usually due to parietal lobe pathology) results in the contralateral inferior homonymous quadrantic hemianopia (Fig. 68.3F).

Lesion of Visual Cortex
If there is occlusion of posterior cerebral artery there is contralateral homonymous hemianopia with sparing of the macular vision (macula being supplied by middle cerebral artery also). The loss of vision is in notched hemifield (Fig. 68.3G).

Lesion at Occipital Pole
This being an exclusively macular area, lesion here causes loss of half macular vision. Right occipital pole lesion results in loss of left half of macular vision.

Pupillary Light Reflexes (Fig. 68.4)
i. The direct pupillary reflex consists of reflex constriction of the pupil in response to bright light shone in the eye.
ii. The consensual light reflex consists of reflex constriction in pupil of the opposite eye in response to light shone in one eye.

In both the direct and consensual light reflexes the optic nerve is the afferent limb, pretectal nucleus is the center and the oculomotor nerve is the efferent limb.

Accommodation Reflex
For viewing near objects the eyes converge, the ciliaris muscles contract to modify the shape of the lens and the pupils constrict to increase the depth of the focus. The afferent limb consists of optic nerve, optic tract, lateral geniculate body and optic radiation. The center of the reflex is the cortical visual area. The efferent limb consists of corticocollicular fibers, tectobulbar fibers, Edinger-Westphal nucleus and the oculomotor nerve.

Argyll-Robertson Pupil
If there is lesion in pupillary reflex center (pretectal nucleus in midbrain) the path of light reflex is disrupted but the path of accommodation reflex remains intact. As a consequence, the pupillary constriction in response to light is lost but in response to accommodation is retained. Such a pupil is known as Argyll-Robertson pupil.
(Note: ARP-Accommodation Reflex Present, PRA- Pupillary Reflex Absent)
Before describing the third to twelfth cranial nerves, which emerge from the brainstem, it is appropriate to revise the functional classification of cranial nerve nuclei to understand the functional components of the cranial nerves (refer to chapter 57).

**Functional Classification (Fig. 69.1)**

There are three types of motor nuclei and four types of sensory nuclei in the brainstem. Accordingly, the cranial nerves contain functionally different types of fibers.

**Motor Fibers**

The axons of motor nuclei constitute the motor fibers of the cranial nerves.

i. Somatic efferent fibers supply striated muscles developed from somites.

ii. Special visceral efferent fibers supply striated muscles developed from branchial mesoderm.

iii. General visceral efferent fibers supply postganglionic parasympathetic fibers to the glands and to some smooth muscles inside the eyeball.

**Sensory Fibers**

The cranial nerves contain the peripheral processes of the related sensory ganglia. The central processes of the sensory ganglia terminate on the sensory nuclei related to the nerves.

i. General visceral afferent fibers carry general sensations from viscera.

ii. Special visceral afferent fibers carry special sensations like taste.

iii. General somatic afferent fibers carry cutaneous sensations.

iv. Special somatic afferent fibers carry auditory and vestibular sensations.

**OCULOMOTOR NERVE**

The oculomotor nerve is the third cranial nerve. It is a purely motor nerve that is responsible for the movements of the eyeball, constriction of the pupil and accommodation. It is also known as the nerve of accommodation.

**Nuclei of Origin (Fig. 69.2)**

The oculomotor nucleus is located in the periaqueductal gray in the midbrain at the level of superior colliculi, ante-
ior to the cerebral aqueduct and posterior to the medial longitudinal bundle.

It consists of somatic part called main oculomotor nucleus and autonomic part called Edinger-Westphal nucleus.

i. The main nucleus is subdivided into different groups, which supply the individual intraorbital muscles (inferior oblique, inferior rectus, medial rectus, superior rectus and levator palpebrae superioris).

ii. The Edinger-Westphal nucleus gives parasympathetic supply to the ciliaris and sphincter pupillae muscles.

**Functional Components**

i. Somatic efferent fibers arise in the main nucleus of oculomotor for the supply of muscles mentioned above (developing from preotic somites).

ii. General visceral efferent fibers arise in Edinger-Westphal nucleus for relay in ciliary ganglion and supply of ciliaris and sphincter pupillae muscles.

**Connections**

The nuclei are connected to corticonuclear fibers from the opposite cerebral cortex and also to the superior colliculi and the pretectal nucleus. The vestibular nuclei are connected through the medial longitudinal bundle.

**Intraneural Course (Fig. 69.2)**

The course of axons of oculomotor nerve inside the midbrain is called intraneural course. The axons of the neurons of oculomotor nucleus travel in anterior direction through the red nucleus and the medial part of the substantia nigra.

**Point of Emergence (Figs 58.1A and B)**

The oculomotor nerve emerges from the ventral aspect of midbrain by piercing the medial aspect of cerebral peduncle. It appears in the posterior part of the interpeduncular fossa.

**Location of Fibers in Oculomotor Nerve**

i. The general visceral efferent fibers (supplying sphincter pupillae and ciliaris) are located peripherally.

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**Fig. 69.1:** Functional classification of cranial nerve nuclei in brainstem.

**Fig. 69.2:** Nuclei of origin, intraneural course and point of emergence of oculomotor nerve
Cranial Nerves

Section

I. Intracranial Course

i. In its subarachnoid course, the oculomotor nerve lies between the posterior cerebral artery and the superior cerebellar artery. It is also in close relation to the posterior communicating artery. The aneurysm of any of these related arteries causes the compression of the superficial fibers in the oculomotor nerve.

ii. The oculomotor nerve passes through the tentorial notch (Fig. 56.3) and then enters the lateral wall of the cavernous sinus, where it lies in most superior position in relation to trochlear, ophthalmic and maxillary nerves.

iii. The oculomotor nerve is in danger of compression at the tentorial notch as a result of herniation of uncus and also in cavernous sinus thrombosis.

Exit from Cranium (Fig. 46.2)

The oculomotor nerve leaves the middle cranial fossa to enter the orbit through the superior orbital fissure. Before entering the fissure, it divides into superior and inferior divisions. Both the divisions are enclosed in the common tendinous ring along with the nasociliary and abducent nerves.

Intraorbital Course and Branches (Fig. 69.3)

i. The superior division passes forwards and upwards lateral to the optic nerve and supplies the superior rectus and levator palpebrae superioris muscles.

ii. The inferior division gives three branches for the supply of medial rectus, inferior rectus and inferior oblique muscles.

iii. The branch to inferior oblique muscle provides a communicating twig to the ciliary ganglion. The communicating twig contains preganglionic parasympathetic fibers from the Edinger-Westphal nucleus.

Ciliary Ganglion (Fig. 69.3)

This is a peripheral parasympathetic ganglion located in the posterior part of the orbit. The preganglionic fibers originate in the Edinger-Westphal nucleus and pass through the oculomotor nerve. They leave the oculomotor nerve through its branch to inferior oblique. They make synaptic contacts with the neurons in the ciliary ganglion. The postganglionic fibers leave through short ciliary nerves, which arise from the ganglion. The short ciliary nerves pierce the sclera to enter the eyeball and supply the sphincter pupillae and ciliaris muscles.

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Fig. 69.3: Distribution of oculomotor nerve inside the orbit parasympathetic fibers in orange and muscular branches in pink color.
The trochlear nerve is the fourth cranial nerve.

**Unique Features**

i. It is the most slender among the cranial nerves.

ii. It is the only nerve to emerge from the dorsal aspect of the brainstem.

iii. It is the only nerve that shows decussation of fibers before emerging from the midbrain so that the left trochlear nerve contains fibers originating in the right trochlear nucleus.

**Nucleus of Origin (Fig. 69.5)**

The trochlear nucleus lies immediately caudal to the oculomotor nucleus in the periaqueductal gray matter at the level of inferior colliculus. The nucleus receives corticonuclear fibers and medial longitudinal bundle.

**Functional Component**

The general somatic efferent fibers originate in trochlear nucleus for the supply of superior oblique muscle (developing from preotic somite).

**Intraneural Course (Fig. 69.5)**

The nerve fibers curve round the periaqueductal gray in backward direction and decussate with fibers from the opposite nucleus in the superior medullary velum.
**Point of Emergence (Fig. 69.5)**
The trochlear nerve emerges from the posterior aspect of the midbrain just below the inferior colliculus on each side of the frenulum veli.

**Intracranial Course**
Each trochlear nerve winds round the cerebral peduncle to reach the front of the midbrain. While crossing the cerebral peduncle it lies between the posterior cerebral and superior cerebellar arteries. The trochlear nerve pierces the dura mater just below the free margin of tentorium cerebelli and enters the lateral wall of the cavernous sinus. Here, it is located between the oculomotor nerve above and the ophthalmic nerve below.

**Exit from Cranium (Fig. 46.2)**
It enters the orbit through the lateral part of the superior orbital fissure lying outside the tendinous ring.

**Intraorbital Course**
The trochlear nerve travels anteromedially above the superior rectus muscle to supply the superior oblique muscle.

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**ABDUCENT NERVE**
The abducent nerve is the sixth cranial nerve. It has a long course in the subarachnoid space.

**Nucleus of Origin (Fig. 58.6)**
The abducent nucleus is located in the lower part of the pons (deep to the facial colliculus in the floor of fourth ventricle). There are two types of neurons in the abducent nucleus, large sized typical motor neurons (supplying lateral rectus muscle of the same side) and smaller interneurons or internuclear or para-abducent neurons (whose axons ascend in contralateral MLF and terminate upon specific cells in the oculomotor nucleus supplying medial rectus muscle of the opposite side). The abducent nucleus is controlled by PPRF or horizontal gaze center, which almost coexists with it. This is to ensure the simultaneous contraction of the ipsilateral lateral rectus and the contralateral medial rectus muscles during horizontal movement of eyeball.

**Lesion of Trochlear Nerve**
In injury to trochlear nerve, the eyeball turns medially and there is diplopia on looking laterally, when the eyeball is depressed (e.g. while descending the steps).

**Lesion of Abducent Nerve**

i. In unilateral lesion of the abducent nerve or its fibers in the pons, the affected eye is adducted (turned towards the nose) due to paralysis of lateral rectus muscle.

ii. Internuclear ophthalmoplegia or MLF syndrome results from the lesion of MLF. It causes ipsilateral medial rectus weakness. So on attempted lateral movement towards the normal side, there is nystagmus in the abducting eye (despite the normal lateral rectus muscle) (Fig. 58.11) and weak adduction in the adducting eye (eye on the side of lesion in MLF).
TRIGEMINAL NERVE

The trigeminal nerve is the fifth cranial nerve. It is the largest cranial nerve. It has a large sensory root and small motor root. Its sensory ganglion is known as trigeminal or Gasserian ganglion. The branches of the main subdivisions of the trigeminal nerve are related to four peripheral parasympathetic ganglia, namely, the otic, ciliary, submandibular and sphenopalatine.

Motor and Sensory Nuclei

The trigeminal nerve is related to one motor nucleus and three sensory nuclei in the brainstem.

1. The motor nucleus is located in the upper pons (Fig. 58.7).

2. The long sensory nucleus extends the entire length of the brainstem and is divided into three parts (Fig. 70.1).
   i. The principal or chief sensory nucleus is present in the pons lateral to the motor nucleus.
   ii. The nucleus of spinal tract of trigeminal nerve begins in the principal nucleus and goes down beyond the lower end of the medulla oblongata, where it is continuous with the substantia gelatinosa of the second cervical segment of the spinal cord.
   iii. The mesencephalic nucleus lies in the midbrain but it is continuous inferiorly with the principal nucleus.

Fig. 70.1: Termination of sensory fibers of trigeminal nerve on its sensory nuclei. Red represents - proprioception, green represents - touch, blue represents - pain and temperature.
Section

Functional Importance of Sensory Nuclei

i. The mesencephalic nucleus is concerned with proprioception. It is equivalent to the sensory ganglion as it contains pseudounipolar neurons.

ii. The principal sensory nucleus receives discriminative touch fibers.

iii. The nucleus of spinal tract is concerned with pain, temperature and light touch.

Functional Components

i. Branchial efferent or special visceral efferent fibers arise from motor nucleus of trigeminal nerve for the supply of muscles that develop from mesoderm of first pharyngeal arch (four muscles of mastication, anterior belly of digastric, mylohyoid, tensor tympani and tensor palati).

ii. General somatic afferent fibers carry general sensations from face and head to sensory nuclei of trigeminal nerve.

Point of Emergence (Figs 58.1A and 58.2A)

The motor and sensory roots of the trigeminal nerve emerge from the ventrolateral aspect of the pons at its junction with the middle cerebellar peduncle. The sensory root bears the trigeminal ganglion.

Trigeminal (Gasserian) Ganglion

The ganglion contains the cell bodies of the pseudounipolar neurons (first order neurons). It is semilunar in shape. Its anterolateral surface is convex and posteromedial surface is concave.

Location

The trigeminal ganglion is located in the middle cranial fossa in contact with the anterior surface of the petrous temporal bone near its apex.

Dural Relations

The trigeminal ganglion is housed in a pouch of dura mater called the trigeminal or Meckel’s cave (Fig. 70.2). This dural pouch is formed by evagination of the inner layer of the tentorium cerebelli. The sensory root of the trigeminal nerve emerges from its posteromedial concave surface. The ophthalmic, maxillary and mandibular divisions of trigeminal nerve emerge from its anterolateral convex surface and pierce the dura mater of trigeminal cave.

Clinical insight ...

Lesions of Trigeminal Ganglion

i. The trigeminal neuralgia or tic doloureux is characterized by paroxysms of acute pain in the sensory area of one of the divisions of the trigeminal nerve on one side. To stop the agonizing pain sometimes the trigeminal ganglion is approached for injecting medicine via foramen ovale inside the infratemporal fossa.

ii. The viral infection of neurons of trigeminal ganglion results in herpes zoster or shingles in which there is eruption of painful blisters in cutaneous distribution of any one or more of the main divisions of the trigeminal nerve.

Intracranial Course of Ophthalmic Nerve

This is a purely sensory nerve. It enters the lateral wall of cavernous sinus, where it lies below the trochlear nerve. It gives a recurrent tentorial branch for the supply of tentorium cerebelli. It divides into nasociliary, lacrimal and frontal branches in the lateral wall of the cavernous sinus. All these branches enter the orbit through the superior orbital fissure.

Intracranial Course of Maxillary Nerve

This is a purely sensory nerve. It enters the lateral wall of the cavernous sinus, where it occupies the lowest position. It gives a meningeal branch to the dura mater of middle cranial fossa and enters the pterygopalatine fossa via the foramen rotundum.

Intracranial Course of Mandibular Nerve

This is the largest of the three divisions and is a mixed nerve containing both sensory and motor fibers. The sensory
root arises from the trigeminal ganglion. The motor root originates from the motor nucleus in the pons and passes deep to the trigeminal ganglion to join the sensory root at or just below the foramen ovale to form a short trunk of the mandibular nerve. It leaves the cranium via the foramen ovale to enter the infratemporal fossa.

**Summary of Sensory Distribution**

1. The sensory area of mandibular nerve is supplied by its following branches:
   i. The nervus spinosus supplies the dura mater of the middle cranial fossa.
   ii. The buccal nerve supplies the skin of the cheek and the buccal mucosa internal to buccinator.
   iii. The auriculotemporal nerve supplies the auricle, external acoustic meatus, lateral aspect of tympanic membrane and the skin of the temple.
   iv. The lingual nerve is sensory to the mucosa of the anterior two-thirds of the dorsum of the tongue.
   v. The inferior alveolar nerve supplies the lower teeth and gums. The mental branch of the inferior alveolar nerve supplies the skin of the lower lip and chin.

2. The sensory area of the maxillary nerve is supplied by following branches:
   i. Its meningeal branch supplies the dura mater of the middle and anterior cranial fossae.
   ii. The zygomatic branches supply the skin of the prominence of the face and of temple.
   iii. The superior alveolar branches are for the upper teeth and gums.
   iv. The infraorbital nerve supplies the lower eyelid, side of nose and upper lip.
   v. The palatine branches supply to the mucosa of the palate.
   vi. The nasopalatine branches supply the mucosa of nasal cavity, palate and maxillary sinus.
   vii. The pharyngeal branch is sensory to the Eustachian tube and mucosa of nasopharynx.
   viii. The orbital branches supply the periosteum of orbit, sphenoidal and ethmoidal sinuses.

3. The sensory area of ophthalmic nerve is supplied by following branches from the trunk, lacrimal nerve, frontal nerve and nasociliary nerve.
   i. The recurrent tentorial branch supplies the tentorium cerebelli.
   ii. The lacrimal nerve is sensory to the upper eyelid and conjunctiva.
   iii. The frontal nerve divides into supratrochlear and supraorbital nerves. The supratrochlear nerve supplies the upper eyelid, conjunctiva and forehead nearer the midline.

   The supraorbital nerve supplies the upper eyelid, conjunctiva, forehead and scalp up to vertex and the frontal sinus.
   iv. The nasociliary nerve gives following branches.
   The anterior ethmoidal nerve supplies the nasal cavity and skin of the tip of nose.
   The posterior ethmoidal nerve supplies the ethmoidal and sphenoidal sinuses.
   The infratrochlear nerve supplies the nose above the medial canthus of eye, conjunctiva, upper eyelid and lacrimal sac.
   The long ciliary nerves supply the ciliary body, iris and cornea.

**Testing Sensory Areas of Trigeminal Subdivisions**

There are distinct zones on the face receiving sensory supply from specific subdivision (Fig. 70.3). To find out the nerve involved the touch sensation on face is tested in a patient.

**Corneal Reflex (Fig. 70.4)**

On touching the cornea with a wisp of cotton, there is reflex closure of both eyes. The afferent limb of the reflex
is ophthalmic division of trigeminal nerve (sensory supply of cornea). The center of the reflex in the motor nucleus of facial nerve and the efferent limb is the facial nerve (supplying orbicularis oculi). For details of corneal reflex refer to cornea in chapter 46.

### TRIGEMINAL SENSORY PATHWAYS

The mandibular, maxillary and ophthalmic nerves carry sensations of touch, pain and temperature to the trigeminal ganglion, from where the sensations are carried to the brainstem. The trigeminal sensory tracts pass through three orders of neurons before reaching the face area of the postcentral gyrus.

i. The sensory path begins in the first order neurons in the trigeminal ganglion.

ii. The central processes of these neurons form the sensory root of the trigeminal nerve, which enters the pons.

iii. They terminate on the second order neurons in the sensory nuclei of the trigeminal nerve (Fig. 70.1). The fibers that terminate on the chief sensory nucleus convey discriminative touch and pressure sensations. The fibers that terminate on the nucleus of spinal tract convey the sensations of pain and temperature.

iv. The second order neurons give rise to ascending trigeminal tracts. The axons of the neurons in the nucleus of spinal tract gradually cross to the opposite side to form ventral trigeminal tract.

v. The axons from the chief sensory nucleus ascend in the same side as dorsal trigeminal tract and also join the ventral tract. The ventral and dorsal trigeminal tracts unite to form trigeminal lemniscus, which is well defined in the upper part of the pons.

vi. The trigeminal lemniscus ascends through the midbrain to terminate on the third order neurons in the VPM nucleus of the thalamus, which projects via the superior thalamic radiation to the face area in the postcentral gyrus.

### Role of Mesencephalic Nucleus

The mesencephalic nucleus is equivalent to the sensory ganglion as its neurons are pseudounipolar. It receives proprioceptive fibers directly from the peripheral receptors (muscle spindles, pressure and joint receptors) from muscles of mastication, extraocular muscles, facial muscles and temporomandibular joints. It projects to the trigeminal motor nucleus of both sides.

### Jaw Jerk (Reflex)

To elicit this reflex the patient opens the mouth slightly and then the examiner places the index finger on the middle of patient’s chin and gently taps it (causing bilateral contraction of masseter muscles).

i. Afferent limb is the sensory component of mandibular nerve bringing proprioceptive impulses from muscles of mastication to the mesencephalic nucleus, which is connected to the motor nucleus of trigeminal nerve of both sides.

ii. Reflex center is the motor nucleus.

iii. The efferent limb is the motor component of mandibular nerve.
ANATOMY OF FACIAL NERVE

The facial nerve is the seventh cranial nerve. It is the nerve of second branchial arch hence supplies all the muscles that develop from the mesoderm of this arch. It is a mixed nerve with a large motor root and a small sensory root (nervus intermedius). The sensory root carries taste sensations from anterior two-thirds of the tongue and cutaneous sensations from the external ear. It also carries secretomotor fibers for submandibular and sublingual salivary glands and for the lacrimal gland. A sensory ganglion called geniculate ganglion is located on the trunk of the intrapetrous part of the facial nerve. Functionally the facial nerve is associated with submandibular and sphenopalatine ganglia.

Nuclei of Origin (Fig. 71.1)

i. The motor nucleus of facial nerve lies in the lower part of pons medial to the spinal nucleus of trigeminal nerve. Its corticonuclear connections are important. The neurons in the dorsal group supplying muscles in scalp and upper face receive bilateral corticonuclear fibers. The neurons in the ventral group supplying muscles of lower face receive contralateral corticonuclear fibers (Fig. 71.2).

ii. The superior salivatory nucleus is divisible into salivatory and lacrimalatory nuclei. The axons of the superior salivatory nucleus are the preganglionic parasympathetic fibers for the submandibular and sublingual salivary glands. The axons of lacrimalatory nucleus carry preganglionic parasympathetic fibers for the lacrimal gland.

iii. Nucleus of tractus solitarius in the medulla oblongata is the sensory nucleus. Its upper part receives taste fibers from the anterior two-thirds of tongue.

iv. Nucleus of the spinal tract of trigeminal nerve receives a few cutaneous fibers from the external ear.

Functional Components (Fig.71.1)

i. Branchial efferent fibers originate in facial nucleus to supply muscles derived from mesoderm of second pharyngeal arch.

ii. General visceral efferent fibers originate in superior salivatory nucleus and are secretomotor to lacrimal gland, submandibular salivary gland and sublingual salivary gland.

iii. Special visceral afferent fibers carry taste sensation from anterior two-thirds of tongue to the nucleus of tracts solitarius.

iv. General somatic afferent fibers carry general sensations from anterior two-thirds of tongue to spinal nucleus of trigeminal nerve.

Intrapontine Course (Fig. 58.6)

The fibers from the motor nucleus pursue an unusual course through the pons. They take a sharp bend around the abducent nucleus producing internal genu of the facial nerve. The internal genu causes an elevation called facial colliculus on the floor of fourth ventricle. The fibers of the motor nucleus leave the pons between the nucleus of spinal tract of trigeminal nerve and the facial nucleus.

Chapter Contents

- ANATOMY OF FACIAL NERVE
  - Nuclei of Origin
  - Functional Components
  - Intrapontine Course
  - Attachment to Brainstem
- Course through Posterior Cranial Fossa
  - Intrapetrous Course
  - Geniculate Ganglion
  - Branches of Facial Nerve in Facial Canal
- Exit from Cranium
  - Extracranial Course
  - Chorda Tympani Nerve
Section

Fig. 71.2: Corticonuclear connections of facial nucleus (Note the bilateral control of upper face and contralateral control of lower face)

Attachment to Brainstem (Fig. 58.1)
The sensory and motor roots are attached to the lateral aspect of pontomedullary junction.

Course through Posterior Cranial Fossa
From the superficial attachment to the brainstem to the opening of internal acoustic meatus the two roots of the facial nerve pass laterally and forwards in the cerebello-pontine angle along with vestibulocochlear nerve and labyrinthine artery. These structures together enter the internal acoustic meatus.

Intrapetrous Course (Fig. 71.3)
The intrapetrous course is divided into two parts, meatal and in the facial canal.
1. The meatal part is in the internal acoustic meatus, where the motor root is lodged in a groove on the
Facial Nerve

Chapter

Fig. 71.3: Intrapetrous course and branches of facial nerve

anteroinferior surface of the vestibulocochlear nerve but the sensory root separates them. At the bottom of the internal acoustic meatus the two roots unite to form the trunk of facial nerve and then the facial nerve enters the facial canal.

2. The course in the facial canal is divided into three segments.
   i. The first or labyrinthine segment passes laterally above the vestibule of the inner ear to reach the anterior end of the medial wall of the middle ear. Here, it bends backwards at a sharp turn called external genu of the facial nerve, which has geniculate ganglion on it.
   ii. The second or tympanic segment passes backwards in the medial wall of the middle ear till it reaches the posterior end of this wall. The second part is also known as horizontal part.
   iii. The third or mastoid segment (vertical segment) begins at the posterior end of the medial wall and passes downwards in relation to the posterior wall of the middle ear to reach the stylomastoid foramen.

Geniculate Ganglion

It is a sensory ganglion (Figs 71.1 and 71.3) on the facial nerve located at the external genu in the facial canal. It contains pseudounipolar neurons. The peripheral processes of the neurons bring sensations of taste via chorda tympani branch of facial nerve and general sensations from auricle via communicating branch of facial nerve to auricular branch of vagus nerve. The central processes of ganglion cells are carried to the brainstem by nervus intermedius. The central processes carrying taste sensation terminate on nucleus of tractus solitarius and those carrying cutaneous sensations terminate on spinal nucleus. Apart from these functional connections the geniculate ganglion receives preganglionic parasympathetic fibers via nervus intermedius. These fibers pass out from the ganglion in the greater petrosal nerve, which joins the deep petrosal nerve (containing sympathetic fibers) to form nerve of pterygoid canal. The nerve of pterygoid canal brings the preganglionic parasympathetic fibers to the sphenopalatine ganglion. The geniculate ganglion also receives external petrosal nerve, which begins in the sympathetic plexus around the middle meningeal artery.

Branches of Facial Nerve in Facial Canal

   i. A communicating branch is given to the auricular branch of vagus (Alderman’s nerve).
   ii. Nerve to stapedius arises at the junction of horizontal and vertical segments.
   iii. The chorda tympani nerve arises from the vertical segment 6 mm above the stylomastoid foramen.

Exit from Cranium

The facial nerve leaves the cranium through stylomastoid foramen.

Extracranial Course (Fig. 38.10A)

The extracranial course of the facial nerve through the parotid gland and in the face is described in chapters 38 and 39.

Chorda Tympani Nerve (Fig. 71.4)

This branch of facial nerve is a mixed nerve as it carries taste sensations from the anterior two-thirds of the tongue and secretomotor fibers for the submandibular and sublingual salivary glands.

Fig. 71.4: Course and distribution of chorda tympani nerve (Note the nerves related to spine of sphenoid)
Origin
It arises from the vertical part of the facial nerve about 6 mm above the stylomastoid foramen.

Course
The chorda tympani nerve at first travels inside the tympanic membrane on the lateral wall of middle ear. On its way anteriorly it crosses the handle of malleus. At the anterior margin of the tympanic membrane it enters a bony canal called anterior canaliculus, which opens into petrotympanic suture. After coming out of this suture it enters the infratemporal fossa to meet the lingual nerve at an acute angle. On its way to the lingual nerve the chorda tympani crosses medial to the spine of the sphenoid bone. (It must be understood that after joining the lingual nerve the chorda tympani loses its independent existence).

As the lingual nerve passes through the submandibular region it gives a branch to submandibular ganglion. This branch contains preganglionic parasympathetic fibers from the superior salivatory nucleus. After relay in the ganglion the postganglionic fibers supply submandibular and sublingual salivary glands. Along with lingual nerve the chorda tympani supplies the anterior two-thirds of the tongue to carry taste sensation.

Clinical insight ...

Facial Paralysis
The facial paralysis is a very common disorder. It results due to supranuclear, nuclear and infranuclear lesions.

Supranuclear Lesion (Fig. 71.5)
The most common cause of supranuclear lesion (upper motor neuron paralysis) is hemorrhage in the internal capsule involving corticonuclear fibers. This results in contralateral paralysis lower face and contralateral hemiplegia.

Nuclear Lesions
The most common cause of the nuclear lesion is the vascular accident in the pons. The effects are, ipsilateral lower motor neuron facial paralysis involving the entire face. When the pontine lesion includes corticospinal fibers and facial nucleus it gives rise to Millard Gubler syndrome (ipsilateral facial paralysis and contralateral hemiplegia).

Infranuclear Lesions (Fig. 71.6)
The infranuclear lesion involves the facial nerve beyond its attachment to the brainstem. This causes complete facial palsy on the side of the lesion. The site of infranuclear lesion in a patient can be deducted from the level of origin of its branches in the facial canal and the signs and symptoms produced.

i. A lesion in cerebellopontine angle or internal acoustic meatus produces facial paralysis with tinnitus and imbalance due to lesion of vestibulocochlear nerve.

ii. A lesion of facial nerve at external genu involving geniculate ganglion produces ipsilateral facial paralysis associated with reduced lacrimation, decreased salivary secretion of submandibular and sublingual glands, loss of taste sensations on the anterior two-thirds of tongue and hyperacusis on the ipsilateral side. Herpes zoster infection of the geniculate ganglion causes Ramsey-Hunt syndrome, which results in facial paralysis and eruption of painful vesicles on the external ear.
iii. A lesion in the medial wall of the middle ear gives rise to ipsilateral facial paralysis accompanied by loss of taste sensation on the anterior two-thirds of tongue and hyperacusis.

iv. A lesion in the vertical part of the facial canal causes facial palsy and the loss of taste on the ipsilateral side.

v. A lesion at the stylomastoid foramen results in ipsilateral facial paralysis only. The term Bell’s palsy is synonymous with idiopathic facial palsy. In Bell’s palsy there is loss of horizontal wrinkles on the forehead, inability to close the eye, epiphora, loss of corneal reflex, absence of nasolabial fold, inability to show the teeth. While smiling the angle of mouth on the affected side remains motionless and that of the normal side moves upwards and laterally. All these defects occur due to paralysis of muscles of facial expression.

Contd...
VESTIBULOCOCHLEAR NERVE

This is the eighth cranial nerve, which is composed of the cochlear and the vestibular nerves. The vestibulocochlear nerve carries special somatic afferent fibers from the internal ear. The unique feature about the sensory ganglia related to these two nerves is that they contain bipolar neurons unlike the sensory ganglia elsewhere.

Functional Components

The special somatic afferent fibers originate in vestibular and cochlear receptors in internal ear (Fig. 72.1). They are carried in the vestibulocochlear nerve for termination on vestibular and cochlear nuclei.

Vestibular Nerve (Fig. 72.2)

The vestibular nerve carries sensation of positions and movements of head in space from the maculae (static labyrinth) and the cristae (kinetic labyrinth) of the inner ear. The sensory ganglion related to the vestibular nerve is called vestibular or Scarpa’s ganglion.

Origin and Intracranial Course

The nerve begins in the vestibular ganglion located at the lateral end of internal acoustic meatus. The peripheral processes (dendrites) of the bipolar neurons pass through the foramina in the lateral end of the internal acoustic meatus (tractus spiralis foraminosus) and supply the ampullary cristae and the maculae. The central processes (axons) of the ganglion cells collect to form the trunk of vestibular nerve. In the internal meatus, the vestibular nerve is in close relation to the cochlear nerve, facial nerve and the labyrinthine vessels.

Course through Posterior Cranial Fossa

The vestibular nerve enters the posterior cranial fossa and passes through the cerebellopontine angle to reach the brainstem. It enters the brainstem at the
Afferent and efferent connections of vestibular nuclei

Lesion of Vestibular Nerve
Lesion of vestibular nerve results in disequilibrium, vertigo and nystagmus. Vertigo is a feeling of giddiness with a sense of rotation of head. It may occur due to excessive stimulation of semicircular canals and is associated with nystagmus (involuntary and inco-ordinated eye movements).
**Cochlear Nerve**

The cochlear nerve carries the sound impulses to the cochlear nuclei in the brainstem from where the central auditory pathway carries the impulses to the auditory cortex. This pathway is unique in having more than three neurons in its course, bipolar cells, cochlear nuclei, superior olivary nucleus (dorsal trapezoid nucleus and nucleus of lateral lemniscus) and medial geniculate body.

**Origin and Intrapetrous Course (Fig. 72.3)**

The peripheral processes of the bipolar neurons of spiral ganglion innervate the hair cells in the organ of Corti. The spiral ganglion is located in spiral canal in the modiolus. The bipolar neurons are the first order neurons of the auditory path. The central processes of the bipolar neurons pass through the tractus spiralis foraminosus at the medial end of the internal acoustic meatus, where they assemble to form the cochlear nerve. The further course of cochlear nerve in the internal meatus is similar to that of the vestibular nerve.

**Course in Posterior Cranial Fossa**

The cochlear nerve (along with the vestibular and facial nerves) passes through the pontocerebellar angle to reach the lateral aspect of pontomedullary junction. It enters the pons and divides into ascending and descending fibers, which terminate in ventral and dorsal nuclei (the second order neuron of auditory path) in the floor of the fourth ventricle.

**Auditory Pathway (Fig. 72.3)**

A large number of axons from the ventral cochlear nuclei decussate with those of the other side to give rise to trapezoid body in the lower pons. The trapezoid body has some scattered nuclei, where a few axons relay. Others terminate in contralateral superior olivary nuclei for relay. A few other axons that do not relay in superior olivary nuclei do so in the nuclei of lateral lemniscus. The uncrossed axons synapse in ipsilateral superior olivary nuclei and then ascend in the lateral lemniscus of the same side. Some axons from ventral cochlear neurons pass dorsally to reach the opposite side as intermediate acoustic striae. In their further course they probably join contralateral lateral lemniscus. Axons from dorsal cochlear nucleus turn dorsomedially across the midline as dorsal acoustic striae. They ascend in contralateral lateral lemniscus (bypassing superior olivary nuclei) and probably relay in the nuclei of lateral lemniscus. The neurons of the superior olivary complex, trapezoid nuclei, lateral lemniscus nuclei and some neurons of inferior colliculi are regarded as the third order neurons in the auditory path.

**Lateral Lemniscus**

This fiber tract is the main ascending tract of the auditory pathway. It extends from superior olivary nucleus to the inferior colliculus. It is composed of both crossed and uncrossed fibers, which belong to second and third order neurons. It is connected to the contralateral lateral lemniscus via commissural fibers, through which it receives fibers from the contralateral superior olivary nuclei. A minority of fibers in lateral lemniscus terminates in the inferior colliculus for relay. But the majority passes through the colliculus without relay.

**Inferior Colliculus**

The inferior colliculi receive auditory input from lateral lemniscus. It is also connected to opposite colliculus. Both relayed and non-relayed fibers project to medial geniculate body through the brachium of inferior colliculus. The structural arrangement of neurons suggests a tonotopic organization between the neuronal layers and cochlear turns. The inferior colliculus is concerned with localization of the source of sound and is the center of auditory reflexes.

**Medial Geniculate Body**

The medial geniculate body is a part of metathalamus. The neurons show laminar organization. The brachium of inferior colliculus ends in medial geniculate body, which is the highest order neuron to project to the auditory cortex.
The higher frequency sound impulses are received medi-ally and the low frequency impulses are received laterally in MGB.

**Auditory Radiation**

The auditory radiation is composed of axons of the neurons of medial geniculate body. It passes through the sublenti-form part of internal capsule to reach the auditory cortex.

**Auditory Cortex**

The primary auditory area is located on superior aspect of superior temporal gyrus (on the transverse temporal gyri of Heschl) in area 41 and 42. It projects to the auditory association area or area 22 on the lateral aspect of superior temporal gyrus. The auditory area receives impulses from both cochleae. Therefore, lesion in auditory cortex of one side will not cause hearing loss.
The glossopharyngeal nerve is the ninth cranial nerve. Developmentally it is the nerve of the third pharyngeal arch. It is a mixed nerve with larger sensory component and smaller motor component. The nerve bears two sensory ganglia (superior and inferior).

**Nuclei of Origin (Fig. 73.1)**

i. Nucleus ambiguus
ii. Inferior salivatory nucleus
iii. Nucleus of tractus solitarius
iv. Spinal nucleus of trigeminal nerve.

**Functional Components**

i. The special visceral efferent fibers arise in nucleus ambiguus for the supply of stylopharyngeus muscle.

ii. The general visceral efferent fibers arise in inferior salivatory nucleus. These preganglionic fibers synapse in otic ganglion from where the postganglionic fibers supply the parotid gland.

iii. The special visceral afferent fibers terminate on nucleus of tractus solitarius. These are the central processes of the inferior ganglion. The peripheral processes bring taste sensation from the posterior one-third of the tongue (including circumvallate papillae).

iv. The general visceral afferent fibers, which are the central processes of inferior ganglion terminate on nucleus of tractus solitarius. The peripheral processes of the ganglion bring sensations from the carotid body and carotid sinus.

v. The general somatic afferent fibers bring pain and temperature sensations from posterior one-third of tongue, tonsil, auditory tube and middle ear to the sensory nucleus of trigeminal nerve.

**Point of Emergence (Figs 58.1A and 58.2A)**

The glossopharyngeal nerve leaves the medulla oblongata as five to six rootlets at the posterolateral sulcus between the olive and the inferior cerebellar peduncle (just above the rootlets of vagus nerve).

**Course in Posterior Cranial Fossa**

After emerging into posterior cranial fossa the rootlets unite to form nerve trunk. Then the nerve passes laterally and anteriorly. On its way to the jugular foramen, it grooves the jugular tubercle of occipital bone and then turns abruptly down to enter the jugular foramen.

**Exit from Cranium**

It passes through the central part of jugular foramen lying in front of the vagus and accessory nerves but in a separate dural sheath.
Chapter 73

Glossopharyngeal Nerve

Relations in Jugular Foramen

The jugular foramen is divided into three parts. The ante-
rior part gives passage to inferior petrosal sinus. The central part contains ninth, tenth and eleventh cranial nerves in that order from anterior to posterior. The posterior part contains the beginning of internal jugular vein. The supe-
rior and inferior sensory ganglia of glossopharyngeal nerve lie on its trunk in the jugular foramen. The inferior ganglion is concerned with taste sensation from the vallate papillae. The superior ganglion is concerned with general sensations from the areas of supply of the nerve.

Extracranial Course (Fig. 73.2)

Below the jugular foramen the glossopharyngeal nerve courses downward and forward between the internal carotid artery and the internal jugular vein and then between the external and internal carotid arteries. It then turns anteriorly and winds around the lateral aspect of stylopharyngeus muscle to reach its anterior aspect. On their way to the pharyngeal wall, the nerve and the muscle are related to the superior constrictor at the tonsillar fossa. They enter the pharynx in the gap between the superior and middle constrictor muscles.

Branches

i. Tympanic nerve (Jacobson’s nerve) is the first branch that leaves the inferior ganglion. It enters a small foramen in the jugular fossa leading into the tympanic canaliculus. Through this canal the tympanic branch reaches the middle ear, where it forms a tympanic plexus on the surface of promontory. The tympanic plexus supplies sensory branches to the middle ear, lateral part of auditory tube and mastoid antrum and air cells. The lesser petrosal nerve arises from the plexus. It carries preganglionic parasympathetic fibers. First it enters the middle cranial fossa and then the infratemporal fossa to end in the otic ganglion. The postganglionic fibers supply the parotid gland.

ii. Carotid sinus nerve arises just below the inferior ganglion for the supply to the carotid body and carotid sinus. The carotid body contains chemoreceptors that monitor CO₂ and O₂ concentration in blood and the carotid sinus contains baroreceptors that monitor arterial blood pressure.

iii. Pharyngeal branches arise in the pharyngeal wall. These filaments form a pharyngeal plexus (in the buccopharyngeal fascia covering the middle constrictor) by uniting with pharyngeal branch of vagus and pharyngeal branch of sympathetic. The glossopharyngeal nerve supplies the pharyngeal mucosa via the plexus.

iv. Muscular branch supplies the stylopharyngeus muscle.

v. Tonsillar branches supply the tonsil, fauces and soft palate.

vi. Lingual branches supply the circumvallate papillae and the mucosa of posterior third of the tongue.

Clinical insight ...

i. For assessing the function of glossopharyngeal nerve, the general sensations of the mucosa of posterior wall of oropharynx, soft palate and palatine tonsils are tested.

ii. The gag reflex is elicited by applying stimulus to the posterior pharyngeal wall or soft palate. This results in elevation of pharynx, elevation of soft palate and retraction of tongue. The afferent limb of this reflex is the glossopharyngeal nerve and efferent limb is the vagus nerve. The gag reflex is lost in lesion of either of the nerves.

iii. Glossopharyngeal neuralgia is characterized by intractable episodic pain precipitated by swallowing and felt in throat, behind the angle of jaw and in the ear. Surgical sectioning of the glossopharyngeal nerve (neurectomy) or nerve block relieves the symptoms. The nerve is approached through the tonsillar fossa for this purpose.

iv. Isolated injury to glossopharyngeal nerve may occur during tonsillectomy. This results in ipsilateral loss of gag reflex, ipsilateral loss of taste from vallate papillae, ipsilateral loss of general sensations in pharynx, soft palate and posterior third of tongue.
The vagus nerve is the tenth cranial nerve. It is the longest and the most widely distributed cranial nerve. It is the only cranial nerve that has the thoracic and abdominal distribution. The vagus nerve carries the cranial part of accessory nerve inside it for distribution. It is a mixed nerve containing both motor and sensory fibers. It has two sensory ganglia (superior or jugular and inferior or nodosum) on its trunk.

Nuclei of Origin (Fig. 74.1)
i. The nucleus ambiguus lies deep in the medulla oblongata. It supplies the striated muscles developed from fourth and sixth pharyngeal arches. It also supplies the striated muscle of the upper third of esophagus.
ii. The dorsal nucleus of vagus lies below the floor of fourth ventricle in the vagal trigone. It is a mixed nucleus as it performs both visceromotor and secretomotor functions plus the viscerosensory function.
iii. The nucleus of tractus solitarius receives afferent gustatory fibers from the valleculae of oropharynx and the epiglottis.
iv. The spinal nucleus of trigeminal nerve receives cutaneous sensations from the external ear carried through auricular branch of vagus.

Functional Components
i. The branchial efferent or special visceral efferent fibers arising from nucleus ambiguus supply the palatal muscles (except tensor palati) pharyngeal muscles (except stylopharyngeus) and laryngeal muscles.
ii. The general visceral efferent fibers arise in dorsal nucleus of vagus for the supply of the myocardium and smooth muscle and glands of the digestive tract (up to the junction of right two-thirds and left one-third of transverse colon) and of the respiratory tract.
iii. The general visceral afferent fibers bring visceral sensations via the processes of the inferior ganglion to the nucleus of tractus solitarius and dorsal nucleus.
iv. The special visceral afferent fibers from the taste buds in the vallecula and epiglottis reach the nucleus of tractus solitarius from the inferior ganglion.
v. The general somatic afferent fibers from the external ear reach the spinal nucleus of trigeminal nerve.

Point of Emergence (Figs 58.1A and 58.2A)
The vagus nerve emerges from the medulla by 10 to 12 rootlets is series with the cranial part of accessory and glossopharyngeal nerve in the posterolateral sulcus (post-olivary sulcus) between the olive and inferior cerebellar peduncle.
Intracranial Course

The vagal rootlets unite to form a flat nerve trunk, which passes below the flocculus of cerebellum along with the cranial accessory nerve towards the jugular foramen. These two nerves are inside the common dural and arachnoid sheath.

Exit from Cranium

The vagus nerve passes through the central part of jugular foramen along with glossopharyngeal and accessory nerves. The inferior petrosal sinus is anterior and beginning of internal jugular vein is posterior to the nerves inside the foramen.

Sensory Ganglia

The superior ganglion is located in the jugular foramen. The inferior ganglion lies just below the jugular foramen.

Branches in Jugular Foramen

i. The auricular branch of vagus arises from the superior ganglion. It is known as Alderman’s nerve. It gives a few twigs to the cranial surface of the auricle, the external acoustic meatus and the posteroinferior part of the lateral surface of the tympanic membrane.

ii. The meningeal branches arising from superior ganglion enter the posterior cranial fossa. They supply sensory fibers (C1 and C2) and sympathetic fibers to the dura mater of posterior cranial fossa.

Extracranial Course (Fig. 74.2)

The extracranial course of vagus is divided into three parts: cervical, thoracic and abdominal.

Cervical Course

The vagus nerve descends vertically in the carotid sheath. It lies between the internal carotid artery and internal jugular vein but on a slightly posterior plane up to the level of superior margin of thyroid cartilage. Below this level, it lies between the common carotid artery and the internal jugular vein. At the root of the neck, it comes out of the carotid sheath.

Branches of Cervical Part

i. Pharyngeal branch is the first to arise just below the inferior ganglion. It carries cranial accessory fibers in it. It takes part in pharyngeal plexus, through which it supplies the pharyngeal muscles (except stylopharyngeus and palatine muscles (except tensor palati)).

ii. Superior laryngeal nerve arises just below the pharyngeal branch. It soon divides into internal and external laryngeal nerves. The external laryngeal nerve supplies the cricothyroid and inferior constrictor. The internal laryngeal nerve is sensory to the mucosa of larynx above the vocal folds.

iii. A small twig supplies the carotid body and sinus.

iv. Superior and inferior cervical cardiac branches enter the thorax. The inferior cervical cardiac branch of left vagus takes part in superficial cardiac plexus and the other three cervical cardiac branches end in the deep cardiac plexus.
v. The right recurrent laryngeal nerve originates from the right vagus anterior to the first part of subclavian artery. It winds round the artery to occupy the groove between the trachea and esophagus on the right side. Its relation to inferior thyroid artery is of surgical importance (Refer to chapter 43 on thyroid gland). The recurrent laryngeal nerve supplies all the intrinsic laryngeal muscles except cricothyroid. It sends motor twigs to the inferior constrictor muscle and cardiac filaments to deep cardiac plexus. It is sensory to laryngeal mucosa below the vocal folds.

**Entry into Thorax**

The vagus nerves enter the thorax by passing through the thoracic inlet. The right vagus nerve crosses in front of the first part of subclavian artery but behind the internal jugular vein. The left vagus nerve enters the thorax between the left subclavian and left common carotid arteries but behind the left brachiocephalic vein.

**Course of Right Vagus Nerve in Thorax**

In the superior mediastinum, the right vagus nerve passes downwards posterior to the right brachiocephalic vein and the superior vena cava and in contact with the right surface of trachea. To enter the posterior mediastinum, the nerve passes behind the right principal bronchus and reaches the posterior aspect of hilum of right lung, where it breaks up to form posterior pulmonary plexus by uniting with the sympathetic fibers from upper thoracic ganglia. At the lower end of the lung hilum, two or three branches arise from the pulmonary plexus and reach the posterior aspect of esophagus. Here, these branches of right side meet a few branches from left vagus to form posterior esophageal plexus. The posterior vagal trunk arising from the esophageal plexus descends posterior to the esophagus to enter the abdomen through the esophageal opening in the diaphragm.

**Branches of Right Vagus Nerve in Thorax**

i. The left recurrent laryngeal nerve originates from the left vagus nerve, where it crosses the left and anterior surface of the arch of aorta. It winds round the ligamentum arteriosum and then it ascends in relation to the right and posterior surface of the aortic arch to lie in a groove between the trachea and esophagus on left side. It is liable for damage in thorax if compressed by aneurysm of aorta or enlarged left atrium or bronchogenic carcinoma. Its distribution in the neck is similar to that of right recurrent laryngeal nerve.

ii. The left vagus nerve gives the cardiac, pulmonary and esophageal branches via corresponding plexuses. It also supplies the aortic bodies.

**Abdominal Course**

The anterior trunk contains mostly the fibers of left vagus and the posterior trunk contains the fibers of right vagus. (For distribution of anterior and posterior vagal or gastric trunks refer to chapter 81 on stomach. For distribution to other abdominal organs refer to chapter on abdominal part of autonomic nervous system in chapter 84).

**Lesions of Vagus Nerve**

Effects of unilateral complete section of vagus nerve are as follows:

i. Unilateral paralysis of soft palate muscles (except tensor palati) results in lowering of the palate on affected side and on phonation the palate fails to elevate. The uvula moves to the normal side (Fig. 74.3). There is nasal voice and nasal regurgitation of food.

ii. Unilateral paralysis of pharyngeal muscles leads to deviation of the posterior pharyngeal wall, on phonation, to the normal side. The paralyzed side moves like a sliding curtain towards the normal side.

**Clinical insight ...**

Contd...
Fig. 74.3: Deviation of uvula towards normal side in lesion of vagus nerve (Large arrow indicates the deviation of uvula to the normal site, small arrow shows the drooping of palatopharyngeal arch)

Contd...

iii. There is ipsilateral loss of gag reflex (normally, touching one side of the pharyngeal wall with a swab stick evokes the contraction of pharyngeal muscles and elevation of the posterior one-third of the tongue resulting in a feeling to vomit).

iv. There is ipsilateral loss of sensations in the pharyngeal mucosa.

v. There is paralysis of laryngeal muscles (refer to chapter 50 on larynx).
The accessory nerve is the eleventh cranial nerve. It consists of spinal part and cranial part.

i. The cranial part originates from nucleus ambiguous. It is composed of branchial efferent fibers. It emerges from the ventral surface of medulla oblongata through posterolateral sulcus below the rootlets of vagus nerve.

ii. The spinal part arises from ventral horns of C1 to C5 segments of the spinal cord by separate rootlets midway between the attachments of the cervical ventral and dorsal rootlets. The rootlets join to form the nerve, which ascends in the cervical vertebral canal and enters the cranium through the foramen magnum.

**Formation of Accessory Nerve (Fig. 75.1)**

In the posterior cranial fossa the spinal accessory nerve joins the cranial accessory nerve to form the trunk of the accessory nerve near the jugular foramen. The nerve trunk leaves through the middle compartment of the jugular foramen.

**Splitting of Accessory Nerve**

After reaching the base of cranium the accessory nerve divides into the spinal and cranial parts. The cranial part joins the vagus nerve and is distributed through its branches to pharyngeal, palatal and laryngeal muscles.

**Extracranial Course of Spinal Part**

As the nerve descends it lies anterior to the tip of the transverse process of the atlas. From here it descends in posterior direction deep to the styloid process, stylohyoid muscle and posterior belly of digastric muscle. It passes through the upper part of the carotid triangle and then enters the substance of the sternomastoid muscle, to which it gives branches. The nerve enters the posterior triangle around the midpoint of the posterior margin of the sternomastoid. At this point the lesser occipital nerve hooks round the accessory nerve to turn in the upward direction and the accessory nerve is surrounded by superficial cervical lymph nodes. The spinal accessory nerve descends in the posterior triangle from medial to lateral side between the fascial floor and fascial roof, but lying adherent to the roof. It enters the trapezius about five centimeter above the clavicle and travels towards the back lying plastered to the deep surface of the trapezius and along with the superficial branch of the transverse cervical artery. It gives branches to the trapezius.

**Lesion of Spinal Accessory Nerve**

i. If the spinal accessory nerve is injured before entering the sternomastoid muscle or inside the muscle, the nerve supply of sternomastoid and trapezius muscle is endangered.

ii. If the spinal accessory nerve is injured in posterior triangle, branch to sternomastoid muscle escapes but trapezius is affected.

Clinical insight ...

**Fig. 75.1:** Origin of cranial and spinal parts of accessory nerve and course of spinal accessory nerve
ANATOMY OF HYPOGLOSSAL NERVE

The hypoglossal nerve is the twelfth cranial nerve. It is a purely motor nerve. It has only one functional component (general somatic efferent). It supplies the lingual muscles developed from occipital myotomes (all intrinsic muscles and all extrinsic muscles of tongue except palatoglossus).

Nucleus of Origin
The hypoglossal nucleus is located in the inferior half of the floor of fourth ventricle deep to the hypoglossal trigone in the medulla oblongata (Fig. 58.5). It receives corticospinal connections from precentral gyrus of opposite cerebrum.

Functional Component
The somatic efferent fibers arise in hypoglossal nucleus for the supply of all muscles of tongue except palatoglossus.

Intramedullary Course (Fig. 76.1)
After emerging from the nucleus the hypoglossal fibers traverse anteriorly in the reticular formation of medulla oblongata lying very close to the medial lemniscus. Near the anterior end of medial lemniscus the nerve fibers emerge between the pyramid and the inferior olivary nucleus as rootlets.

Point of Emergence (Figs 58.1A and 58.2A)
The hypoglossal nerve emerges as a series of rootlets from the anterolateral sulcus between the pyramid and olive.

Intracranial Course
The rootlets of the hypoglossal nerve run laterally posterior to the vertebral artery and collect into two bundles, which perforate the dura mater separately near the anterior condylar foramen in the occipital bone.

 Exit from Cranium
The two bundles unite in the anterior condylar canal to form the trunk of hypoglossal nerve, which leaves...
the posterior cranial fossa through anterior condylar foramen.

**Extracranial Course (Fig. 76.1)**

i. At the base of cranium the hypoglossal nerve lies medial to the internal carotid artery. It inclines laterally to pass behind the internal carotid artery and the ninth and tenth cranial nerves. It spirals around the lateral aspect of inferior ganglion of the vagus to lie in front of the vagus nerve (outside the carotid sheath). Then it passes vertically downward medial to the posterior belly of digastric. At the level of angle of mandible it passes deep to the posterior belly of digastric and turns forward to enter the carotid triangle.

ii. In the carotid triangle the hypoglossal nerve crosses first the internal carotid artery and then the external carotid artery. It crosses the loop of the lingual artery just above the tip of greater cornu of hyoid bone. It enters the digastric triangle by passing deep to intermediate tendon of digastric and stylohyoid.

iii. In the digastric triangle (submandibular region), the hypoglossal nerve crosses the hyoglossus muscle on its superficial aspect (Fig. 47.4). It lies below the submandibular duct and the deep part of submandibular gland and then passes deep to mylohyoid to pierce the genioglossus for the supply of lingual musculature.

**Branches of Communication**

It receives a large communication from the ventral ramus of first cervical nerve.

**Branches (carrying C1 fibers)**

i. The meningeal branch arises at the level of anterior condylar foramen to supply the dura mater of posterior cranial fossa.

ii. The upper limb of ansa cervicalis (carrying C1 fibers) arises in carotid triangle. It joins the lower limb of ansa cervicalis (carrying C2 and C3 fibers) to form ansa cervicalis.

iii. Nerve to thyrohyoid contains C1 fibers.

iv. Nerve to geniohyoid contains C1 fibers.

**Branches of Hypoglossal Nerve**

The hypoglossal nerve supplies all intrinsic muscles of tongue and three of the extrinsic muscles of tongue (styloglossus, hyoglossus and genioglossus).

**Testing Nerve Function**

The subject is asked to protrude the tongue. If the hypoglossal nerves are intact the protruded tongue lies in the midline.

**Lesion of Hypoglossal Nerve Proper**

i. Unilateral lesion of hypoglossal nucleus or of the hypoglossal nerve causes unilateral lower motor neuron paralysis of the tongue. The protruded tongue deviates to the side of the lesion (Fig. 76.2).

ii. In bilateral lesion of hypoglossal nerve the tongue lies motionless causing difficulty in speech and swallowing.

iii. In upper motor hypoglossal lesion of hypoglossal nerve (lesion of corticonuclear fibers in the genu of internal capsule) neuron nucleus is normal but there is paralysis of the muscles of the side opposite to that of the lesion hence on protrusion the tongue deviates to normal side.

iv. For medial medullary syndrome refer to chapter 58.
**CASE 1**
A 10-year-old girl undergoes bilateral tonsillectomy on account of recurrent tonsillitis. On fourth postoperative day the ENT surgeon finds that the girl has loss of both general and special sensations on posterior one-third of the tongue and there is absence of gag reflex.

Questions and Solutions

1. **Which nerves are bilaterally damaged in this patient?**
   
The glossopharyngeal nerves are damaged during removal of the tonsils from the tonsillar fossa.

2. **What is the relation of this nerve to the tonsil?**
   
The glossopharyngeal nerve is related to superior constrictor, where the muscle forms lateral wall of the tonsillar fossa. In recurrent tonsillitis the inflamed tonsil is likely to be adherent to the superior constrictor muscle. Therefore, during removal of tonsil from the superior constrictor the closely related glossopharyngeal nerve is in danger of injury.

3. **Name the sensory ganglia of this nerve.**
   
   There are two sensory ganglia, superior and inferior.

4. **Name the parasympathetic ganglion related to this nerve.**
   
The otic ganglion is functionally related to glossopharyngeal nerve.

5. **Enumerate the branches of distribution of this nerve.**
   
   Tympanic branch or Jacobson’s nerve (carrying preganglionic parasympathetic fibers to the otic ganglion, carotid sinus nerve, pharyngeal branches, muscular branch to stylopharyngeus, tonsillar branches to tonsil and soft palate and lingual branches to posterior one-third of tongue.

6. **Will there be loss of secretion of parotid gland in the above patient? Describe the secretomotor innervation of parotid gland.**
   
The secretion of parotid gland will not be affected if glossopharyngeal nerve is injured during tonsillectomy because the tympanic branch is the first branch of glossopharyngeal nerve. It arises at the level of jugular foramen. The course of preganglionic parasympathetic fibers contained in it is as follows. The preganglionic fibers are carried in tympanic branch, which breaks up into tympanic plexus in the middle ear. The lesser petrosal nerve arises from the tympanic plexus and ends into otic ganglion for synapse. The postganglionic fibers reach the parotid gland via auriculotemporal nerve.

**CASE 2**
A 14-year-old boy suffered fracture of nasal bone, when he was hit by a cricket ball. There was watery discharge from his nose and loss of smell (anosmia). X-ray of cranium revealed fracture of cribriform plate of ethmoid bone.

Questions and Solutions

1. **Which nerves are affected?**
   
The olfactory nerves are affected. They are the first cranial nerves.

2. **Give the origin and termination of these nerves.**
   
The olfactory nerves arise in the olfactory mucosa in the nasal cavity from the bipolar olfactory receptor cells. The long axons of these cells collect to form about 20 bundles in each olfactory nerve. They pass through the
cribriform plate of ethmoid bone to enter the anterior cranial fossa, where they terminate on the olfactory bulb.

3. **What is the route of infection from the nasal cavity to the anterior cranial fossa?**

The bundles of axons inside olfactory nerve are surrounded by the meninges at the cribriform plate. This provides a communication between the subarachnoid space and the lymphatics of the nasal cavity and a route for the infection from the nasal cavity to the meninges.

**CASE 3**

A patient was diagnosed with medial medullary syndrome. He experienced difficulty in moving the tongue during eating and speaking. On examination, it was found that his tongue deviated to the right side on protrusion.

**Questions and Solutions**

1. **Which nerve (of which side) is injured in this patient?**

   The right hypoglossal nerve is injured in this patient.

2. **What is the site of lesion of the nerve in this patient?**

   Intramedullary fibers of hypoglossal nerve and hypoglossal nucleus are injured.

3. **Enumerate the muscles of tongue paralyzed in this patient.**

   All intrinsic muscles of tongue and all extrinsic muscles (genioglossus, styloglossus and hyoglossus) except palatoglossus are paralyzed.

4. **Is it an upper motor neuron lesion or a lower motor neuron lesion?**

   It is a lower motor neuron lesion of hypoglossal nerve.

5. **Mention the changes in tongue due to LMN lesion of hypoglossal nerve.**

   The ipsilateral tongue is flaccid, wasted and shows fasciculation. On protrusion, it deviates to the side of lesion.

**CASE 4**

The ophthalmologist found that a 53-year-old woman had tunnel vision. MRI scan of the head showed a tumor of pituitary gland.

**Questions and Solutions**

1. **Which structure is compressed by the pituitary tumor?**

   Optic chiasma is compressed.

2. **Describe the formation and relations of this structure.**

   The optic chiasma is a flattened band of nerve fibers located in the midline in the middle cranial fossa. It is formed by partial decussation of the fibers in the optic nerves. The nasal fibers arising from nasal half of each retina cross the midline of optic chiasma and enter the opposite optic tract.

   The temporal fibers arising from temporal half of retina crossing through the lateral half of optic chiasma are uncrossed. They continue backward into the optic tract of the same side.

   The optic chiasma is related to several structures. Superiorly it is related to floor of third ventricle. Laterally it is related to bifurcation of internal carotid artery. Anteriorly the lamina terminalis extends from it to the paraterminal gyrus. The anterior communicating artery is its anterior relation. Posteriorly, there are structures in the interpeduncular fossa (infundibulum, tuber cinereum and mamillary bodies). The pituitary gland is its posteroinferior relation. The pituitary tumors expand superiorly and compress optic chiasma in the midline affecting the crossing nasal fibers and producing the typical field defect called binasal hemianopia. In this defect the patient can see the objects placed in the nasal halves of the visual fields but not in the temporal halves. This is known as tunnel vision.

3. **Name the arteries supplying this structure.**

   The optic chiasma receives twigs from anterior communicating artery, anterior cerebral arteries, internal carotid arteries and middle cerebral arteries.

**CASE 5**

A young man involved in road traffic accident was found to have ruptured the tympanic membrane on the left side.

**Questions and Solutions**

1. **Name the nerve in close relation to the tympanic membrane that is injured in this patient.**

   Chorda tympani nerve.

2. **What is this nerve a branch of and where does it originate?**

   The chorda tympani is a branch of facial nerve. It arises from the facial nerve in the vertical segment
3. **Name the fibers contained inside the injured nerve.**

The chorda tympani nerve contains two types of fibers. It carries taste sensation from the anterior two-thirds of tongue and preganglionic parasympathetic fibers for relay in submandibular ganglion (to provide secretomotor innervation to submandibular and sublingual salivary glands).

4. **What is the effect of injury to this nerve?**

There will be loss of taste sensation on anterior two-thirds of tongue and loss secretion of submandibular and sublingual salivary glands.

5. **Name the bony structure to which it is related in the roof of infratemporal fossa.**

The chorda tympani is closely related to the medial aspect of the spine of sphenoid in the roof of infratemporal fossa.

6. **How does this nerve reach the tongue?**

The chorda tympani nerve joins the lingual nerve in the infratemporal fossa. It travels inside the lingual nerve to reach the tongue.

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**CASE 6**

A 54-year-old woman complains of double vision. While testing her eye movements the physician notes that the patient cannot elevate her right eye in abducted position of eyeball. The physician also notes that the patient’s right pupil is dilated and nonreactive to light. CT head shows aneurysm of superior cerebellar artery.

**Questions and Solutions**

1. **Name the nerve that is injured.**

Oculomotor nerve.

2. **Give the reason of compression of the nerve.**

The oculomotor nerve is compressed due to aneurysm of superior cerebellar artery as the nerve passes between the superior cerebellar and posterior cerebral arteries.

3. **Which muscle is paralyzed in this patient?**

The superior rectus is paralyzed in this patient.

4. **What is the position of eyeball if all the extraocular muscles supplied by the injured nerve are paralyzed?**

The eyeball is turned downwards and laterally.

5. **What is the reason for dilated and fixed pupil?**

The parasympathetic component of the oculomotor nerve supplies the sphincter pupillae and ciliaris muscles inside the eyeball. In compression of the nerve the superficially placed parasympathetic fibers undergo damage first. So the pupil is dilated and fixed.
1. A sudden onset of left third nerve palsy and right hemiplegia could be caused by
   a. Infarction in left internal capsule
   b. Infarction in right internal capsule
   c. Infarction in left half of midbrain
   d. Infarction in right half of midbrain

2. Which cranial nerve supplies the muscle that raises the upper eyelid?
   a. Facial
   b. Oculomotor
   c. Trochlear
   d. Abducent

3. The anterior division of mandibular nerve supplies all the following except.
   a. Temporalis
   b. Medial pterygoid
   c. Lateral pterygoid
   d. Masseter

4. All the following glands receive secretomotor innervation by facial nerve except:
   a. Parotid
   b. Lacrimal
   c. Submandibular
   d. Sublingual

5. In which of the following lesions the patient presents with paralysis of lower face on right side?
   a. Right LMN
   b. Left LMN
   c. Right UMN
   d. Left UMN

6. What is the name of the area where optic nerve leaves the eyeball?
   a. Macula
   b. Fovea
   c. Blind spot
   d. Hyaloid fossa

7. All the following nerves carry parasympathetic fibers except:
   a. Mandibular
   b. Oculomotor

8. To test the function of hypoglossal nerve the physician asks the patient to protrude the tongue. On doing so, patients tongue deviates to the right side. This is due to paralysis of:
   a. Left genioglossus
   b. Right genioglossus
   c. Left Hyoglossus
   d. Right hyoglossus

9. A woman who suffered head trauma in the road traffic accident was brought to the casualty. CT scan of head revealed a fracture of middle cranial fossa passing through the foramen ovale. Which functional loss is expected in this patient?
   a. Loss of sensation over forehead
   b. Loss of sensation over zygomatic bone
   c. Inability to blow the cheeks
   d. Inability to chew food

10. A 30-year-old woman comes to her doctor with complaint of inability to close the right eye. Examination confirms the weakness of right orbicularis oculi muscle. Which of the following symptoms would also be present in this patient?
    a. Double vision
    b. Inability to chew
    c. Hyperacusis
    d. Inability to shrug the shoulder

11. A 60-year-old woman is not able to distinguish smells like coffee and orange. CT scan of cranium revealed growth in the anterior cranial fossa nearer the cribiform plate. The nerves likely to be compressed by the growth project to following area.
    a. Piriform lobe
    b. Cingulate gyrus
    c. Hypothalamus
    d. Insula

12. Which of the following muscles receives C1 fibers directly from the hypoglossal nerve?
    a. Geniohyoid
    b. Genioglossus
13. The following nucleus belongs to branchial efferent functional column
   a. Edinger-Westphal nucleus
   b. Nucleus ambiguus
   c. Dorsal nucleus of vagus
   d. Salivatory nucleus

14. The following second order neurons receive fibers carrying discriminative touch from face.
   a. Chief sensory nucleus of trigeminal nerve
   b. Nucleus of spinal tract of trigeminal nerve
   c. Mesencephalic nucleus
   d. VPM nucleus of thalamus

15. Which of the following nerves is the efferent limb of corneal reflex?
   a. Oculomotor
   b. Ophthalmic
   c. Abducent
   d. Facial

16. Select the incorrect pair
   a. Nucleus ambiguus muscles of palate except tensor palati
   b. Nucleus of spinal tract pain and temperature from ipsilateral face
   c. Vestibular nuclei trapezoid body
   d. Lesion of right trochlear nucleus—Paralysis of left superior oblique

17. Which of the following is not a branch of posterior division of mandibular nerve?
   a. Auriculotemporal
   b. Buccal
   c. Lingual
   d. Inferior alveolar

18. All the following are correct regarding trochlear nerve except:
   a. Its nucleus is at the level of inferior colliculus
   b. It supplies the muscle that depresses the eyeball
   c. It exits the midbrain on dorsal side
   d. It crosses the superior cerebellar peduncle

19. What is untrue about geniculate ganglion?
   a. Contains pseudounipolar neurons
   b. Located in temporal bone
   c. Lesser petrosal nerve is its branch
   d. Herpes zoster of the ganglion causes Ramsay Hunt syndrome

20. Which of the following structures is involved in transmission of sound impulse?
   a. Restiform body
   b. Lateral lemniscus
   c. Medial lemniscus
   d. Trigeminal lemniscus

21. Effect of injury to the right optic tract results in:
   a. Bitemporal hemianopia
   b. Right homonymous hemianopia
   c. Left homonymous hemianopia
   d. Amblyopia

22. Which of the following is the correct association?
   a. CN V—Swallowing
   b. CN III—Closure of eye
   c. CN IX—Elevation of palate
   d. CN VII—Lacrimation

23. What is true about optic nerve?
   a. Contains axons of bipolar neurons
   b. Is the afferent limb of corneal reflex?
   c. Myelination by oligodendroglia
   d. Regenerates after injury

24. Which of the following contains pseudounipolar neurons?
   a. Spiral ganglion
   b. Vestibular ganglion
   c. Olfactory mucosa
   d. Geniculate ganglion

25. The vagus nerve supplies preganglionic parasympathetic fibers to all the following except:
   a. Myocardium
   b. Esophageal musculature
   c. Descending colon
   d. Cecum

KEY TO MCQs
1-c, 2-b, 3-b, 4-a, 5-b, 6-c, 7-a, 8-b, 9-d, 10-c, 11-a, 12-a, 13-b, 14-a, 15-d, 16-c, 17-b, 18-d, 19-c, 20-b, 21-c, 22-d, 23-c, 24-d, 25-c.
ABDOMEN, PELVIS AND PERINEUM
LUMBAR VERTEBRAE

There are five lumbar vertebrae. The first four lumbar vertebrae confirm to common features. The fifth lumbar vertebra shows atypical features.

Typical Lumbar Vertebra (Fig. 78.1)

i. The body of lumbar vertebra is very large and the vertebral foramen is large and triangular.
ii. Each transverse process presents an accessory process at its root.
iii. The spine is quadrilateral.
iv. Each superior articular process bears a rough projection called mamillary process on its posterior margin. The superior articular facet is concave and faces medially. The inferior articular process is convex and faces laterally.
v. The lower end of the spinal cord (conus medullaris) and spinal meninges are present in the vertebral canal of first lumbar vertebra. The vertebral canal of the lower four lumbar vertebrae contains the cauda equina inside the lumbar cistern.

Fifth Lumbar Vertebra (Fig. 78.2)

i. This vertebra is wedge-shaped and hence produces the lumbosacral angle (normal value is 120–130°).
ii. The transverse processes of the fifth lumbar vertebra encroach on its body. This is the distinguishing feature of fifth lumbar vertebra.
iii. The roots of the obturator nerve and the contribution of the fourth lumbar ventral ramus to the lumbosacral trunk pass anterior to the transverse process of the fifth vertebra. These nerves may be damaged in fracture of the transverse process.

Muscle Attachments

i. The right crus of diaphragm originates from bodies of upper three lumbar vertebrae while left crus originates from bodies of upper two lumbar vertebrae.
ii. The psoas major muscle arises from sides of bodies of upper four lumbar vertebrae near their upper and lower margins (and from the side of body of fifth
vertebra near its upper margin). It also takes origin from the anterior surface of the transverse processes of all the lumbar vertebrae.

iii. The quadratus lumborum takes origin from the anterior surface of transverse processes (lateral to origin of psoas major) of upper four lumbar vertebrae.

Attachments of Thoracolumbar Fascia
i. The anterior layer is attached to the ridge on the anterior surface of transverse processes.

ii. The middle layer is attached to the tips of transverse processes.

iii. The posterior layer is attached to the spines of the lumbar vertebrae.

SACRUM (FIG. 78.3)
The sacrum consists of five fused vertebrae. It is a large triangular bone that presents markedly concave anterior or pelvic surface and convex posterior surface.

i. Its broad base is directed above and the apex is at the lower end.

ii. The base is divided into central part consisting of the body of first sacral vertebra and lateral mass or ala on either side.

iii. By its base the sacrum articulates with fifth lumbar vertebra and by its apex it articulates with the coccyx.

iv. The base presents the upper opening of the sacral canal.

v. The superoanterior margin of the body of first sacral vertebra projects forwards as the sacral promontory, which is useful in measuring the diameters of the pelvis.

vi. Weber’s point is situated 1 cm below the sacral promontory and it represents the center of gravity of the body.

vii. The lower end of the sacrum shows sacral hiatus, which is the lower opening of the sacral canal.

viii. The anterior surface of sacrum bears four anterior sacral foramina, which give passage to ventral rami of upper four sacral spinal nerves and lateral sacral arteries.

ix. The dorsal surface of sacrum bears four posterior sacral foramina, which give passage to posterior rami of the upper four sacral spinal nerves.

Ala of Sacrum
The upper surface of the lateral mass of sacrum is termed the ala of sacrum. The ala is covered by psoas major muscle. Its smooth medial part is related to sympathetic chain, iliolumbar artery, lumbosacral trunk (L4, L5) and the obturator nerve from medial to lateral side.

Relations of Pelvic Surface
i. The pelvic surface on the first, second and upper half of third piece of sacrum is covered with peritoneum.

ii. The rectum is related to the pelvic surface of lower half of third, fourth and fifth pieces of sacrum.

iii. The sympathetic chains are directly related to the pelvic surface (medial to the anterior sacral foramina).

iv. The median sacral artery (a branch from abdominal aorta) and the superior rectal artery (a continuation of inferior mesenteric artery) are related in the

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**Fig. 78.2:** Fifth lumbar vertebra seen from above

**Fig. 78.3:** Relations and attachments of anterior surface of sacrum and attachments of coccyx
midline. The superior rectal artery bifurcates behind the rectum on the third piece of sacrum.

v. The piriformis muscle has E-shaped origin from middle three pieces of sacrum.

**Dorsal Surface**
The erector spinae takes U-shaped origin from the dorsal surface.

**Lateral Surface**
i. The upper part has L-shaped auricular surface (for articulation with ilium at sacroiliac joint).

ii. The nonarticular part of lateral surface provides attachments to ventral, dorsal and interosseous sacroiliac ligaments.

iii. Lower narrow part of lateral surface provides attachment to sacrospinous and sacrotuberous ligaments in addition to coccygeus and gluteus maximus muscles.

**Contents of Sacral Canal**
The sacral canal contains the cauda equina, dura mater and arachnoid mater. At the lower margin of second sacral vertebra the subarchnoid and subdural spaces terminate. The fifth sacral roots, coccygeal roots and filum terminale pierce the blind end of the dural tube. Beyond the dural tube there is roomy extradural space in the sacral canal (capacity is 25–30 ml).

**Sacral Hiatus**
The structures that emerge from the sacral hiatus are the filum terminale, fifth sacral nerves and coccygeal nerves. The sacral hiatus provides access to the extradural space in the sacral canal. The sacral hiatus lies about 5 cm above the tip of the coccyx, directly beneath the upper end of natal cleft. The other method to locate the sacral hiatus is to draw an equilateral triangle. The base of the triangle is the line connecting the posterior superior iliac spines (PSIS). The apex of the triangle indicates the sacral hiatus.

**Coccyx**
i. The coccyx consists of four rudimentary vertebrae, which are fused to form a triangular bone. It articulates by its base with the apex of sacrum at a mobile sacro-coccygeal joint.

ii. Its base presents two cornua that project upwards to connect with cornu of sacrum by intercornual ligaments.

iii. The apex provides attachment to anococcygeal raphe.

iv. The pelvic surface is related to ganglion impar (lower fused end of sympathetic chains) and gives origin to levator ani and coccygeus muscles.

v. Its dorsal surface provides attachment to film terminale, gluteus maximus and sphincter ani externus (superficial part).

vi. Coccydynia (pain in coccyx) is usually caused by direct trauma to the coccyx.

**Bony Pelvis (Figs 78.4 and 78.5)**
The bony pelvis consists of four bones united by four joints and two ligaments. The bones include two hip bones,
sacrum and coccyx. The joints are, right and left sacroiliac joints, pubic symphysis and sacrococcygeal joint. The ligaments are the sacrospinous and sacrotuberous. The pelvis houses the pelvic viscera, blood vessels and nerves. In the female it has an important function of accommodating the growing fetus in the uterus and at the end of gestation it provides a bony canal through which the fetus passes during vaginal delivery.

Joints of Pelvis
1. The sacroiliac joint is the articulation between the sacral and iliac auricular surfaces. It is a plane variety of synovial joint. Its function is to transmit the weight of body from the vertebral column to lower limbs.
   i. The anterior and posterior sacroiliac ligaments and the interosseous sacroiliac ligament fill the irregularities between the articulating bones. These ligaments soften during pregnancy and hence the mobility of joint becomes slightly more. This is the reason for frequency of subluxation of the joint during pregnancy.
   ii. The erector spinae and gluteus maximus muscles cover the dorsal surface of the joint. The psoas major and iliacus muscles cover the ventral or pelvic surface of the joint.
   iii. The nerves related to ventral or pelvic surface are the obturator, femoral nerves and lumbosacral trunk.
   iv. The formation of common iliac vein and bifurcation of common iliac artery occur in front of the joint.
   v. The ureter crosses the front of the joint.
2. The pubic symphysis is the joint between the two pubic bones. It is located anteriorly in the midline. It is a secondary cartilaginous joint. Very slight movements are possible in this joint.
3. The sacrococcygeal joint is a secondary cartilaginous joint between the base of coccyx and apex of sacrum. It is the mobile joint of the bony pelvis.

Subdivisions of Pelvis
The pelvis is divided into a false pelvis (greater pelvis) and a true pelvis (lesser pelvis) by the pelvic brim.

Clinical insight ...

Complications of Pelvic Fractures
Fractures of pelvic bones are common in accidents.

i. A heavy fall on the greater trochanter of femur may dislocate the femoral head upwards into the pelvic cavity through fracture of acetabulum. There may be fracture of sacrum, coccyx, pubic bones and sacral foramina. These fractures are complicated by soft tissue injury.

ii. There may be intraperitoneal or extraperitoneal hemorrhage due to rupture of thin-walled intrapelvic veins.

iii. The rupture of male urethra may occur in fracture of pubic bone.

iv. The urinary bladder is vulnerable as it lies just behind the pubic symphysis.

v. Fracture of sacrum may rupture rectum and injure sacral plexus.
i. The boundaries of the pelvic brim consist of sacral promontory and linea terminalis (arcuate line of ilium, pectineal line of the superior ramus of pubis and pubic crest).
ii. The false pelvis lies above the pelvic brim. It is formed by the iliac fossa and limited above by iliac crest. The cavity of the false pelvis is part of abdominal cavity.
iii. The true pelvis is divided into inlet, cavity and outlet.

**Pelvic Inlet**
The pelvic inlet is the brim of the true pelvis. It is an oblique plane. The bony parts taking part in it on both sides are upper border of symphysis pubis, linea terminalis, sacroiliac joint, ala of sacrum and sacral promontory. The pelvic inlet is heart shaped in male but in female it is transversely oval. The diameters of the inlet are particularly important in female because it is through the inlet that the fetal head enters the true pelvis during labor.

**Structures Crossing Pelvic Brim**
- i. Sympathetic chains
- ii. Lumbosacral trunks
- iii. Obturator nerves
- iv. Ureters
- v. Ovarian vessels and the round ligament of uterus in female
- vi. Vas deferens in the male
- vii. Internal iliac arteries
- viii. Median sacral artery
- ix. Superior rectal artery
- x. Iliolumbar branch of internal iliac artery

**Pelvic Cavity**
The pelvic cavity lies between the inlet and outlet. It is continuous above with abdominal cavity and closed below by pelvic diaphragm. The reproductive, urinary and alimentary tracts in both sexes perforate the pelvic floor. The cavity is curved in such a way that it is directed at first downwards and backwards and then downwards and forwards. Its anterior wall is shorter than its posterior wall. During normal delivery the fetus passes through the pelvic cavity, so the assessment of the size of the cavity before delivery is very important.

**Pelvic Outlet**
The pelvic outlet is diamond-shaped. It is wider in female. Its anterior boundary is the lower margin of symphysis pubis and anterolaterally it is bounded by the conjoint ischiopubic rami, laterally by ischial tuberosities, posterolaterally by sacrotuberous ligaments and posteriorly by the tip of coccyx.

**Sex Differences in Pelvis**
- i. The ischiopubic rami are everted in male but not in female. This difference is due to the attachment of strong crus penis and well-developed ischiocavernosus muscle in male.
- ii. The cavity of acetabulum is larger in males.
- iii. Preauricular sulcus is not distinct in males but prominent in females.
- iv. The body of first sacral vertebra is wider than ala of sacrum in male but in female the body of first sacral vertebra is equal to the ala of sacrum.
- v. The subpubic angle is acute in male (Fig.78.6) and wider in female.
- vi. The pelvic inlet is heart-shaped in male and transversely oval in female.
- vii. The pelvic outlet is smaller in males and much larger in female.
- viii. The pelvic cavity is shorter and more conical in male but wider and roomy in female.
- ix. The diameters of the pelvis are smaller in male compared to the female.

**Diameters of Female Pelvis**
Successful labor and delivery depend on compatibility of pelvic dimensions of the fetal head. In cephalopelvic disproportion (CPD) normal delivery cannot take place.

*Contd...*
Abdomen, Pelvis and Perineum

Section

Types of Female Pelvis

i. Gynecoid pelvis is the one in which pelvic inlet is circular and its transverse diameter is maximum. It is the normal female pelvis.

ii. Android pelvis is the one in which pelvic inlet is heart-shaped like that of male pelvis. This type of pelvis may cause difficulty during childbirth.

iii. Anthropoid pelvis is the one in which anteroposterior diameter of the inlet is more than the transverse diameter. This type will cause difficulty in normal delivery.

iv. Platypelloid pelvis (flat pelvis) is the one in which the transverse diameter is very wide compared to the AP diameter so the pelvis is anteroposteriorly compressed. This is due to deficiency of vitamin D. This is a truly contracted pelvis, which causes difficulty in normal delivery.

Diameters of Pelvic Inlet

i. The AP diameter or true conjugate is the distance from the midpoint of sacral promontory to the inner margin of the upper border of symphysis pubis.

ii. The diagonal conjugate can be measured by digital examination. It is the distance between the lower margin of symphysis pubis and the midpoint of sacral promontory. The diagonal conjugate is usually 12 cm. The anatomical conjugate can be inferred by subtracting 1.2 cm from the diagonal conjugate and obstetrical conjugate can be inferred by subtracting 2 cm from the diagonal conjugate.

iii. The transverse diameter is the distance between the farthest points on the pelvic brim.

iv. The oblique diameters extend from one sacroiliac joint to the opposite iliopubic eminence.

Diameters of Pelvic Cavity

i. The AP diameter is from the middle of the back of symphysis pubis to the central point of the third piece of sacrum. The pelvic cavity is most roomy at this plane.

ii. The midpelvic diameter between the ischial spines is the smallest diameter of the pelvis and is the place, where difficulty is encountered during childbirth.

Diameters of Pelvic Outlet

i. The transverse or intertuberous diameter is the distance between the inner borders of the ischial tuberosities.

ii. The AP diameter extends from the lower border of symphysis pubis to the tip of coccyx. This diameter is the longest at the outlet.
ABDOMEN

Abdomen is the part of the trunk extending from the thoracic diaphragm to the pelvic diaphragm. Its cavity consists of two parts, abdomen proper and lesser pelvis (pelvic cavity or true pelvis). The two cavities are continuous with each other at the pelvic inlet (Fig. 79.1).

Boundaries of Abdomen Proper

i. The diaphragm is the superior boundary of abdominal cavity. The upper abdominal organs, which fill the concavity of the diaphragm, lie internal to the lower part of the thoracic cage, pleura and lungs. Due to the overlapping of the upper abdominal cavity by the lower thorax the penetrating wounds of the lower thorax injure the abdominal viscera.

ii. The anterior wall below the costal margin is musculoaponeurotic.

iii. The posterior wall is constituted by lumbar vertebrae, diaphragmatic crurae, psoas major and quadratus lumborum muscles.

iv. Inferiorly, the abdominal cavity is in continuity with the true pelvis through the pelvic inlet.

ANTERIOR ABDOMINAL WALL (FIG. 79.2)

The anterior abdominal wall is divided into nine regions by transpyloric plane, transtubercular plane and right and left lateral planes.

- The transpyloric plane passes through the midpoint between jugular notch and the symphysis pubis. It corresponds to the lower border of first lumbar vertebra.

- The transtubercular plane passes through the tubercles of iliac crests and corresponds to upper border of fifth lumbar vertebra.

**Chapter Contents**

- **ABDOMEN**
- **ANTERIOR ABDOMINAL WALL**
  - Layers of Anterior Abdominal Wall
  - Rectus Sheath
  - Nerves of Anterior Abdominal Wall
- **Arteries of Anterior Abdominal Wall**
- **UMBILICUS**
- **SURGICAL INCISIONS ON ANTERIOR ABDOMINAL WALL**
- **INGUINAL CANAL**
- **Contents of Inguinal Canal in Male and female**
- **Walls of Inguinal Canal**
- **Inguinal Hernia**
iii. The vertical right and left lateral planes pass through the midinguinal point.

Thus, the anterior abdominal wall is divided into three midline and three left and right regions (Fig. 79.2). From above downward, the midline regions are epigastrium, umbilical and hypogastrium (pubic). From above downward, the lateral regions are hypochondrium, lumbar (lateral) and iliac (inguinal). These regions are of use to the clinician, while describing the site of pain felt by the patient, areas of swelling in the abdomen and for locating the internal organs.

In addition to the above planes, the following reference planes are used.

i. The subcostal plane passes through the lowest part of the costal margin (10th rib). It corresponds to the L3 vertebra.

ii. The supracristal plane passes through the highest point of iliac crest. It corresponds to the spine of L4 vertebra.

Surface Features

i. Umbilicus is a prominent landmark that lies below the midpoint of linea alba (a midline whitish line).

ii. The linea semilunaris extends from the pubic tubercle to the tip of the ninth costal cartilage. It indicates the lateral margin of rectus abdominis muscle.

iii. The tendinous intersections of the rectus abdominis are visible through the skin as three grooves crossing the rectus muscle between the xiphoid process and the umbilicus.

iv. The midinguinal point is the point between the pubic symphysis and the anterior superior iliac spine. It marks the position of femoral pulse, which is felt immediately below it.

Layers of Anterior Abdominal Wall

From superficial to deeper plane the anterior abdominal wall has eight layers as follows.

i. Skin
ii. Superficial fascia
iii. External oblique abdominis
iv. Internal oblique abdominis
v. Transversus abdominis
vi. Fascia transversalis
vii. Extraperitoneal tissue
viii. Parietal peritoneum.

There is continuity between the layers of abdominal wall, coverings of the spermatic cord and coverings of testis inside the scrotum (Fig. 79.3).

Skin

i. The skin is marked by the umbilicus, which indicates the site of attachment of the umbilical cord to the anterior abdominal wall of fetus. In a healthy lean and young adult, the umbilicus is located at the level of lower border of third lumbar vertebra, but its position tends to change with deposition of fat in the anterior abdominal wall. The midline pigmentation and striae gravidarum in the lower part are the signs of previous pregnancy in female.

ii. The superficial fascia in the infraumbilical abdominal wall is composed of the superficial fatty layer or Camper’s fascia and the deep membranous layer or Scarpa’s fascia. The fatty layer is continuous below with the superficial fascia of the perineum and thighs. The membranous layer passes in front of the inguinal ligament in to the thigh to become continuous with the membranous layer of superficial fascia of the upper part of thigh. In the midline, it passes in front of the pubis and is continuous with the membranous layer of superficial fascia in the perineum. Thus, the potential space between the membranous layer and the external oblique aponeurosis is continuous with the superficial perineal pouch. In case of rupture of male urethra, the extravasated urine enters this potential space but cannot enter the thigh because of the fusion of the membranous layer of superficial fascia of the upper thigh with the fascia lata along Holden’s line (Fig. 93.2).

iii. The cutaneous nerves and the dermatomes of the anterior abdominal wall are clinically important. The lower five intercostal (T7 to T11), subcostal (T12) and the iliohypogastric (L1) nerves supply the skin segmentally (Figs 79.4 and 55.6). There are seven consecutive dermatomes from T7 to L1 on the anterior abdominal wall. T7 dermatome is located over...
the xiphoid process T10 dermatome overlies the band of skin at the level of the umbilicus and LI lies on the pubic symphysis and inguinal ligament. The pain of appendicitis is referred to T10 dermatome (around the umbilicus) and the pain of renal colic is referred from T10 to L1 dermatomes.

iv. The arteries accompanying the lateral cutaneous branches of intercostal nerves arise from the posterior intercostal arteries of corresponding spaces. The arteries, which accompany the anterior cutaneous nerves, arise from the superior and inferior epigastric arteries (Fig. 79.4). The infraumbilical skin and superficial fascia are supplied by three branches of femoral artery namely, superficial epigastric, superficial circumflex iliac and superficial external pudendal.

v. The venous drainage of supraumbilical part of the anterior abdominal wall is as follows (Fig. 79.5A). The superficial veins (closer to the midline) drain into superior epigastric veins. On the lateral sides, the venous network drains into axillary vein via the lateral thoracic vein. The thoracoepigastric vein is a connecting link between lateral thoracic vein and the superficial epigastric venous network. Thus, the veins of the supraumbilical abdominal wall drain into superior vena cava.

vi. The venous drainage of infraumbilical part of the anterior abdominal wall is as follows. The superficial veins (closer to the midline) drain into inferior epigastric vein. On the lateral side the venous network drains via the superficial epigastric, superficial circumflex iliac and superficial external pudendal veins into the great saphenous vein. Thus, the veins of the infraumbilical abdominal wall drain finally into inferior vena cava.

**Clinical insight ...**

**Vena Caval Obstruction**

If there is obstruction of either the superior vena cava or the inferior vena cava, the thoracoepigastric veins, along the anterolateral abdominal wall, enlarge and become tortuous.

*Contd...*
Anterolateral Muscles of Anterior Abdominal Wall

The anterolateral muscles are disposed as three flat muscles (external oblique abdominis, internal oblique abdominis and transversus abdominis). They are fleshy laterally and aponeurotic medially. The aponeurotic parts of all the three muscles take part in the formation of rectus sheath.

External Oblique Abdominis (Fig. 79.6)

This muscle takes origin from the outer surfaces of the fifth to twelfth ribs by fleshy slips. It has a wide insertion. The fleshy fibers from the eleventh and twelfth ribs form a free posterior border. They are inserted into the anterior two-thirds of the outer lip of the iliac crest. The fleshy fibers from the fifth to tenth ribs end in a wide aponeurosis. The upper margin of this aponeurosis is attached to xiphoid process. Succeeding part of the aponeurosis is attached to linea alba and its lower part has bony attachment to the pubic crest and pubic tubercle. The aponeurosis has an inrolled free margin called the inguinal ligament between the anterior superior iliac spine and the pubic tubercle.

Nerve Supply

The lower five intercostal nerves and the subcostal nerve supply the external oblique muscle.

Modifications of External Oblique Aponeurosis

1. The inguinal ligament (Fig. 79.7) is located at the junction between the anterior abdominal wall and the front of the thigh. It is attached medially to the pubic tubercle and laterally to anterior superior iliac spine. Its length in the adult is about 12 to 14 cm. The fascia lata is attached to its lower surface. It exerts a downward pull on the ligament because of which the lower surface of the ligament is convex.
   i. The internal oblique originates from lateral two-thirds of the inguinal ligament and the transversus from the lateral one-third.
   ii. The structures that enter the thigh behind the inguinal ligament are the femoral nerve, lateral
2. The lacunar ligament or the pectineal part of inguinal ligament is the extension of inguinal ligament from its medial end. It is triangular and has an apex and a base. The apex is at the pubic tubercle. The base or free margin is directed laterally and forms the medial margin of femoral ring. Anteriorly the lacunar ligament is continuous with the inguinal ligament and posteriorly it is attached to the medial part of pecten pubis. Its upper surface forms part of the floor of the inguinal canal. Its concave free margin bounds the femoral ring medially. Hence, it is of importance to the surgeon, who operates on strangulated femoral hernia. The surgeon cuts the free margin of the ligament to increase the size of the femoral ring to facilitate reduction of the strangulated hernia (for surgical importance refer chapter 93). The pectineal ligament of Astley-Cooper extends from the lacunar ligament along the pecten pubis.

3. The reflected part of the inguinal ligament (reflex inguinal ligament) is an extension from the lateral crus of superficial ring upwards and medially behind the external oblique but in front of the conjoint tendon. The right and left ligaments decussate in the linea alba.

Superficial Inguinal Ring
This is an opening in the aponeurosis of the external oblique muscle just above the pubic crest. It is triangular in shape. It has two margins called the crura. The lateral crus is stronger and formed by fibers of inguinal ligament attached to pubic tubercle. The medial crus is attached to the front of pubic symphysis. The intercruclal fibers arch above the apex of the ring and help in holding the crura together (intercrural fibers are derived from the fascial covering of the external oblique muscle and are at right angles to the fibers in the aponeurosis of the muscle). The aponeurosis of external oblique prolongs around the spermatic cord from the margins of the superficial ring as the external spermatic fascia (structures passing through the superficial ring are described with inguinal canal).

Internal Oblique Muscle (Fig. 79.8)
This muscle takes origin from the lateral two-thirds of the upper surface of inguinal ligament, anterior two-thirds of the iliac crest and the thoracolumbar fascia. It has wide insertion as follows.

i. The fibers taking origin from the thoracolumbar fascia and the posterior part of iliac crest have fleshy insertion...
Section Abdomen, Pelvis and Perineum

in the lower borders of the tenth, eleventh and twelfth ribs.

ii. The fibers arising from the rest of the iliac crest and the lateral part of inguinal ligament end in a wide aponeurosis, which is attached to the costal cartilages of the seventh, eighth and ninth ribs at the costal margin and the entire length of linea alba. The aponeurosis splits in two laminae at the lateral margin of rectus muscle. The anterior lamina fuses with the aponeurosis of external oblique and the posterior lamina fuses with the aponeurosis of transversus muscle. The fused laminae enclose the rectus muscle and insert into the linea alba. Below the level of anterior superior iliac spine, the aponeurosis of internal oblique does not split but passes in front of the rectus along with the other two muscles.

iii. The fibers taking origin from middle third of inguinal ligament arch over the inguinal canal and become tendinous in the posterior wall of the canal, where they fuse with tendinous fibers of transversus muscle to form the conjoint tendon or falx inguinalis. Thus, through the conjoint tendon the internal oblique is attached to the pubic crest and pecten pubis.

Nerve Supply
The lower five intercostal, subcostal and both ilioinguinal and iliohypogastric nerves supply the internal oblique muscle.

Cremaster Muscle and Fascia
The internal oblique contributes a thin musculofascial covering to the spermatic cord as it passes under the arched fibers of the muscle in the inguinal canal. This covering is known as cremaster muscle and fascia. The cremaster is attached to the middle-third of the upper surface of inguinal ligament, the pubic tubercle and crest and the conjoint tendon. The muscle fibers form a series of loops around the cord. The contraction of the muscle pulls the testis up towards the superficial ring, which may help in plugging the ring. Its other possible role is in the control of the temperature of the testis. The genital branch of genitofemoral nerve (L1, L2) supplies the cremaster muscle (the cremaster muscle in female consists of a few nonfunctional muscle fibers around the round ligament of uterus).

Cremasteric Reflex
On stroking the skin of the medial side of the upper thigh, there is elevation of the testis and scrotum on the stimulated side. The afferent limb of the reflex is the ilioinguinal nerve, the reflex center is in the L1 and L2 segments of the spinal cord and the efferent limb is the genitofemoral nerve.

Transversus Abdominis (Fig. 79.9)

i. The transversus abdominis muscle takes origin from the inner aspect of lower six costal cartilages near the costal margin, thoracolumbar fascia, anterior two-thirds of the iliac crest and the lateral one-third of the upper surface of inguinal ligament.

ii. It is inserted into the linea alba. The inguinal fibers arch over the inguinal canal and then end in the aponeurosis, which fuses with that of internal oblique to form conjoint tendon through which it is attached to pecten pubis and pubic crest.

Nerve Supply
The lower five intercostal, subcostal and both ilioinguinal and iliohypogastric nerves supply the muscle.

Actions of Flat Muscles of Abdomen
i. The abdominal muscles give support to the abdominal viscera.

ii. Contraction of muscles increases the intra-abdominal pressure, which pushes up the diaphragm during forced expiration. The increased intra-abdominal pressure helps in expulsive processes like vomiting, defecation, micturition and parturition.

iii. The muscles cause flexion of vertebral column.

iv. The rotation of trunk to right is brought about by left external oblique acting with right internal oblique and to the left by right external oblique acting with left internal oblique.

Fig. 79.9: Attachments of transversus abdominis
Conjoint Tendon or Falx Inguinalis
The lower arched fibers of the internal oblique and transversus muscles end in the aponeurosis behind the medial end of the inguinal ligament. The fusion of the two aponeuroses forms the conjoint tendon, which is attached to the pubic crest and pecten pubis. The conjoint tendon forms the medial half of the posterior wall of the inguinal canal. It strengthens this wall opposite the deficiency (superficial ring) in the anterior wall. Medially it blends with the anterior wall of rectus sheath. Laterally it may extend occasionally as interfoveolar ligament (which is medial to deep ring as it passes to be attached to the inguinal ligament and superior ramus of pubis). The conjoint tendon may weaken in old age due to decreased tone of the muscles of the anterior abdominal wall. It weakens in injury to iliohypogastric and ilioinguinal nerves. The weakened conjoint tendon predisposes to direct inguinal hernia.

Rectus Sheath (Figs 79.10A to C)
The rectus sheath is an aponeurotic covering for the rectus abdominis and pyramidalis muscles on either side of the linea alba. Its aponeurotic anterior wall covers the muscles from end to end while the aponeurotic posterior wall is deficient at the upper and lower ends. The anterior wall fuses with the rectus muscle at intervals but the posterior wall is free. The rectus sheath extends laterally up to the linea semilunaris. The formation of rectus sheath differs at three levels as follows.

**Above the Level of Costal Margin**
i. Anterior wall is formed by the aponeurosis of the external oblique muscle only.
ii. Posterior wall is deficient hence the rectus muscle rests directly on the fifth, sixth and seventh costal cartilages.

**From the Costal Margin to Midway between Umbilicus and Pubic Symphysis**
i. Anterior wall is formed by fusion of aponeurosis of external oblique with the anterior lamina of the aponeurosis of internal oblique.
ii. Posterior wall is formed by fusion of posterior lamina of internal oblique aponeurosis with the aponeurosis of transversus abdominis. The lower margin of the aponeurotic posterior wall is called arcuate line or linea semilunaris of Douglas. It lies at the level of anterior superior iliac spine. The inferior epigastric artery enters the rectus sheath at the arcuate line.

**Below the Level of the Point Midway between Umbilicus and Pubic Symphysis**
i. Anterior wall is formed by fusion of the aponeuroses of the three muscles.
ii. Posterior wall is deficient hence the rectus muscle rests directly on fascia transversalis.

Figs 79.10A to C: Formation of rectus sheath at three levels. (A) Above the level of costal margin; (B) Between costal margin and a point midway between umbilicus and symphysis pubis; (C) Below the point midway between umbilicus and symphysis pubis
Abdomen, Pelvis and Perineum

Section

Contents of Rectus Sheath

The rectus sheath contains muscles (rectus abdominis and pyramidalis), vessels (superior and inferior epigastric) and nerves (lower five intercostal nerves and subcostal nerve).

Rectus Abdominis

This muscle derives its name from its straight vertical course. The right and left muscles are separated by the linea alba (Fig. 79.11).

i. The rectus abdominis arises by two tendinous heads, the medial from the anterior surface of symphysis pubis and the lateral from the pubic crest.

ii. It has fleshy insertion in to the xiphoid process and the fifth, sixth and seventh costal cartilages.

iii. This muscle is characterized by three tendinous intersections, which are located at the tip of the xiphoid process, at the umbilicus and midway between the previous two. Each intersection is attached to the anterior wall of the rectus sheath but not to the posterior wall. The intersections divide the long muscle into shorter segments for better action.

Nerve Supply

The lower five intercostal nerves and the subcostal nerve supply the rectus muscle.

Actions

The rectus abdominis is the flexor of the vertebral column. It supports the abdominal viscera.

Testing Muscle Function

For testing the function of the rectus abdominis the subject is asked to raise the head and shoulder from the bed against resistance. The contraction of the normal muscle can be seen and felt.

Pyramidalis

This is a small muscle situated in front of the lower part of the rectus muscle. It takes origin from the anterior surface of the body of pubis by a rounded tendon and is inserted in to the linea alba. The subcostal nerve supplies it. It is supposed to be the tensor of the linea alba.

Linea Alba

It is a tendinous raphe extending from the xiphoid process to the pubic symphysis. It is formed by the decussation of the fibers in the aponeurosis of the flat muscles of the two sides. Therefore, linea alba can be regarded as a common insertion of the right and left oblique and transversus muscles. The pyramidalis muscles are inserted in its lower part. The umbilicus is located just below its midpoint. Its infraumbilical part is narrower compared to the supraumbilical part, where due to divergence of recti the linea alba is relatively broader.
Fascia Transversalis

It is a thin layer of connective tissue lying between the transversus muscle and extraperitoneal connective tissue. It is continuous with the diaphragmatic fascia above. Posteriorly it is continuous with anterior layer of the renal fascia. Inferiorly its attachments are as follows. It is attached to the whole length of iliac crest between the origins of transversus and iliacus muscles. Between the anterior superior iliac spine and femoral vessels it is attached to the pecten pubis and conjoint tendon. The deep inguinal ring is the deficiency in the fascia transversalis and the internal spermatic fascia. The deep inguinal ring is the defect in the fascia transversalis and the internal spermatic fascia. Along this attachment it fuses with iliac fascia. In the region of the femoral vessels the transversalis fascia passes over the vessels for a distance of 3 to 4 cm and forms the anterior wall of the femoral sheath. Medially to femoral vessels it is attached to the pecten pubis and conjoint tendon. The deep inguinal ring is the deficiency in the fascia transversalis and the internal spermatic fascia is a prolongation of the transversalis fascia on the spermatic cord at the deep ring.

Nerves of Anterior Abdominal Wall

1. The thoracoabdominal nerves are the lower five intercostal nerves (T7 to T11). These nerves are distributed to both the thoracic and abdominal walls. In their thoracic course, the nerves travel in the neurovascular plane of the thoracic wall (between the internal intercostal and intercostalis intimus muscles) to reach the anterior ends of the respective intercostal spaces. They supply the motor branches to the intercostal muscles and sensory branches to the parietal pleura and perios teum of the ribs of their respective spaces. The seventh and eighth intercostal nerves enter the abdominal wall between the digitations of transversus abdominis and then curve superomedially across the deep costal surface to reach the deep aspect of posterior lamina of the internal oblique aponeurosis. Thus, these two nerves immediately enter the rectus sheath by piercing its posterior wall. The ninth to eleventh intercostal nerves enter the abdominal wall by passing through the gap between digitations of diaphragm and transversus abdominis muscle. These nerves travel in the neurovascular plane of the anterior abdominal wall between internal oblique and transversus muscles and pierce the lateral margin of the rectus sheath. The collateral branches of all the thoracoabdominal nerves supply the three flat muscles of the anterior abdominal wall. Inside the rectus sheath, the main nerves supply the rectus abdominis. The cutaneous branches of the main nerves pierce the rectus abdominis and the anterior wall of the rectus sheath. Inwardly directed branches of the intercostal nerves are sensory to the parietal peritoneum.

2. The subcostal nerve is the ventral ramus of the twelfth thoracic nerve. In its thoracic course, it passes along the inferior border of the twelfth rib accompanied by subcostal artery (a branch of descending thoracic aorta) and accompanying vein. It leaves the thorax by passing behind the lateral arcuate ligament to enter the lumbar region of abdomen, where it lies between the posterior surface of the kidney and the anterior surface of quadratus lumborum muscle. In the lumbar region, it supplies the serratus posterior inferior muscle and the quadratus lumborum muscle. It perforates the aponeurotic origin of transversus muscle at the lateral margin of the thoracolumbar fascia to gain entry into the neurovascular plane of anterior abdominal wall. Finally, it enters the rectus sheath. The subcostal nerve supplies the three flat muscles of the anterior abdominal wall. Inside the rectus sheath, it supplies the rectus abdominis and the pyramidalis muscles. Its lateral cutaneous branch crosses the iliac crest to distribute branches to the skin of the upper lateral part of the parietal peritoneum (including part of thigh over the greater trochanter). Its anterior cutaneous branches supply the infraumbilical skin of anterior abdominal wall.

3. The iliohypogastric and ilioinguinal nerves are the branches of the lumbar plexus, the root value of each being L1. The iliohypogastric nerve is located higher and it is larger in size compared to the ilioinguinal nerve.

i. The iliohypogastric nerve comes out from the lateral margin of the psoas major muscle and runs laterally in the lumbar region lying in front of the anterior layer of lumbar fascia and behind the kidney. Then it enters the neurovascular plane of anterior abdominal wall by piercing the aponeurotic origin of transversus abdominis muscle. After giving its lateral cutaneous branch a little behind the iliac tubercle, it pierces the internal oblique muscle to course downwards and medially between the external oblique aponeurosis and internal oblique. Just above the superficial inguinal ring, it pierces the aponeurosis of external oblique and terminates as anterior cutaneous branch, which supplies the skin above the pubis. Its lateral cutaneous branch supplies the skin of the gluteal region. The motor branches supply the internal oblique and transversus muscles.
ii. The ilioinguinal nerve is smaller and lies at a little lower level compared to the iliofemoral nerve. It pierces the transversus abdominis near the anterior end of the iliac crest and runs downward and medially to pierce the arched fibers of the internal oblique and enter the inguinal canal. It accompanies the spermatic cord (or the round ligament of uterus) and comes out through the superficial ring. The ilioinguinal nerve gives motor branches to the internal oblique and transversus muscles. It has no lateral cutaneous branch. It supplies the skin of the upper part of the medial surface of the thigh and the skin covering the root of penis and upper part of scrotum in the male or that covering the mons pubis and adjacent labium majus in the female. Like the thoracoabdominal and subcostal nerves the iliohypogastric and ilioinguinal nerves give sensory branches to the parietal peritoneum.

iii. The tenth and eleventh posterior intercostal arteries and the subcostal artery enter along with the corresponding nerves into the neurovascular plane of the abdominal wall. The subcostal artery accompanies the subcostal nerve.

iv. The inferior epigastric artery is a branch of the external iliac artery. Its surface marking corresponds to a line joining the midinguinal point to a point about one fingerbreadth from the midline at the level of anterior superior iliac spine. The inferior epigastric artery lies medial to the deep inguinal ring and ascends in the extraperitoneal tissue towards the rectus sheath. When it reaches the lateral margin of rectus sheath, it pierces the transversalis fascia to enter inside the sheath by crossing the arcuate line. It supplies muscular and cutaneous branches. The inferior epigastric artery gives two named branches outside the rectus sheath, the cremasteric and the pubic. The cremasteric branch enters the spermatic cord and the pubic branch passes medially in close relation to the lacunar ligament to anastomose with the pubic branch of the obturator artery. When the pubic branch of inferior epigastric artery is large, it is called abnormal obturator artery. This artery is often called the “artery of death” by surgeons since it may be injured while cutting the lacunar ligament (during the operation for strangulated femoral hernia) resulting in life-threatening hemorrhage.

v. The deep circumflex iliac artery is a branch of the external iliac artery. It courses laterally along the inguinal ligament towards the anterior superior iliac spine. Here it gives a large ascending branch, which travels in the neurovascular plane. The main trunk runs backwards along the inner lip of the iliac crest. At the midpoint of the iliac crest, it pierces the transversus muscle to enter the neurovascular plane and terminates by anastomosing with the iliolumbar and superior gluteal arteries. The lumbar arteries (the dorsal branches of abdominal aorta) enter the abdominal wall from the side.

Arteries of Anterior Abdominal Wall

i. The superior epigastric artery (the medial terminal branch of the internal mammary artery) enters the rectus sheath by passing through the gap between the sternal and costal origins of the diaphragm. The artery lies deep to the rectus abdominis muscle resting on the posterior wall of the sheath and ends by anastomosing with the inferior epigastric artery at the level of umbilicus.

ii. The musculophrenic artery (lateral terminal branch of internal mammary artery) pierces the diaphragm between the costal slips of origin to enter the anterior abdominal wall.

iii. The tenth and eleventh posterior intercostal arteries and the subcostal artery enter along with the corresponding nerves into the neurovascular plane of the abdominal wall. The subcostal artery accompanies the subcostal nerve.

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Clinical insight ...

Muscle Guarding

The segmental nerves of the anterior abdominal wall supply the skin, the muscles and the parietal peritoneum lining the anterior abdominal wall. The inflammation of parietal peritoneum causes severe pain in the skin. Local reflexes involving the same nerves bring about protective increase in the tone of the muscles of the anterior abdominal wall. The increased tone and reflex rigidity are referred to as muscle guarding. It is important to understand that inflammation of parietal pleura (pleurisy) may give rise to above mentioned symptoms and signs in the anterior abdominal wall on account of the same nerve supply.

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UMBILICUS

The umbilicus lies in the linea alba in a skin depression which, has a puckered appearance. It denotes the site of attachment of umbilical cord to the ventral body wall of the fetus.

i. T10 dermatome overlies the band of skin surrounding the umbilicus. This is the reason why visceral pain of appendicitis is referred to the umbilicus.

ii. The umbilicus is the lymphatic watershed because the abdominal wall above it drains into the anterior axillary nodes and below it into the superficial inguinal nodes.

iii. Caput medusae is a characteristic clinical sign of portal hypertension, in which dilated and tortuous superficial veins radiate from the umbilicus.
iv. For clinical testing of the muscles of the abdominal wall, the movement of the umbilicus is watched as follows. Ask the supine patient to lift the head and shoulder from the bed against light resistance. If the abdominal muscles contract normally, the umbilicus is stationary.

**Clinical insight ...**

i. If the abdominal muscles in the infraumbilical part are paralyzed, the umbilicus will move straight upwards by active contraction of the supraumbilical part of the muscles. This is called Beevor’s sign and is positive in lesion of the spinal cord at T10 level.

ii. Umbilical hernia may be congenital or acquired. The acquired hernia occurs due to weakness of the anterior abdominal wall as for example, in long standing ascites.

**Embryologic insight ...**

**Embryological Importance of Umbilicus**

During the fifth to tenth weeks of intrauterine life, the midgut herniates into the umbilical cord. This physiological umbilical hernia returns to the abdominal cavity during tenth to twelfth weeks. Two endodermal tubes (allantois and vitellointestinal duct) project into the umbilical cord. The allantois is a diverticulum from endodermal cloaca and vitellointestinal duct is a diverticulum from the midgut. There are three blood vessels in the umbilical cord (two umbilical arteries and one umbilical vein). After birth when the cord is severed these structures are cut at the root of umbilical cord. The fate of the intra-abdominal parts of the contents of the umbilical cord after birth is as follows. The allantois becomes the urachus, which changes to median umbilical ligament. The vitellointestinal duct completely obliterates. The left umbilical vein becomes the round ligament of liver. The right and left umbilical arteries become the fibrous medial umbilical ligaments and the superior vesical arteries.

**Congenital Anomalies**

i. Complete patency of vitellointestinal duct results in fecal fistula at the umbilicus.

ii. Patent urachus (Fig. 79.12) results in urinary fistula at the umbilicus.

iii. Exomphalos or omphalocele (Fig. 79.13) is due to failure of the midgut hernia to return to the abdominal cavity during tenth to twelfth weeks of intrauterine life (due to defective lateral folding of the embryo and the resultant defect in anterior abdominal wall near the umbilicus. The umbilical swelling containing loops of intestine is transparent as it is covered with amnion and the umbilical cord is attached to the swelling at one end.

iv. The congenital umbilical hernia is due to weakness or deficiency of umbilicus, through which intestines protrude. Such a swelling is covered with peritoneum.

**Surgical Incisions on Anterior Abdominal Wall**

Surgeries on the abdominal and pelvic organs are very common. The principles observed while placing the surgical incision on the anterior abdominal wall to open the abdominal cavity, are to protect nerves and blood vessels of the wall and to cut the muscles in the direction of their fibers in order to promote healing with minimum scar tissue formation. Different types of incisions are used as given in Figure 79.14.
Abdomen, Pelvis and Perineum

Fig. 79.14: Locations of surgical incisions on anterior abdominal wall

Contd...

Midline Incisions

Since the incision is placed on the linea alba, it provides a bloodless exposure (linea alba being avascular). The incision includes skin, superficial fascia, linea alba, transversalis fascia and parietal peritoneum (no muscle is cut). The disadvantage of midline incision is that healing is delayed hence there is more scar tissue.

Incidences Related to Rectus Sheath

i. Paramedian incision is placed 2.5 cm lateral and parallel to the midline. At first the skin, superficial fascia and anterior wall of rectus sheath are incised. Then the tendinous intersections are divided to free the rectus muscle from the anterior wall and the muscle is retracted laterally to preserve the nerves entering the muscle from the lateral side. The posterior wall of the rectus sheath is incised followed by transversalis fascia and parietal peritoneum. This is the most preferred incision.

ii. Pararectal incision is placed over the lateral part of rectus sheath just internal to the linea semilunaris. The skin, fascia and anterior wall of rectus sheath are cut along the line of incision. The rectus muscle is retracted medially to expose the posterior wall. The nerves entering the posterior wall are also retracted before incising the posterior wall.

iii. Transrectal muscle splitting incision is placed 3 to 4 cm lateral and parallel to the midline. The skin, superficial fascia and the anterior wall of rectus sheath are cut and then the rectus muscle is cut vertically and finally the posterior wall of the sheath. In this incision the rectus is not freed from the anterior wall of its sheath. The only disadvantage is that the medial part of the muscle loses its nerve supply.

Contd...

Gridiron Muscle Splitting Incision

This incision is usually used for conventional appendicectomy. An oblique incision is placed at the McBurney’s point right angles to the right spinoumbilical line. The skin, superficial fascia and the external oblique aponeurosis are incised along the line of incision. The fleshy fibers of the internal oblique and of transversus are split along their directions. The muscles are retracted to expose the fascia transversalis and the parietal peritoneum. If the iliohypogastric nerve is damaged in this location the conjoint tendon will be weakened. Unless carefully identified there is likelihood of injuring the ascending branch of the deep circumflex iliac artery, which travels vertically upwards from the anterior superior iliac spine.

Transverse Incisions

The transverse incisions heal quickly and have better cosmetic value since the incisions lie along the Langer’s lines (cleavage lines) of the abdominal skin. These lines represent the direction of collagen bundles in the dermis of the skin.

i. In transverse incisions in the upper abdomen, the skin and superficial fascia are cut in the line of incision. Both the recti including their sheaths are divided transversely in the intersegmental plane (between the points of entry of the nerves). Laterally beyond the sheath, three flat muscles are incised. The drawback of the transverse incision is that the blood vessels are cut, which may lead to excessive bleeding.

ii. The transverse incision in the lower abdomen (Pfannenstiel’s incision) is commonly used for surgeries on female reproductive organs. The incision is placed just above the symphysis pubis. It cuts through the skin, two layers of superficial fascia and the anterior wall of the rectus sheath. The recti and pyramidalis muscles of two sides are separated to expose the transversalis fascia and the parietal peritoneum (the posterior wall of the rectus sheath is deficient here), which are incised for intraperitoneal approach to the uterus or ovary. For extraperitoneal approach to the urinary bladder, the transversalis fascia and parietal peritoneum are pushed upwards.

Paracentesis of Abdomen (Fig. 79.15)

The paracentesis means withdrawing excessive fluid from the serous cavities. Accumulation of fluid in the peritoneal cavity is called ascites. Either the infraumbilical midline approach or the lateral approach is used.

Laparoscopy

Nowadays in place of the conventional open surgery, minimum access surgery using laparoscope is gaining popularity. In this technique, an endoscope is introduced through a small keyhole port in the anterior abdominal wall, in to the peritoneal cavity (which is already inflated by CO₂).
**Chapter 79**

**Anterior Abdominal Wall and Inguinal Canal**

**INGUINAL CANAL**

The inguinal canal is about 4 cm long oblique intermuscular passage in the lower part of the anterior abdominal wall. It is located just above the medial half of the inguinal ligament.

**Extent**

It begins at the deep inguinal ring in the fascia transversalis and courses in the anterior, inferior and medial direction to end at the superficial inguinal ring in the external oblique aponeurosis. Thus, its lateral end is the deep ring and its medial end is the superficial ring.

**Surface Marking (Fig. 79.16)**

The inguinal canal is marked by drawing two parallel lines (which are 1 cm apart and 4 cm long) just above the medial half of inguinal ligament. The deep ring is drawn at the lateral end of these lines one cm above the midinguinal point. The superficial ring is drawn at the medial end of the parallel lines just above the pubic tubercle.

**Contents of Inguinal Canal in Male**

The spermatic cord and the ilioinguinal nerve are the main contents. The spermatic cord consists of vas deferens, testicular artery, pampiniform plexus of veins, artery to ductus deferens, cremasteric artery, fibrous remnant of processus vaginalis, lymphatics, genital branch of genitofemoral nerve and autonomic nerve plexuses. The three coverings of the cord from inside out are internal spermatic fascia, cremasteric muscle and fascia transversalis fascia.

**Fig. 79.15:** Point A (at linea alba) and point B (at linea semilunaris) for withdrawing fluid in peritoneal cavity

**Fig. 79.16:** Surface marking of inguinal canal (Note the relation of deep inguinal ring to the inferior epigastric artery)

**Development of Inguinal Canal**

The inguinal canal is created in intrauterine life during the descent of the gonads (Fig. 88.5). The gonads develop in the lumbar region of the dorsal body wall of the embryo. The gonads are pulled down in to the scrotal region via the passage in the lower abdominal wall in the male. The gonads are pulled down into the pelvic cavity in the female.

**Mechanism of Descent of Gonads**

i. The gubernaculum testis or ovari is a fibrous strand that extends from the lower pole of the gonad to the labioscroatal swelling (future site of scrotum or labium majus) during fourth month. It pulls the gonad downwards.

ii. The processus vaginalis is a peritoneal pouch that follows the course of the gubernaculum.

iii. Thus the inguinal canal is created inside the abdominal wall by the passage of the gubernaculum and the processus vaginalis.

iv. During this passage the layers of the abdominal are dragged along in the canal. After the testis reaches the scrotum the gubernaculum is reduced in size and the inguinal canal is occupied by the spermatic cord.

v. The caudal part of the processus vaginalis forms the tunica vaginalis testis (a serous covering of the testis) and the part between the tunica vaginalis and the general peritoneal cavity is reduced to a fibrous remnant.

vi. In the female, the ovary is retained in the pelvic cavity. Therefore, the gubernaculum ovari remains long and becomes the ligament of ovary (between the ovary and the uterus) and the round ligament of uterus (between the uterus and labium majus). Thus, it is the round ligament of uterus, which comes to occupy the inguinal canal in female and the entire processus vaginalis is reduced to a fibrous remnant.
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(derived from internal oblique muscle and external spermatic fascia (derived from external oblique aponeurosis).

The iliioinguinal nerve (L1) enters the inguinal canal by piercing its roof.

Contents of Inguinal Canal in Female

The round ligament of uterus accompanied by an artery to round ligament (a branch of the inferior epigastric artery), iliioinguinal nerve, genital branch of genitofemoral nerve and the fibrous remnant of processus vaginalis are the contents in the female.

Walls of Inguinal Canal

i. The floor of the inguinal canal is formed by the grooved upper surface of the medial half of the inguinal ligament. The abdominal surface of lacunar ligament contributes to the floor at its medial end.

ii. Anterior wall (Figs 79.17A and B) consists of, from superficial to deep, the skin and superficial fascia, external oblique aponeurosis in the entire extent and the inguinal fibers of internal oblique muscle in the lateral third. The superficial inguinal ring is the deficiency in the anterior wall.

iii. The roof consists of the arched fibers of internal oblique muscle. Above the internal oblique the inguinal fibers of transversus abdominis also arch over the roof of the canal. The iliioinguinal nerve enters the canal by piercing the arched fibers of the internal oblique muscle.

iv. The posterior wall (Figs 79.18A and B) consists of the transversalis fascia in the entire extent. The conjoint tendon (formed by fusion of aponeuroses of internal oblique and transversus muscles) is present in the medial half of posterior wall (in front of the fascial wall). The reflected part of inguinal ligament forms the medial most part of the posterior wall (in front of the conjoint tendon).

The deep inguinal ring is a deficiency in the posterior wall (transversalis fascia). Hesselbach's triangle (inguinal triangle) is an area of surgical importance on the posterior wall. It is bounded laterally by inferior epigastric artery, medially by lateral margin of rectus abdominis and inferiorly by medial part of inguinal ligament. The triangle is divided into lateral and medial parts by the ligamentous remnant of obliterated umbilical artery. The hernia protruding through its medial part is called the medial direct hernia and the one protruding through its lateral part is called the lateral direct hernia.

Deep (internal) Inguinal Ring

The deep ring is a circular opening in the fascia transversalis. It is located 1.25 cm above the midinguinal point. The internal spermatic fascia is the extension of the fascia transversalis from the margins of the deep ring. The inferior epigastric artery is its medial relation. The oblique or indirect inguinal hernia enters the canal through the deep ring.

i. In the male, the ductus deferens, testicular artery, artery to cremaster, artery to vas deferens, testicular veins, genital branch of genitofemoral nerve, autonomic plexuses and lymphatics pass through the deep ring.

ii. In the female the round ligament of uterus and genital branch of genitofemoral nerve pass through the deep ring.

Superficial (external) Inguinal Ring

This is a triangular opening in aponeurosis of external oblique muscle. The aponeurosis of external oblique prolongs from the margins of the ring as external spermatic fascia in male.

i. The superficial ring lies just above the pubic crest and the pubic tubercle.

ii. The pubic crest forms the base of the ring.

iii. The margins of the ring are called lateral and medial crura, which are held together by intercrural fibers.

iv. The stronger lateral crus formed by fibers of inguinal ligament is attached to the pubic tubercle. The weaker
Anterior Abdominal Wall and Inguinal Canal

medial crus is attached to the front of the pubic symphysis.

v. The lateral crus is curved in male because it supports the heavy spermatic cord.

vi. In the male, following structures pass through the superficial ring, ductus deferens, testicular artery, pampiniform plexus, artery to vas deferens, cremasteric artery, genital branch of genitofemoral nerve, ilioinguinal nerve, autonomic nerve plexuses, lymphatics and two fascial layers (cremaster muscle and fascia and internal spermatic fascia).

vii. In the female the structures passing through the small sized ring are the round ligament of uterus, ilioinguinal nerve, genital branch of genitofemoral nerve and a few lymphatics.

Examination of Superficial Ring in Male

It is easy to palpate the ring in a supine patient. The skin of the bottom of the scrotum is invaginated with a finger in superolateral direction until the pubic tubercle is felt. The finger is then rotated and pushed further up to enter the ring, where the crura of the ring can be felt.

Protection of Inguinal Canal

The inguinal canal is the weak part of the abdominal wall because it is constantly subjected to the weight of the abdominal contents in the erect position. So, the abdominal contents tend to herniate through the canal. To counteract this tendency there are some inherent protective devices.

i. Obliquity of the inguinal canal facilitates its closure during rise in intra-abdominal pressure by approximation of its anterior and posterior walls.

ii. The fleshy fibers of the internal oblique muscle in the anterior wall compensate the weakness in the posterior wall (deep ring). The strong conjoint tendon in the posterior wall compensates the weakness in the anterior wall (superficial ring).

iii. The internal oblique muscle surrounds the canal from front, above and behind (triple relation). Hence, its contraction obliterates the canal by bringing the roof in contact with the floor, whenever there is rise in intra-abdominal pressure. This is described as the shutter mechanism of the inguinal canal.

iv. The contraction of cremaster provides an effective plug for the superficial inguinal ring in the male.

v. The intercrural fibers hold the crura of the superficial ring together whenever pressure rises in the abdomen.

Clinical insight ...

**Inguinal Hernia**

A hernia is a protrusion of the peritoneal sac with or without a contained viscus through any weakness in the abdominal wall. The inguinal canal is a common site of herniation since it is a weakness in the anterior abdominal wall. A hernia in the inguinal canal is known as inguinal hernia.

**Types of Inguinal Herniae**

i. Oblique or indirect hernia

ii. Direct hernia

The inguinal hernia usually presents as a swelling in the inguinal region or groin (Figs 79.19A and B). The swelling increases in size on coughing. It is possible to reduce the hernia manually by pushing it upwards or the hernial swelling may disappear automatically in supine position.

Contd...
Ring Occlusion Test
This test is performed to distinguish the indirect from the direct hernia. After reducing the hernia, the deep ring is occluded with thumb and then the patient is asked to cough. If the swelling appears medial to the thumb it is direct hernia. If the swelling does not appear it is an indirect hernia.

Relation of Hernia to Pubic Tubercle
The relation of the hernia to the pubic tubercle Differentiates inguinal from the femoral hernia. The inguinal hernia lies above the pubic tubercle as against the femoral hernia, which lies below and lateral to the pubic tubercle.

Indirect or Oblique Inguinal Hernia
i. It is more common in children and younger age boys as the predisposing congenital factor for this type of hernia is the complete or partial patency of the processus vaginalis.
ii. The hernia enters the inguinal canal via the deep inguinal ring and then passes through the entire inguinal canal to come out through the superficial inguinal ring.
iii. It is inside the coverings of spermatic cord hence enters the scrotum.
iv. The neck of hernial sac is lateral to the inferior epigastric artery.

Direct Inguinal Hernia
i. It is more common in old age. The predisposing factor in old age is weakness of abdominal muscles. There are various factors are responsible for weakening the anterior abdominal wall muscles, rise in intra-abdominal pressure, chronic constipation, chronic cough, lifting heavy weights, etc.).
ii. The hernia enters the inguinal canal through the Hesselbach’s triangle.
iii. The hernia comes out via the superficial inguinal ring.
iv. It lies outside the spermatic cord.
v. The neck of hernial sac is medial to the inferior epigastric artery.

Coverings of Inguinal Herniae
i. The indirect hernia is covered in succession with, parietal peritoneum, extraperitoneal tissue, internal spermatic fascia, cremaster muscle and fascia, external spermatic fascia and skin.
ii. The lateral direct hernia is covered with parietal peritoneum, extraperitoneal tissue, fascia transversalis, cremaster muscle and fascia, external spermatic fascia and skin.
iii. The medial direct hernia is covered with parietal peritoneum, extraperitoneal tissue, fascia transversalis, conjoint tendon, external spermatic fascia and skin.

Repair of direct Inguinal Hernia
For surgical repair of inguinal hernia the skin incision is placed above and parallel to the inguinal ligament. The skin and the subcutaneous tissue are retracted and after incising the external oblique aponeurosis, a local anesthetic is infiltrated into the exposed area to numb the ilioinguinal nerve (Fig. 79.20A). The spermatic cord is dissected and grasped on the hook (Fig. 79.20B). The hernial sac is pushed manually into the abdominal cavity. The prolene mesh (Fig. 79.20C) is inserted behind the spermatic cord and is sutured to the conjoint tendon. The spermatic cord is placed in position and the incision is closed.
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ABDOMINOPELVIC CAVITY

The abdominopelvic cavity is the largest cavity in the body. It is completely filled with viscera. The cavity appears kidney-shaped because of the forward bulging of the lumbar vertebral column and the backward protrusion of the pelvic cavity. The abdominal and pelvic cavities, though continuous, are not in the same plane (Fig. 79.1).

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Peritoneal cavity, which is the largest and most complexly arranged serous sac, is present inside the abdominopelvic cavity. It is a potential space between the parietal and visceral layers of peritoneum. The parietal layer lines the inner surfaces of the abdominal walls and pelvic walls. The visceral layer completely or partially covers the viscera. The visceral and parietal layers are continuous with each other along the lines of reflection of the peritoneum on the abdominal and pelvic walls. Along these lines, the parietal peritoneum leaves as two layered fold, which reaches a particular organ to become continuous with the visceral peritoneum surrounding the same organ. The purpose of such peritoneal folds is to carry blood vessels to the viscera from the major vessels located behind the parietal peritoneum (retroperitoneally) on the posterior abdominal wall.

General Disposition of Viscera

i. The liver is a massive organ occupying the right hypochondrium, extending into the epigastrium and also in the left hypochondrium. It is almost completely covered with peritoneum except for some non-peritoneal areas. The falciform ligament connects the anterior surface of liver to the anterior abdominal wall. The right and left triangular and coronary ligaments connect the liver to the diaphragm. The lesser omentum connects the liver to the lesser curvature of stomach. The major part of gall bladder lies hidden under the inferior surface of the liver. However, its fundus projects below the inferior margin of the liver at the tip of right ninth costal cartilage.

ii. The spleen is located deep in the left hypochondrium posterior to the stomach and anterior to the upper part of left kidney. The gastroplenic ligament connects it to the greater curvature of stomach and the lienorenal ligament to the posterior abdominal wall.

iii. The stomach lies obliquely in the epigastrium and the left hypochondrium. The liver and diaphragm cover the greater part of the stomach. The lesser omentum passes from the lesser curvature of stomach to the liver, carrying in its free margin the portal vein, common bile duct and hepatic artery. The greater omentum
connects the greater curvature of stomach to the posterior abdominal wall. The gastroplenic ligament connects the stomach to the spleen and gastrophrenic ligament to the diaphragm.

iv. The C-shaped duodenum is the first part of the small intestine. It is divided into four parts. Except the proximal 2 cm of the first part the rest of the duodenum is retroperitoneal. The duodenum is located to the right of the midline except the duodenojejunal junction, which lies to the left of midline just below the level of transpyloric plane. Being retroperitoneal, the duodenum lies hidden under the liver, gall bladder and the transverse colon.

v. The pancreas is a retroperitoneal organ disposed horizontally across the posterior abdominal wall posterior to the stomach and transverse colon. Its head lies in the concavity formed by the C-shape of the duodenum while its tail passes through the lienorenal ligament to reach the hilum of the spleen.

vi. The jejunum and ileum are about six meters long coils of small intestine. They are suspended from the posterior abdominal wall by means of the mesentery. The line of attachment of the mesentery extends from the duodenojejunal flexure to the iliocecal junction. The coils of small intestine seem to completely fill the abdominal cavity. They are covered anteriorly by the greater omentum.

vii. The large intestine begins in the right iliac fossa. The vermiform appendix and cecum are located in the right iliac fossa. The appendix is usually retrocecal. The cecum is a mobile blind sac that continues as ascending colon. The ascending colon is retroperitoneal and occupies the right paravertebral gutter in the right lumbar region. The hepatic or right colic flexure is anterior to the lower part of right kidney. The transverse colon lies transversely across the abdominal cavity and is suspended by a fold of peritoneum called transverse mesocolon. The transverse colon and its mesocolon are posterior to the greater omentum and adherent to it. The transverse mesocolon is attached to posterior abdominal wall along a line crossing the second part of duodenum and the head and body of pancreas. The splenic or left colic flexure denotes the junction of transverse colon and descending colon. The descending colon is retroperitoneal and located in the left paravertebral gutter. It ends at the margin of pelvic inlet, where it becomes the pelvic or sigmoid colon. Hence, the descending colon is located in left lumbar and left iliac regions reaching as low as the inguinal ligament. The sigmoid colon is situated in the pelvic cavity and is suspended by pelvic mesocolon, which is attached to the posterior wall of the pelvic cavity by an inverted V-shaped root. The sigmoid colon becomes the rectum at the level of third piece of sacrum.

viii. The rectum is located in the concavity of the sacrum and coccyx in the pelvic cavity. It continues as the anal canal at the anorectal junction, which passes through the muscular pelvic floor to enter the perineum.

ix. The kidneys are retroperitoneal organs lying in the lumbar regions. The ureters are retroperitoneal tubes passing through the abdominal and pelvic cavities. The empty urinary bladder in the adult is a pelvic organ. At the pelvic floor, the bladder neck becomes the urethra.

x. Each suprarenal gland is in contact with respective kidney superomedially.

xi. In the male, the reproductive organs are partly inside the pelvis and partly outside the abdomen. The prostate gland, seminal vesicle, vas deferens and ejaculatory ducts are present in the pelvis below, the lower limit of the peritoneum. In the female, the ovaries, fallopian tubes (uterine tubes), uterus and the upper part of the vagina are located in the pelvis. The ovaries are placed on the lateral pelvic wall covered by the modified coelomic epithelium (called germinal epithelium), which is continuous with the mesovarium. The fallopian tubes are enclosed in the upper free margin of the broad ligament, a large peritoneal fold extending from the side of the uterus to the lateral pelvic wall. The uterus is located in the midline between the rectum behind and the urinary bladder in front.

xii. The retroperitoneal structures on the posterior abdominal wall are the abdominal aorta and its branches, the inferior vena cava and its tributaries, the portal vein, cisterna chyli and lymph nodes, sympathetic chains and sympathetic plexuses and the lumbar plexus in addition to muscles of posterior abdominal wall. The retroperitoneal structures in the pelvic cavity are the internal and external iliac vessels, sympathetic chains, the sacral and coccygeal plexuses, lymph nodes and the muscles of pelvis.

Abdominopelvic Cavity in Newborn

The abdomen is relatively wide and protuberant in the newborn. The liver projects down so that its lower margin reaches the level of umbilicus. The stomach is small and hidden by the liver. The pelvic cavity is narrow. The intestine except for the rectum lies in the abdominal cavity. At birth, much of the urinary bladder is located above the pelvic cavity so the anterior surface of the urinary bladder is in close contact with infraumbilical anterior abdominal wall.
Chapter 80

Disposition of Viscera and Peritoneum in Abdominopelvic Cavity

**Formation of Embryonic Mesenteries**

The ventral and dorsal mesenteries (peritoneal folds) suspend the gut from the ventral and dorsal body walls respectively. However, the ventral mesentery (septum transversum) degenerates except in the region of the foregut. The dorsal mesentery is important since it carries blood vessels and nerve plexuses to the gut. The artery of the foregut is the celiac trunk, that of midgut is the superior mesenteric artery, and that of hindgut is the inferior mesenteric artery. These arteries supply the derivatives of the respective parts of the gut. The derivatives of foregut and midgut receive parasympathetic supply from the vagus and those of the hindgut from the sacral parasympathetic nerves.

**Derivatives of Abdominal Part of Foregut**

The abdominal part of foregut develops into the stomach, first part of duodenum and second part of the duodenum proximal to the opening of common bile duct, liver, biliary apparatus (consisting of gallbladder, cystic duct, hepatic ducts and common bile duct) and the pancreas.

**Derivatives of Ventral Mesogastrium**

The ventral mesentery of the foregut is called the ventral mesogastrium (it is part of septum transversum). It gives rise to:

- Lesser omentum
- Falciform ligament
- Right triangular ligament
- Left triangular ligament
- Coronary ligament.

**Derivatives of Dorsal Mesogastrium**

The dorsal mesentery of the foregut is called the dorsal mesogastrium. It undergoes changes as a result development of lesser sac and the development of spleen inside it. It gives rise to:

- Greater omentum
- Lienorenal ligament
- Gastroplenic ligament
- Gastrophrenic ligament.

**Derivatives of Midgut**

The midgut gives rise to the duodenum beyond the opening of common bile duct, jejunum, ileum, cecum and appendix, ascending colon and right two-thirds of transverse colon.

**Formation of Midgut Loop (Fig. 80.2A)**

The midgut elongates rapidly and forms a U-shaped loop known as primary intestinal loop, which has cranial and caudal limbs. The dorsal mesentery is prolonged between the two limbs and the superior mesenteric artery runs through the mesentery to distribute branches to the two limbs. Hence, the cranial limb is called the prearterial and caudal limb the postarterial. At the junction of the two limbs, the vitellointestinal duct is attached. This duct normally degenerates by fifth to sixth weeks.
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Derivatives of Hindgut

The hindgut lies in the tail fold of the embryo. From its ventral aspect, it sends a diverticulum called the allantois, towards the umbilical opening. The allantois divides the hindgut into preallantoic and postallantoic parts.

Derivatives of Preallantoic Hindgut

The preallantoic hindgut develops into left one-third of the transverse colon, descending colon, sigmoid colon and rectum up to the middle valve of Houston.

Derivatives of Postallantoic Hindgut

The postallantoic hindgut is called endodermal cloaca (Fig. 80.2B). It is common to both digestive and genitourinary tracts. The urorectal septum divides the postallantoic hindgut into ventral and dorsal parts.

1. The dorsal part is in continuity with the preallantoic hindgut proximally. The derivatives of the dorsal part of postallantoic gut are rectum below the level of middle valve of Houston and anal canal up to the level of pectinate line.

2. The ventral part with which the allantois is in continuity is called the primitive urogenital sinus.

Fate of Mesenteries of Midgut and Hindgut

The midgut and hindgut are suspended from the dorsal body wall by dorsal mesentery. With differentiation of

Embryologic insight ...

Physiological Herniation of Midgut Loop

Due to the large size of liver at this stage of embryo, the space in the abdominal cavity is insufficient to accommodate the rapidly elongating intestinal loop. Hence, the midgut loop herniates into the umbilical cord during fifth week. This is known as physiological umbilical herniation. The midgut loop remains in the umbilical cord till tenth week.

Stages in Rotation of Midgut Loop

The rotation of the midgut loop plays a crucial role in attaining the final position of the different derivatives of the gut in the abdominal cavity. There are specific steps in this process, which take place in an orderly sequence.

First Stage

The midgut loop undergoes anticlockwise rotation to the right through 90 degrees around the axis of superior mesenteric artery because of which the prearterial limb becomes the right limb and the postarterial limb becomes the left. The right limb soon becomes coiled due to rapid elongation and the left limb shows a cecal bud near the apex of the loop.

Second Stage

There is reduction of the physiological hernia in a sequential manner during tenth to twelfth weeks. During reduction the midgut undergoes a further 180° rotation in an anticlockwise direction. The right limb enters the abdominal cavity first by passing behind the superior mesenteric artery to occupy the left half of the abdominal cavity. This explains why the superior mesenteric artery gives jejunal and ilial branches from its left side. After this, the left limb rotates through 180° before it comes to occupy the right half of the abdominal cavity. The left limb passes in front of the superior mesenteric artery. The superior mesenteric artery lies between the third part of the duodenum (posteriorly) and transverse colon (anteriorly). This definitive relationship is the consequence of the process of reduction.

Third Stage

After the return of hernia, the cecal bud is in the subhepatic position and the ascending colon is not distinguishable. There is descent of the cecum and development of ascending colon. The details of this process are described with cecum and appendix in Chapter 81.

Contd...

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the various derivatives of the midgut and the hindgut and with attainment of the definitive positions in the abdominal cavity, the dorsal mesentery undergoes profound changes. Some parts of the gut lose their mesentery and become secondarily retroperitoneal (duodenum except the proximal 2 cm, cecum, ascending colon, descending colon and the rectum). This process is known as fixation of the gut. The dorsal mesentery of the midgut changes into the mesentery (attached to jejunum and ileum) and that of hindgut into transverse mesocolon and sigmoid mesocolon.

Peritoneum

The peritoneum is a thin but firm serous membrane. The surface area of the peritoneum is very vast, almost equaling to that of the skin covering the entire body. The epithelial lining of the peritoneum is called the mesothelium, which is single layer of squamous cells supported by submesothelial connective tissue containing lymphocytes, macrophages and adipocytes (fat cells). The walls of the abdominopelvic cavity are lined with parietal peritoneum. The viscera in the
cavity are covered completely or partially with visceral peritoneum. The parietal and visceral layers of the peritoneum are continuous with each other along the lines of peritoneal reflection. Thus, the folds of visceral peritoneum suspend the viscera from the posterior abdominal wall. Such double-layered peritoneal folds include the omenta, mesenteries, mesocolons and ligaments in different situations.

**Functions of Peritoneum**

The peritoneal fluid secreted by the lining epithelium (mesothelium) keeps the surfaces moist and prevents friction between adjacent viscera. The presence of the antibody producing cells in its submesothelial tissue helps in resisting infections. The peritoneal fluid is rapidly absorbed by the mesothelium of peritoneum.

**Subdivisions of Peritoneal Cavity (Fig. 80.5A)**

There are two subdivisions of the peritoneal cavity.

i. The larger, greater sac

ii. The smaller, lesser sac.

The two sacs are in communication with each other only at the epiploic foramen.

The greater sac is further divided into supracolic and infracolic compartments. The supracolic space occupies the upper anterior part of the abdominal cavity. The infracolic space occupies the entire abdominopelvic cavity below the transverse colon.

The lesser sac lies hidden behind the lesser omentum and the stomach and in front of the pancreas and transverse mesocolon.

**Vertical Disposition of Peritoneum**

Prior knowledge of peritoneal relations of the liver is essential to trace the continuity of the peritoneum in its vertical extent. The liver is connected to the diaphragm, anterior and posterior abdominal walls and the stomach by various peritoneal folds. The lines of attachments of these peritoneal folds, though present on different places on the liver, are continuous with each other.

**Falciform Ligament**

The falciform ligament leaves the supraumbilical part of the anterior abdominal wall as two layers, which enclose the ligamentum teres of the liver in its free margin. It reaches the anterior surface of the liver, where its two layers become continuous with the visceral peritoneum covering the anterior surfaces of the right and the left lobes of the liver. The line of attachment of this ligament to the anterior surface of the liver demarcates the right and left lobes.

**Coronary and Triangular Ligaments**

The coronary, left triangular and right triangular ligaments connect the diaphragm and the liver.

i. The coronary and right triangular ligaments connect the right lobe of the liver to the diaphragm as follows.

ii. The superior layer of the coronary ligament reflects from the posterior surface of the right lobe to the diaphragm.

iii. The inferior layer of the coronary ligament reflects from the posterior surface of the right lobe on to the posterior abdominal wall in the region of right kidney.

iv. The superior and inferior layers of coronary ligament are separated from each other to enclose a triangular bare area on the posterior surface of liver.
v. These two layers meet each other at the apex of the bare area to form the right triangular ligament, which connects the right lateral surface of the liver to the diaphragm.

vi. The left triangular ligament connects the posterior surface of the left lobe of the liver to the diaphragm.

**Lesser Omentum (Fig. 81.3)**

The lesser omentum is a double fold of peritoneum extending from the liver to the lesser curvature of stomach. It has an anterior and a posterior layer.

i. Its attachment to the liver is L-shaped. The vertical limb of the L is attached to the bottom of the fissure for ligamentum venosum on the posterior surface and the horizontal limb is attached to the lips of porta hepatis on the inferior surface of the liver (Fig. 82.7).

ii. The lesser omentum becomes continuous with the visceral peritoneum of the liver at the bottom of the fissure for ligamentum venosum as follows. Its posterior layer is continuous with the peritoneum covering the right wall of the fissure (formed by left surface of caudate lobe). Its anterior layer is continuous with the peritoneum covering the left wall of the fissure. Due to this peculiar reflexion, the fissure for ligamentum venosum contains four layers of peritoneum inside it.

iii. The line of attachment of the vertical limb of L is in continuity with the attachment of the horizontal limb at the margins of the porta hepatis (Fig. 82.7).

iv. From this L-shaped line of peritoneal reflection the lesser omentum passes towards the stomach as two layers, which are continuous with each other around the right free margin of the lesser omentum.

v. The right free margin carries three structure inside it (portal vein and hepatic artery to the liver and the common bile duct from the liver to the duodenum).

vi. At the lesser curvature of the stomach, the anterior and posterior layers of the lesser omentum separate to cover the anterosuperior and posteriorinferior surfaces of stomach respectively and again meet at the greater curvature to form the greater omentum.

**Greater Omentum (Fig. 81.3)**

The greater omentum extends from the greater curvature of the stomach to the posterior abdominal wall, where it is attached along the anterior surface of the head and the anterior margin of the body of pancreas.

i. It is composed of four layers of peritoneum. The two anterior layers leave at the greater curvature of the stomach and descend to a variable distance before doubling to form the two posterior layers. These layers are continuous with each other at the sides. The posterior two layers ascend in front of the transverse colon and its mesocolon to reach the pancreas. They usually fuse with the anterior surface of the transverse colon and its mesocolon, which gives an impression that the greater omentum extends from the greater curvature of stomach to the transverse colon (hence, the term gastrocolic ligament for the greater omentum).

ii. After reaching the anterior aspect of the pancreas, the third layer of the greater omentum becomes continuous with the peritoneum lining the posterior abdominal wall of the supracolic compartment. On reaching the medial side of the cardiac end of the esophagus, the peritoneum covers the diaphragm and then is reflected on the liver at the upper margin of caudate lobe.

**Transverse Mesocolon**

After reaching the anterior margin of the body of pancreas, the fourth layer of the greater omentum is reflected downwards as the upper layer of transverse mesocolon, which encloses the transverse colon and returns back to the anterior margin of pancreas, as the lower layer of transverse mesocolon. The transverse mesocolon and the greater omentum are adherent but separable from each other (for embryological plane of cleavage refer to stomach in chapter 81).

The lower layer of the transverse mesocolon becomes continuous with the parietal peritoneum on the inferior surface of the body of pancreas. Below this, it is continuous with the peritoneum on the posterior abdominal wall of infracolic compartment.

**The Mesentery**

The mesentery is a fold of peritoneum that suspends the small intestine (jejunum and ileum) from the posterior abdominal wall. The parietal peritoneum which is continuous with lower layer of transverse colon above is reflected as the right layer of the root of the mesentery. This layer covers the jejunum and ileum and returns to the posterior abdominal wall as the left layer of the mesentery. The line of reflection of the mesentery (root of mesentery) runs obliquely on the posterior wall dividing the infracolic compartment into right superior and left inferior regions. From the root of the mesentery, its left layer can be traced as the parietal peritoneum covering the left inferior region of the infracolic compartment, from where it crosses the pelvic brim to become the pelvic peritoneum.

**Pelvic Mesocolon**

Once inside the pelvis, the parietal peritoneum on the left side is reflected as the anterior layer of pelvic mesocolon,
which encloses the sigmoid colon and returns to the pelvic wall as its posterior layer. The root of the pelvic mesocolon is inverted V-shaped. Its left limb is attached to the left pelvic brim and the right limb extends up to the third sacral vertebral, the apex of the V being near the division of left common iliac vessels. The pelvic peritoneum descends on the anterior surface and sides of the upper third and the front of the middle third of the rectum.

Peritoneal Tracing in Female Pelvis (Fig. 80.5A)
The peritoneum is reflected from the anterior surface of the rectum at the level of the junction of middle and lower third. It passes forwards to cover the posterior fornix of vagina and ascends to cover the posterior surface of uterus. The peritoneal pouch between the rectum and the uterus is called the rectouterine pouch of Douglas. The bottom of this pouch is the lowest part of the peritoneal cavity in female and lies 5.5 cm above the anal orifice. After covering the fundus of the uterus, the peritoneum covers the anterior surface of uterus as far as the junction of the body and cervix. From here, it is reflected on the superior surface of the urinary bladder forming a shallow uterovesical pouch. From the urinary bladder, the visceral peritoneum is reflected on the anterior abdominal wall, where it is continuous with the parietal peritoneum. Laterally, the peritoneum leaves the uterus as the two layers of broad ligament, which connects the uterus to the lateral walls of the pelvic cavity. The broad ligament consists of antero-inferior and postero-superior layers, which are continuous with each other at the upper free margin of the broad ligament. The fallopian tube is enclosed in the free margin. The part of the broad ligament, which is continuous with the germinal epithelium of ovary is called the mesovarium. The ovum liberated into the peritoneal cavity at the time of ovulation, is picked up by the tubal ostium with the help of fimbriae at the lateral end of the fallopian tube. In this way, through the tubal ostium and the fallopian tube the peritoneal cavity is in communication with the uterine cavity (and through it with the exterior via the vaginal orifice). Hence, the peritoneal cavity in the female is open unlike in the male.

Peritoneal Tracing in Male Pelvis (Fig. 80.5B)
The peritoneum is reflected from the anterior surface of the rectum at the level of the junction of the middle third and lower third. It passes forward along the superior surface of the seminal vesicle to the superior surface of the urinary bladder, forming the rectovesical peritoneal pouch. The bottom of this pouch lies 7.5 cm above the anal orifice. This is the lowest limit of the peritoneal cavity in male. From the superior surface of urinary bladder, the peritoneum is reflected on the anterior abdominal wall, where it is continuous with the parietal peritoneum. Laterally to
the rectum and the urinary bladder the peritoneum can be traced along the superior surface of pelvic diaphragm until it is continuous with the parietal peritoneum on the lateral pelvic walls. The peritoneal cavity in the male is a closed space.

**Transverse Disposition of Peritoneum**

Tracing the continuity of the peritoneum in a transverse plane at the level of epiploic foramen in the supracolic compartment can be understood from the Figure 80.6.

**Epiploic Foramen (Foramen of Winslow)**
The epiploic foramen is located at the level of the twelfth thoracic vertebra. It is the only site, where the peritoneum of the greater sac and lesser sac is in continuity with each other.

**Boundaries (Fig. 80.7)**

i. The free margin of the lesser omentum with its three contents namely portal vein, bile duct and hepatic artery forms the anterior boundary.

ii. The inferior vena cava forms the posterior boundary.

iii. The caudate process of the liver forms the superior boundary.

iv. The first part of the duodenum is the inferior boundary.

**Lesser Sac or Omental Bursa**
The lesser sac is an irregular shaped recess of the peritoneal cavity that is hidden behind the lesser omentum and the posterior surface of stomach. The lesser sac communicates with the greater sac only through the epiploic foramen. It is called omental bursa because the space acts as a bursa for the stomach allowing for its expansion and mobility.

**Boundaries (Figs 80.5, 80.6 and 80.8)**
The lesser sac has two walls, four margins, three recesses and one opening.

i. The anterior wall of the lesser sac (from above downward) is formed by posterior layer of the lesser omentum, peritoneum covering the posterior surface of stomach and the anterior two layers of greater omentum.

ii. The posterior wall of the lesser sac (from below upward) is formed by posterior two layers of the greater omentum and the parietal peritoneum covering the stomach bed in the supracolic compartment. (Note: It is useful to recapitulate the structures in stomach bed on the posterior abdominal wall-body of pancreas, splenic artery, left suprarenal gland, left kidney, crura of diaphragm, transverse mesocolon and left colic flexure).

iii. The upper margin is the peritoneal continuity from the caudate lobe of the liver to the diaphragm (on right side) and the gastrophrenic ligament (on the left of the caudate lobe).

iv. The blind lower margin is the line of continuity of the two anterior layers of the greater omentum with its two posterior layers.

v. The left margin (from below upward) is formed by the left margin of the greater omentum, lienorenal ligament and the gastroplenic ligament.

vi. The right margin is complex. It is formed (from below upward) in the infracolic compartment by the right margin of greater omentum and by the reflection of peritoneum from the pancreas to the posterior
aspect of the proximal part of the duodenum (the cross section of the peritoneal cavity at the level of L1 vertebra depicts this part of right margin of the lesser sac). Immediately above the first part of the duodenum, the right margin is deficient (this site being called the epiploic foramen). Above this level, the right margin is formed by the peritoneum covering the caudate lobe, at the upper end of which it is continuous with the superior margin of lesser sac.

Subdivisions of Lesser Sac
The lesser sac is divided into five parts, vestibule, body and three recesses (superior, splenic and inferior).

i. The vestibule is the part of the lesser sac immediately to the left of epiploic foramen. Superiorly, it leads into the superior recess of the lesser sac. To the left, the vestibule leads in to the space (foramen bursae omenti majoris) between the right and left gastro-pancreatic folds of peritoneum (which are produced by the common hepatic and left gastric arteries respectively).

ii. The body of the omental bursa lies posterior to the lesser omentum and stomach.

iii. The splenic recess is the extension of the body of omental bursa to the hilum of spleen in between the gastroplenic and lienorenal ligaments.

iv. The inferior recess is the part extending into the greater omentum. It is normally obliterated in adult stage due to fusion of the layers of greater omentum.

v. The superior recess extends above the epiploic foramen posterior to the caudate lobe of liver.

Clinical insight ...

i. In internal herniation, a loop of intestine herniates through the epiploic foramen into the omental bursa. If the herniated loop is strangulated the reduction of hernia is not possible through the epiploic foramen because of its important relations. The herniated loop is approached through the posterior wall of the lesser sac by dissecting along the plane of cleavage between the greater omentum and transverse mesocolon. This is a bloodless plane between the gastroepiploic vessels in the greater omentum and the middle colic vessels in the transverse mesocolon. This approach is utilized for aspiration of the swollen intestinal loop. After this, it is easier to reduce the herniated loop back into the greater sac through epiploic foramen.

ii. The collection of inflammatory fluid in the omental bursa may occur due to perforation of the gastric ulcer located on the posterior wall of stomach or from the postoperative collection of fluid in the hepatorenal pouch via the epiploic foramen. The collection of fluid in this space due to pancreatitis is known as pseudopancreatic cyst.

Cross-sectional Anatomy of Abdomen
The abdominal structures as revealed by CT scan with contrast at T12 and L3 levels are depicted in Figures 80.9A and 80.9B respectively.

Subphrenic Spaces (Fig. 80.10)
These spaces are in close proximity to the liver. They are of great surgical importance. The knowledge of their boundaries and communications is helpful in diagnosis of
subphrenic abscess (when any one of the spaces is filled with pus and is cut off from the general peritoneal cavity forming an abscess).

Classification
The subphrenic spaces are classified into right and left spaces. The right subphrenic spaces include right anterior intraperitoneal and right posterior intraperitoneal spaces in addition to right extraperitoneal space. The left subphrenic spaces include left anterior intraperitoneal and left posterior intraperitoneal spaces in addition to left extraperitoneal space.

Right Subphrenic Spaces
i. Right anterior intraperitoneal space (right subdiaphragmatic).
ii. Right posterior intraperitoneal space (right subhepatic or Morison’s hepatorenal pouch).
iii. Right extraperitoneal space (bare area of liver).

Left Subphrenic Spaces
i. Left anterior intraperitoneal space (left subdiaphragmatic).
ii. Left posterior intraperitoneal space (lesser sac).
iii. Left extraperitoneal space.

Boundaries of Right Anterior Intraperitoneal Space
i. Superior boundary is the superior layer of coronary ligament.
ii. Anterior boundary is anterior abdominal wall in relation to anterior surface of right lobe of liver.
iii. Posterior boundary is formed by anterior and superior surfaces of the right lobe of liver.
iv. On the left, the space is limited by falciform ligament.
v. Inferiorly and to the right, the space is open.

Boundaries of Left Anterior Intraperitoneal Space
i. Superior boundary is the anterior layer of the left triangular ligament.
ii. Anterior boundary is anterior abdominal wall in relation to anterior surface of left lobe of liver.
iii. Posterior boundary is formed by anterior surface of the left lobe of the liver.
iv. On the right, the space is limited by falciform ligament.
v. Inferiorly and to the left the space is open.

Boundaries of Right Posterior Intraperitoneal Space (Morison’s Hepatorenal Pouch)
i. Superior boundary is inferior layer of coronary ligament.
ii. Anterior boundary is visceral surface of right lobe of liver.
iii. Posterior boundary is formed by parietal peritoneum covering right suprarenal and right kidney (on posterior abdominal wall).
iv. Inferiorly the space opens into the right paracolic gutter, through which it communicates with the pelvic cavity.
v. To the left the space is in communication with the lesser sac via the epiploic foramen.

Left Posterior Intraperitoneal Space
This space is equivalent to the lesser sac (for its boundaries refer to lesser sac).

Boundaries of Right Extraperitoneal Space (Bare Area of Liver)
i. Superior boundary is the superior layer of coronary ligament.
ii. Inferior boundary is the inferior layer of coronary ligament.
iii. Anterior boundary is the bare area of the liver.
iv. Posteriorly, the space is limited by—diaphragm (in contact with bare area).
v. On the left, it is limited by groove for inferior vena cava.
vi. On the right, it is limited by right triangular ligament.

Left Extraperitoneal Space
This space is located behind the bare area of stomach and in front of the diaphragm, left suprarenal and upper part of left kidney.

Clinical insight...

Subphrenic Abscesses
The subphrenic abscess forms if any one of the six subphrenic spaces harbors infection, collects space and is loculated. The subphrenic abscesses are inaccessible to clinical examination hence, diagnosis often poses a problem.
i. The amoebic abscess in the right extraperitoneal space may rupture into the right pleural cavity through the diaphragm.
ii. Morison’s hepatorenal pouch is the common site of abscess formation postoperatively because it is the dependent space in the supine position. It is in continuity with the epiploic foramen to the left and the right paracolic gutter below. The abscess may form secondary to appendicitis, cholecystitis, perforated duodenal ulcer or upper abdominal surgery.

Spaces of Infracolic Compartment
There are right and left lateral paracolic gutters and right and left medial paracolic gutters. These spaces are the dependent parts of the peritoneal cavity in supine position.

The right lateral gutter is in continuity with Morison’s hepatorenal pouch above and pelvic cavity below. The left lateral gutter is separated from the supracolic compartment by the phrenicocolic ligament but is in free communication with the pelvic cavity.

Peritoneal Recesses or Fosse
At the transition sites, where the embryonic intraperitoneal gut loses its mesentery to become retroperitoneal, small peritoneal folds may persist. Such folds occur at the duodenojejunal junction, ileocecal junction and at the root of the pelvic mesocolon. The locations of the recesses, their surgical importance and important vascular relations are described with the fourth part of duodenum (Chapter 81), cecum (Chapter 81) and pelvic mesocolon (Chapter 87).

Nerve Supply
i. The parietal peritoneum is sensitive to touch, pain and temperature. The phrenic nerves supply the central part of diaphragmatic peritoneum and the lower intercostal and subcostal nerves supply its peripheral part. In irritation of the central part of diaphragmatic peritoneum, the pain is referred to C4 dermatome causing shoulder pain.
ii. The lower five intercostal, subcostal and first lumbar spinal nerves supply the rest of the peritoneum. Irritation of the peritoneum in these areas causes muscle stiffness and referred pain in the anterior abdominal wall.
iii. The parietal peritoneum in the pelvic cavity is supplied by obturator nerve (L2, L3, L4).
iv. The visceral peritoneum receives autonomic innervation like the viscera. It is pain insensitive. Stretching the viscera due to acute distension or ischemia of the visceral musculature causes diffuse pain, which may be referred to the skin corresponding to the segmental level of autonomic innervation.

Blood Supply
The parietal peritoneum shares its blood supply with abdominal walls. The visceral peritoneum shares its blood supply with the viscera that it covers.

Clinical insight...
i. Ascites is accumulation of fluid in the peritoneal cavity. A few causes of ascites include, congestive cardiac failure (CCF), cirrhosis of liver, abdominal malignancy and chronic renal failure. The removal of fluid (by tapping or abdominal paracentesis) is necessary to relieve the distress to the patient. While choosing the site for puncture care is taken to avoid inferior epigastric vessels.
ii. The peritoneal dialysis is a method by which waste products like urea are removed from the blood in patients with renal failure. The mesothelium of the peritoneum offers a large surface area with rapid absorptive properties.

iii. Peritonitis is the inflammation of the peritoneum, which may be localized or generalized. The generalized peritonitis is a much-feared complication after abdominal and pelvic surgery.

iv. Hemoperitoneum is accumulation of blood in the peritoneal cavity. Some causes of hemoperitoneum include injury to major blood vessels in abdomen during surgery, rupture of the fallopian tube in ectopic pregnancy and traumatic rupture of any viscera for example, spleen, liver, etc.

v. Pneumoperitoneum is accumulation of air in the peritoneal cavity. This is usually due to perforation of intestine. Presence of air under the right side of diaphragm in a plain radiograph of abdomen is the early sign of pneumoperitoneum.
The stomach is the most dilated and distensible part of the digestive tube. It is obliquely placed in upper part of abdominal cavity, where it occupies epigastrium and left hypogastrium and extends to a variable extent into the umbilical region.

**Functions**

i. The stomach is a reservoir of food. Its capacity in an adult is 1000 to 1500 ml and in a newborn 30 to 50 ml.

ii. It is a seat of digestion of food. The musculature of the stomach contracts to break down the food particles and brings about thorough mixing of the food and the gastric juices. The gastric juice consists of pepsin (secreted by chief cells of gastric glands), HCL and Castle's intrinsic factor (secreted by parietal cells of gastric glands) and mucin (secreted by mucous neck cells of gastric glands).

iii. The hydrochloric acid has bactericidal action.

iv. Castle's intrinsic factor helps in absorption of vitamin B12 in the small intestine.

**Parts (Fig. 81.1A)**

The stomach consists of the fundus, body and pyloric part.

i. The fundus is the projecting part above the level of cardiac orifice.

ii. The body has two surfaces (anterosuperior and posteroinferior), two orifices (cardiac and pyloric) and two borders (greater and lesser curvatures). A line passing through the incisura angularis of the lesser curvature indicates the demarcation of body and pyloric part.

iii. The pyloric part consists of pyloric antrum, pyloric canal and pylorus.

**Embryologic insight ...**

**Development of Stomach**

The stomach is at first recognized as a midline fusiform dilatation of the caudal part of foregut, suspended from the body wall by ventral and dorsal mesogastrium. Then, it undergoes rotation to right through 90 degree around the longitudinal, transverse and anteroposterior axes so that its right and left surfaces, upper and lower ends and anterior and posterior borders acquire definitive shape and orientation.

**Know More ...**

**Surface Marking**

The approximate outline of an empty stomach in supine position is drawn as follows:

i. The cardiac orifice is about 2 cm wide. Its midpoint coincides with a point on the seventh left costal cartilage 2.5 cm from the median plane.
Stomach, Duodenum, Small Intestine and Large Intestine

Chapter

Gastric Orifices

i. The cardiac orifice is the junction between lower end of the esophagus and stomach. It is located 10 cm deep to the anterior abdominal wall and 40 cm from the incisor teeth. It is marked by cardiac notch or angle of His, which is a deep angulation between the stomach and the lower end of left margin of esophagus.

ii. The pyloric orifice is the junction between the pyloric end of the stomach and the first part of the duodenum. The prepyloric vein of Mayo on its anterior surface serves as its identification mark during surgery. The pyloric orifice is surrounded by a true sphincter composed of thick circular muscle layer. On palpation, the sphincter is felt as a firm lump. The sphincter regulates the entry of stomach contents into the duodenum. The pyloric end is thicker, more superficial and more mobile compared to the cardiac end of the stomach.

Curvatures

i. The lesser curvature is the right margin of the stomach. It is concave towards the right side. The incisura angularis marks its most dependent part. It gives attachment to the lesser omentum.

ii. The greater curvature is four or five times longer than the lesser curvature. Opposite the incisura angularis of lesser curvature there is a bulge on the greater curvature. A line passing through the incisura and the corresponding bulge is the junctional line between body and the pyloric antrum.

The greater curvature gives attachments to greater omentum, gastroplenic ligament and gastrophrenic ligament.

Fundus

The fundus of the stomach is the part above the level of angle of His or cardiac notch. The fundus is normally filled with air in the erect posture, which is usually visible in a plain radiograph of the abdomen under the left dome of diaphragm. Superiorly, the fundus touches the left dome of the diaphragm and reaches the level of the left fifth intercostal space just below the nipple.

Traube’s Space (Fig. 81.1B)

This area is tympanic to percussion. It overlies the fundus of stomach.

Boundaries

i. Superiorly—lower margin of resonance of left lung
ii. On the left—superior margin of spleen
iii. On the right—lower margin of left lobe of liver
iv. Inferiorly—left costal margin.

In pleural effusion on left side and hypertrophy of spleen and liver this space is obliterated.

Relations of Gastric Surfaces

1. The relations of the anterosuperior surface of the body of stomach are as follows:
   i. The right half of its upper part is related to the left lobe of liver and nearer the pylorus to the quadrate lobe of liver.
   ii. The left half of its upper part is in contact with the diaphragm and rib cage.
iii. The lower part of this surface is in direct contact with the anterior abdominal wall.

2. The relations of the posteroinferior surface are as follows:
   i. It is related to a number of structures on the posterior abdominal wall, which collectively are called stomach bed (Fig. 81.2).
   ii. The lesser sac intervenes between the stomach and its bed, which consists of the following seven structures, diaphragm, left suprarenal gland, left kidney, splenic artery, anterior surface of pancreas, transverse mesocolon and left colic flexure. (It is obvious that spleen is not part of stomach. It is separated from the stomach by greater sac and comes in contact with the backward facing anterior surface of the stomach on the left end).

Pyloric Part
The pyloric part lies below or to the right of the incisura angularis. It consists of three parts in succession, pyloric antrum, and pyloric canal and pyloric orifice (pylorus). The pyloric antrum is the dilated part between the sulcus intermedius, (which is a slight groove on the pyloric part) on the right and the line joining the incisura angularis and the corresponding bulge on the greater curvature, on the left. The pyloric canal (2 to 3 cm long) begins at the sulcus intermedius and ends at the pyloric orifice.

Peritoneal Relations (Fig. 81.3)
The stomach is completely covered with peritoneum except a small area called the bare area of stomach near the cardiac orifice, where the gastrophrenic ligament is attached.

Lesser Omentum
The lesser omentum extends from the lesser curvature of stomach to the liver. It has a right free margin forming the anterior boundary of the epiploic foramen. The contents of the right free margin are the portal vein, the common bile duct and the hepatic artery. The left and right gastric vessels are located inside the lesser omentum closer to the lesser curvature. The lesser omentum also contains extra-peritoneal tissue, lymphatics, lymph nodes and the gastric nerves.
Greater Omentum

The greater omentum is attached to the greater curvature of the stomach. It is the longest peritoneal fold consisting of four layers. Its layers fuse with each other and contain variable amount of fat depending on the nutritional status of the individual. The posterior two layers ascend in front of the transverse colon and mesocolon to reach the posterior abdominal wall. The plane between the transverse mesocolon and the greater omentum is an embryological plane of adhesion hence, it can be opened up without blood loss (plane passes between the omental vessels and the mesocolic vessels). About a fingerbreadth below the greater curvature the anterior two layers of the greater omentum contain the arterial arcade of right and left gastroepiploic vessels. The other contents of the greater omentum are lymph nodes and lymphatics, fat, extraperitoneal tissue and aggregations of free macrophages (milky spots). The greater omentum is called the policeman of the abdominal cavity because of its defensive functions. It wraps an inflamed organ thereby localizing the infection and the macrophages in the milky spots help in combating the infection.

Gastroplenic Ligament

This ligament connects the upper end of the greater curvature to the spleen near the hilum. It contains short gastric vessels and left gastroepiploic vessels.

Gastrophrenic Ligament

This ligament connects the cardiac end of the stomach to the diaphragm. It encloses a small bare area of stomach between its two layers.

Radiological Appearance

The radiological examination (Fig. 81.4) by barium meal is done to assess the size, shape and position of the stomach. The following radiological types of stomach are encountered, typical J-shaped stomach, steer-horn stomach (horizontally oriented and resembling the shape of the bull’s horn) and intermediate type.

Interior of Stomach (Fig. 81.5)

The gastric mucosa presents longitudinal folds called rugae, which are more marked along the greater curvature. The gastric canal (magenstrasse) extends from the cardiac orifice to the incisura angularis along the lesser curvature. It is apparent during swallowing. This canal is enclosed by longitudinal gastric folds. The saliva and fluids pass towards the pylorus along the gastric canal. Therefore, the mucous membrane of the gastric canal is prone to injury by irritant liquids. Figure 81.6A shows the gastroscopic appearance of normal mucosa and Figure 81.6B shows gastric pathology.

Arterial Supply (Fig. 81.7)

Following five arteries supply the stomach.

i. The left gastric artery, a branch of celiac trunk and the right gastric artery, a branch of the common hepatic
artery, form an arterial arcade in the lesser omentum close to the lesser curvature.
ii. The left gastroepiploic artery, a branch of splenic artery and right gastroepiploic artery, a branch gastroduodenal artery, form an arterial arcade in the greater omentum close to the greater curvature.
iii. The short gastric arteries from the splenic artery reach the fundus via the gastrosplenic ligament.

Venous Drainage
i. The right and left gastric veins are the direct tributaries of portal vein.
ii. The short gastric and left gastroepiploic veins open into the splenic vein.
iii. The right gastroepiploic vein opens into the superior mesenteric vein.
The gastroesophageal junction is the site of portosystemic anastomosis (between the tributaries of the left gastric vein and esophageal tributaries of hemiazygos vein). This anastomosis dilates in portal hypertension. Such dilated veins in the submucosa may burst causing vomiting of frank blood (hematemesis).

Lymphatic Drainage (Fig. 81.8)
For descriptive purposes the stomach is divided into four areas or zones.
1. The fundus and left half of the body drain in to the pancreaticosplenic nodes, which lie near the hilum of spleen.
2. The upper part of the right half of body drains into the left gastric nodes located in lesser omentum.
3. The lower part of the right half of body drains into the right gastroepiploic nodes.
4. The pyloric region drains into pyloric, hepatic and left gastric nodes.
The lymph from these regional nodes passes ultimately to celiac group of preaortic nodes.

Nerve Supply (Figs 81.9A to C)
The stomach presents both intrinsic and extrinsic nerve supply.
i. The intrinsic nerves are present in the myenteric plexus of Aurbach and submucosal plexus of Meissner.
ii. The extrinsic nerves consist of sympathetic and parasympathetic nerves.
iii. The sympathetic branches reach through the celiac plexus. The efferent sympathetic fibers are vasomotor and the afferent fibers carry pain to the spinal cord. Hence, referred pain from the stomach is felt in the epigastrium in the T7 to T9 dermatomes.

iv. The parasympathetic supply is derived from the vagus nerves. Vagal stimulation increases acid and enzymatic secretion, decreases sphincter tone and increases gastric motility. (Note: After entering the abdomen the left vagus nerve becomes the anterior gastric nerve and the right vagus nerve becomes the posterior gastric nerve).

v. The anterior gastric nerve enters the lesser omentum and gives off hepatic branches towards the right. Then it travels down giving gastric branches from its left aspect. Beyond the origin of gastric branches it is called nerve of Latarjet. It breaks into a handful of antral branches for pyloric antrum.

vi. The posterior gastric nerve enters the lesser omentum and gives off its celiac branches. It gives off the nerve of Grassi for the supply of fundus. Then it supplies gastric branches to the posterior surface of stomach. Beyond the origin of gastric branches the nerve is called posterior nerve of Latarjet, which breaks into handful of antral branches.

Figs 81.9A to C: Nerve supply of stomach through branches of vagus nerves in A and B (Note the highly selective vagotomy in C in which gastric branches are cut but pyloric branches are preserved)

Clinical insight ...

1. **Vagotomy (Fig. 81.9)**

Vagotomy means surgical cutting of the vagus nerves. There are three different types of vagotomy operations.

i. In truncal vagotomy, the trunks of both gastric nerves are divided at the lower end of esophagus.

ii. In selective vagotomy the hepatic and celiac branches are preserved but the main trunks of gastric nerves including the nerves of Latarjet are cut to denervate the stomach and pylorus. The disadvantage of the above procedures is the denervation of pyloric antrum as a result of which gastric emptying is affected.

iii. In highly selective vagotomy only the parietal cells of the stomach are denervated. So, the gastric branches alone are cut along the lesser curvature. The nerve of Grassi is carefully dissected and cut. If this nerve is missed the fundic glands will remain functional. The advantage of highly selective vagotomy is that it preserves the nerves of Latarjet and their antral branches (thus gastric emptying remains normal).

2. The gastric cancer spreads by lymph vessels to the five groups of lymph nodes depicted in Figure 81.8. Sometimes the enlarged and palpable left supraclavicular node (Trosier’s sign) may be the first sign of gastric cancer. Therefore, clinicians make it a point to palpate left supraclavicular lymph nodes, whenever gastric cancer is suspected. In the operation of gastrectomy for gastric cancer, the stomach is removed along with its peritoneal folds (Figs 81.10A and B). Occasionally, the cancer cells penetrate the muscular and serous layers to reach the liver, pancreas and colon. The metastasis into the peritoneum leads to ascites. The ovaries may be the sites of transcoelomic spread (Krukenberg’s tumor). In advanced stage, the malignant cells may reach the umbilicus, where they appear as Sister Joseph’s nodules.

Contd...
3. The term peptic ulcer is used for both duodenal and gastric ulcers. The acid in the normal stomach does not injure the mucosa because of the presence of mucus barrier. However, hyperacidity may cause gastric ulcers, which are usually located near the lesser curvature in the pyloric part of the stomach. The ulcer causes pain and bleeding. In perforation of the ulcer on the anterior wall of the stomach the acidic stomach contents are emptied into the greater sac. In perforation of the ulcer on the posterior wall, the stomach contents enter into the lesser sac. The splenic artery in the stomach bed may get eroded, causing serious internal hemorrhage.

4. Pylorospasm is the condition in which the pyloric sphincter fails to relax normally. In such cases the gastric emptying is slow and the food tends to accumulate in the stomach. The infant vomits frequently to relieve the high intragastric pressure. Pylorospasm is treated with drugs that relax the sphincter.

5. Congenital hypertrophic pyloric stenosis is due to hypertrophy of the circular muscle layer in the region of pyloric orifice resulting in narrowing of the pyloric orifice. It occurs more often in first-born male children with O blood group. The characteristic symptom is the projectile vomiting in which there is spraying of the vomitus some distance away from the infant. The hypertrophied sphincter can be palpated per abdomen as a lump. During surgery it is identified by presence of prepyloric vein of Mayo. Ramstedt's operation is the treatment of choice. In this procedure the circular muscle is cut by blunt dissection to widen the pyloric orifice (without cutting the mucosa).

6. In extremely obese persons bariatric surgery is the only option left to reduce weight. Figure 81.11A depicts a simple procedure of gastric banding in which a band regulates the size of the upper smaller pouch of stomach to restrict food entry and food passage to distal part of stomach. Figure 81.11B depicts three steps in the procedure called Roux-en-Y gastric bypass. The stomach is divided into smaller upper part and larger lower part. The jejunum is divided distal to the duodenum. The distal end of the segmented jejunum is anastomozed with proximal part of stomach (gastrojejunostomy). The proximal end of the segmented jejunum is anastomozed to the jejunum (jejunoojejunostomy) so that the gastric juices including intrinsic factor and bile are mixed with the food entering the jejunum via gastrojejunostomy site.

7. The hiatal hernia (Fig. 26.8) is protrusion of a part of stomach into the posterior mediastinum via the esophageal opening of the diaphragm. In the sliding type of hernia, the abdominal esophagus, part of fundus and cardoesophageal junction slide into the thorax. This may cause symptoms like pain, heartburn, etc. In the rolling or paraesophageal type of hernia, the cardio-esophageal junction does not shift upward but a part of stomach slides into the posterior mediastinum.

**SMALL INTESTINE**

**Duodenum**

The duodenum is a Latin word, derived from “Do-deka-dactalos”, which means width of twelve fingers. Since, the length of duodenum is equal to the width of twelve fingers.
put together, (25 cm) it is given the name duodenum. The duodenum is the first part of the small intestine and is the shortest, widest and the most fixed part. It is retroperitoneal except the proximal 2 to 2.5 cm. The main function of the duodenum is digestion. The chyme is mixed with bile and pancreatic enzymes here. The arrival of the chyme stimulates the duodenal mucosa to produce cholecystokinin and secretin. The former stimulates the pancreatic enzymes and the bile and the latter stimulates bicarbonate ions to flow into the duodenum.

**General Features**

The duodenum is 25 cm long. It begins at the pyloric orifice and ends at the duodenojejunal flexure. It is a C-shaped tube with the C open to the left to clasp the head of the pancreas.

**Parts (Fig. 81.13)**

1. The first or superior part is five centimeter long. It passes upward, backward and to the right from the pylorus in the transpyloric plane at the level of L1 vertebra. It ends near the neck of the gallbladder.
2. The second or descending part is eight centimeter long. It extends up to the level of L3 vertebra.
3. The third or horizontal part is about ten centimeter long and passes from the right to the left. It crosses the midline at the level of L3 vertebra.
4. The fourth or ascending part is two centimeter long. It turns upward and to the left and ends by joining the jejunum at the level of L2 vertebra.

**Embryologic insight ...**

Above the level of entry of the common bile duct, the duodenum develops from endoderm of the foregut and below this level from the endoderm of midgut.

(Note: During 8th week, the lumen of duodenum is obliterated by proliferation of lining cells. By the end of third month the lumen is recanalized).

**Congenital Anomalies**

i. Duodenal stenosis (narrowing of lumen) is due to incomplete recanalization.

ii. Duodenal atresia is due to failure of recanalization, usually in the second part beyond the opening of the common bile duct. This causes total obstruction in the second part of the duodenum resulting in distension of the first part and the stomach. The newborn vomits from birth and the vomitus is bile stained. The plain X-ray (or ultrasound scan) depicts the characteristic double bubble sign (air bubble in the fundus and in first part of duodenum as shown in Figure 81.12. The obstruction of second part may also occur due to a ring shaped pancreatic tissue (annular pancreas) surrounding it (Fig. 82.2B).
Abdomen, Pelvis and Perineum

Section

with the right lateral line. The third part is a 10 cm long and 2.5 cm broad line starting from the end of second part and reaching the midline on the subcostal plane just above the umbilicus. The fourth part begins at the end of the third part and reaches the duodenojejunal flexure, which is represented by a point 2.5 cm to the left of median plane and 1 cm below the transpyloric plane.

Relations of First Part (Figs 81.14A and B)
The proximal two centimeter of the first part is intraperitoneal. It gives attachment to both greater and lesser omenta. The part of the lesser omentum extending between the liver and the proximal two centimeter is called hepatoduodenal ligament.

i. Anteriorly, the first part is related to the quadrate lobe of the liver and the neck and body of the gallbladder. This anatomical relation explains how a large gallstone erodes through the anterior wall of the duodenum to enter its cavity.
ii. Posteriorly, it is related to gastroduodenal artery, portal vein and bile duct.
iii. Superiorly, it is related to the horizontal part of hepatic artery and the epiploic foramen.
iv. Inferiorly, it is related to the head and neck of pancreas.

Features
i. It is the most movable part of duodenum.
ii. It is the only part of duodenum that is related to the lesser sac.
iii. It has less blood supply compared to the rest of the duodenum because its arteries are end arteries.
iv. Due to absence of circular folds of mucous membrane, it shows a characteristic smooth appearance in the barium meal radiograph. This is called duodenal cap (bulb).

Fig. 81.13: Shape, parts and vertebral level of duodenum (Parts: (I) Superior; (II) Descending; (III) Horizontal; (IV) Ascending)

Figs 81.14A and B: Relations of first part of duodenum

Artery of Duodenal Hemorrhage
The first part is a common site of peptic ulceration because the acid contents of the stomach first come in contact with its mucosa. If the ulcer perforates the inferior wall it penetrates the pancreas causing pain in the back. In perforation of the anterior wall (Fig. 81.15) the acidic contents enter the greater sac. An ulcer on the posterior wall may erode the gastroduodenal artery leading to serious internal bleeding. Therefore, the gastroduodenal artery is called the “artery of duodenal hemorrhage”.

Clinical insight ...

Relations of Second Part
i. Anteriorly, it is related to three structures, which from above downward are, gallbladder, transverse colon, and coils of jejunum (Fig. 81.16). The proximity to gallbladder may be the cause of erosion of duodenal wall in cases of gallstones leading to entry of gallstones into the lumen of duodenum.
Posteriorly, it is related to the anterior surface of right kidney, structures at the hilum of the kidney, inferior vena cava and right psoas major muscle (Fig. 81.17).

On its right, it is related to the right colic flexure.

On its left, it is related to the head of pancreas. The common bile duct and pancreatic duct enter its medial wall.

Interior of Second Part

The hepatopancreatic ampulla (of Vater) passes through the medial wall of the second part (Fig. 81.19). Usually the common bile duct and the main pancreatic duct unite to form the hepatopancreatic ampulla, but variations are common. The hepatopancreatic sphincter of Oddi surrounds the ampulla. The accessory pancreatic duct if present also passes through the medial wall. The interior of the second part presents mucosal folds, duodenal papillae and the openings of bile and pancreatic ducts. The circular mucosal folds are numerous and increase the surface area. There is one prominent longitudinal fold on the medial wall. The major duodenal papilla lies at the proximal end of this fold. The major duodenal papilla is an elevation of the mucosa on which the ampulla of Vater opens. The accessory pancreatic duct opens at the minor duodenal papilla, which is located proximal to the major papilla. The distance of the major papilla from the pyloric orifice is ten centimeter while that of the minor papilla is seven to eight centimeter.

Relations of Third Part

Anteriorly, it is related to the superior mesenteric vessels (Fig. 81.16) in the root of the mesentery.

Posteriorly, it is related to (Fig. 81.17) the right psoas major muscle and the structures lying on it namely, right ureter, inferior vena cava, right gonadal vessels and the abdominal aorta at the origin of the inferior mesenteric artery.

Superiorly, it is in contact with head of pancreas and its uncinate process.

Inferiorly, there are coils of jejunum and ileum.

The third part of the duodenum is sandwiched between the superior mesenteric artery in front and the abdominal aorta behind, like a nut in the nutcracker (Fig. 81.18). The duodenal stasis may occur as a result of compression between the two arteries (Wilkie’s syndrome).
Abdomen, Pelvis and Perineum

Relations of Fourth Part

i. Anteriorly, it is related to the transverse colon and its mesocolon.

ii. Posteriorly, it is related to the left psoas major muscle and structures in front of it, namely, left sympathetic chain, left renal and gonadal vessels and inferior mesenteric vein.

iii. Superiorly, it is related to the body of pancreas.

iv. Inferiorly, the coils of intestine are related.

Duodenojejunal Flexure

The junction between the retroperitoneal duodenum and intraperitoneal jejunum is marked by a sharp forward bend. It is located on the left of the midline (vertebral level L2). It is held in position by the suspensory muscle of the duodenum (ligament of Treitz). This is a fibromuscular band extending from the duodenojejunal flexure to the right crus of diaphragm close to the esophageal opening. The upper part of this muscle consists of striated muscle (from the diaphragm) and the lower part has smooth muscle (from the duodenum). These two parts are joined by fibrous tissue, which surrounds the celiac trunk. The striated part is innervated by phrenic nerve and the smooth muscle has autonomic innervation. The function of this muscle is to augment the duodenojejunal flexure.

Arterial Supply (Fig. 81.20)

The arterial supply of duodenum denotes its development. The parts developed from foregut receive blood from the branches of celiac artery and parts developed from midgut from the branches of superior mesenteric artery.

i. The first part of duodenum has sparse blood supply. The supraduodenal artery of Wilkie (a branch of gastroduodenal or right gastric or hepatic artery) is absent in 30 percent of subjects. The infraduodenal artery (a branch of right gastroepiploic artery) and the retroduodenal artery (a branch of gastroduodenal artery) are practically end arteries. This is the reason for sparse or less arterial supply to the first part of duodenum and its vulnerability to ischemia.

ii. The second part receives ample blood supply from branches of both celiac and superior mesenteric arteries. The superior pancreaticoduodenal artery divides into anterior and posterior branches, which run in front of and behind the pancreatic head respectively. They supply the second part of duodenum and head of pancreas and anastomose with branches of the inferior pancreaticoduodenal arteries from the superior mesenteric artery.

iii. The third and fourth parts receive branches from the inferior pancreaticoduodenal artery.

Venous Drainage

The veins correspond to the arteries and terminate in the splenic and superior mesenteric veins. Some veins may end directly into the portal vein.

Lymphatic Drainage

The lymph vessels drain in pancreaticoduodenal as well as pyloric groups of lymph nodes. From here, the lymph flows to the celiac nodes.
**Nerve Supply**

Sympathetic supply is derived from the celiac and superior mesenteric plexuses. The segmental innervation is T6 to T8. The parasympathetic supply is derived from vagus nerves.

**Peritoneal Recesses in Relation to Duodenum (Fig. 81.21)**

A number of peritoneal recesses are encountered near the fourth part of duodenum. Occasionally, these recesses trap a loop of intestine, which may strangulate and produce acute symptoms of strangulated internal hernia leading to intestinal obstruction. Depending on the site of the peritoneal folds, the recesses are named, the superior duodenal recess, inferior duodenal recess, paraduodenal recess, retroduodenal recess and the duodenojejunal recess. The paraduodenal recess is the only one bounded by a vascular fold carrying the inferior mesenteric vein inside it.

**Contrast X-ray of Duodenum**

The barium meal shows the proximal part of the first part of duodenum as a homogenous triangular shadow called duodenal cap. The duodenal cap has a well-demarcated base towards the pylorus and a less distinct apex. The remaining parts of the duodenum show feathery shadow. The reason for this difference is that the first part has no circular folds of mucosa and its lumen is kept patent by the pylorus, which protrudes into the proximal duodenum. The rest of the duodenum possesses circular folds of mucosa and being retroperitoneal its lumen remains in a collapsed state. Any filling defect in the duodenal cap is an indication of a duodenal ulcer.

**Jejunum and Ileum**

The jejunum and ileum, the highly coiled parts of the small intestine, are suspended by the mesentery from the posterior abdominal wall. Together they measure about six meters in length, of which upper two fifth is jejunum and lower three fifth is ileum. The coils of small intestine are packed in the infracolic compartment of the greater sac. The greater omentum normally covers the anterior aspect of the coils of small intestine and separates them from the anterior abdominal wall.

**Extent**

The jejunum starts at duodenojejunal junction at the left of midline and the ileum terminates at the ileocecal junction in the right iliac fossa.

**Mesentery**

The mesentery of the small intestine suspends the jejunum and ileum from the posterior abdominal wall. It has the root (attached margin) and the free margin (intestinal margin). The root is roughly 15 cm long and contains the superior mesenteric vessels. The free margin is about six meters long and contains the intestine inside it. The mesentery is highly folded due to the difference between the lengths of its two margins. The root of the mesentery is obliquely attached to the posterior abdominal wall from the left side of second lumbar vertebra to the right sacroiliac joint. It crosses the following structures from above downward, third part of the duodenum, abdominal aorta, inferior vena cava, right
gonadal vessels and right ureter on the anterior surface of right psoas major muscle.

Contents
The mesentery contains the coils of jejunum and ileum, jejunal and ileal branches of superior mesenteric vessels, ileal branches of ileocolic vessels, large numbers of mesenteric lymph nodes, intestinal lymph vessels, nerve plexuses and the extraperitoneal loose connective tissue laden with variable amount of fat.

Surface Marking of Root of Mesentery (Fig. 81.22)
The point representing the duodenojejunal flexure is 2.5 cm to the left of the midline and 1 cm below the transpyloric plane. The point of intersection of right lateral and transtubercular lines represents the ileocecal junction. An oblique line joining the above two points is the surface marking of the root of mesentery.

Distinguishing Features (Fig. 81.23)
i. The diameter and thickness of the wall of the jejunum are greater than that of the ileum.
ii. The arterial arches in the mesentery of the jejunum are less in number hence the vasa recta are longer. In the case of ileum, the arterial arches are more and hence the vasa recta are short.
iii. There are transparent windows in the mesentery of jejunum due to absence of fat while in the case of the ileum there are opaque windows due to the presence of fat.

Small Intestine (Small Bowel)
The small intestine is very long and hence locating lesions can be quite difficult. The imaging techniques include, barium meal follow through, enteroclysis and capsule endoscopy to name a few. Figure 81.24 shows enteroclysis image, which is a fluoroscopic X-ray taken after introducing contrast material into the duodenum. This imaging is highly useful to study mucosa of the small intestine.

Arterial Supply
Several (about 12-20) jejunal and ileal branches arise from the left side of the superior mesenteric artery and enter the mesentery to reach the intestine.
(The only part not supplied by the direct ileal branches of superior mesenteric artery, is the terminal part of the ileum, which is supplied by the ileal branches of ileocolic branch of superior mesenteric artery).

Arterial Arcades
As soon as the jejunal and ileal branches enter the mesentery, they divide into smaller branches that anastomose with each other to form a series of arterial arcades. The vasa recta (straight vessels) arising from terminal arcades enter the gut wall.

i. The arcades are fewer in jejunum compared to the ileum hence the length of the vasa recta is longer in jejunum and shorter in ileum.
ii. The fat in the mesentery of the ileum is present right up to the wall of the gut but in the case of the jejunal mesentery the fat is lacking nearer the gut. Therefore spaces between the long vasa recta in the jejunal mesentery, present the appearance of transparent windows when held against light. On the contrary, the spaces between the short vasa recta in the ileal mesentery present the appearance of opaque windows. This feature helps in identifying the gut loop during abdominal surgery.

Clinical insight ...

Mesenteric Cyst
The mesentery is a site of cystic swellings, which commonly arises from the mesenteric lymph nodes. It presents clinically as a painless fluctuant swelling near the umbilicus. The characteristic feature of the swelling is that it is more mobile in the direction at right angles to the line of attachment of the mesentery but less mobile along the line of attachment.

Fig. 81.22: Surface marking of root of mesentery and its clinical significance
(Note that the cystic swelling in the mesentery is mobile in the direction at right angles to the line representing the root of mesentery)
iii. The arterial arcades provide abundant collateral circulation. This is of particular importance during peristaltic movements, when some of the vasa recta may be constricted.

**Venous Drainage**

The veins follow the arteries and empty into the superior mesenteric vein. They carry the products of digestion of proteins and carbohydrates to the portal circulation.

**Lymphatic Drainage**

The lymph vessels in the small intestine carry products of fat digestion to the thoracic duct in addition to the lymph from the gut. The lymph passes through lymph nodes in the mesentery and ultimately drains into the preaortic nodes in relation to origin of superior mesenteric artery.

**Nerve Supply**

The parasympathetic supply is provided by vagus nerves through the superior mesenteric plexus. The stimulation of vagus promotes peristalsis. The sympathetic supply is provided by lesser splanchnic nerve (T10-T11) through the same plexus. The pain sensation is carried in lesser splanchnic nerves to the sympathetic chain and then to the T10 and T11 segments of the spinal cord. The pain from the jejunum and ileum is referred to umbilical region.

**Clinical insight ...**

i. The Peyer’s patches can be felt through the antimesenteric margin of the ileum. They may ulcerate in typhoid fever and give rise to characteristic vertically oriented ulcers in the intestinal mucosa. In typhoid fever the bacteria, ingested through contaminated food, cause enteritis (inflammation of small intestine). As a generalized immune response of the body, not only the Peyer’s patches but also the mesenteric lymph nodes and the spleen are enlarged in typhoid fever. After healing, the typhoid ulcers do not cause intestinal obstruction unlike the tuberculous ulcers, which are circularly oriented and hence after healing by fibrous tissue, may constrict the lumen.
Functions
The main function of large intestine is absorption of water from the fluid contents of large intestine and help in formation, storage and expulsion of feces. Besides this, the large intestine manufactures vitamin B complex with the help of natural bacterial flora of intestine.

Distinguishing Features
i. The longitudinal muscle layer is disposed as three bands instead of as a uniform layer. The bands are called *taeniae coli*, which are present on all parts of colon and cecum.

ii. The haustrations or sacculations are the dilated parts in between the taeniae coli. They are responsible for the characteristic puckered appearance of the large intestine.

iii. The appendices epiploicae are fat filled bags of visceral peritoneum attached to the *taeniae coli*.

Embryologic insight...
The cecum, appendix, ascending colon and right two-thirds of transverse colon develop from midgut and hence supplied by branches of superior mesenteric artery. The left one-third of transverse colon, descending colon, sigmoid colon, rectum and anal canal above the level of pectinate line, develop from hindgut and hence are supplied by branches of inferior mesenteric artery.

Development of Cecum and Appendix
After the return of the herniated midgut (chapter 80) into the abdominal cavity, the cecal bud is in the subhepatic position. It gradually descends to reach the right iliac fossa. Arrest of descent may lead to ectopic locations of cecum and appendix (Fig. 81.26). At birth, the cecum is conical with tubular appendix attached to its tip. The differential growth of the walls of cecum is essential to acquire definitive shape and for the shift in the position of the appendix. The lack of differential growth leads to infantile or infundibular cecum (conical cecum with appendix attached to its apex).

Cecum (Fig. 81.27)
The meaning of the word cecum in Latin is blind. The cecum is the blind end of the large intestine below the level of ileal opening. Its peculiarity is that its length (6 cm) is smaller than the breadth (7 and ½ cm). The cecum is located in the right iliac fossa just above the lateral half of the inguinal ligament. It is continuous above the level of ileocecal opening with the ascending colon. It has an inferior convex wall, a lateral wall and a medial wall showing openings of ileum and appendix. The vermiform appendix is attached to its posteromedial
Chapter 81: Stomach, Duodenum, Small Intestine and Large Intestine

Stomach, Duodenum, Small Intestine and Large Intestine

There are three taeniae coli, anterior, posteromedial and posterolateral, which converge towards the base of appendix to merge with the uniform longitudinal muscle coat of the appendix. This is the basis of locating the appendix during surgery by tracing the anterior taenia coli to the appendicular base.

Surface Marking (Fig. 81.25)

The point of intersection of transtubercular and right lateral planes indicates the position of ileocecal opening. A 6 cm long line from this point drawn vertically downwards marks the left margin. A 6 cm long parallel line, which is 7.5 cm to the right of the previous line, marks the right margin. Joining the lower ends of the above two lines by a line that is convex downwards indicates the lower margin of the cecum.

Relations

The cecum is almost entirely covered with peritoneum on all sides though it has no mesentery. This gives freedom of movement to the cecum. When distended the cecum comes in contact with the anterior abdominal wall in the right iliac fossa but when empty coils of small intestine lie in front of its anterior surface. Posteriorly, it is related to the iliacus and psoas major muscles, femoral nerve and lateral cutaneous nerve of thigh.

Peritoneal Recesses (Fig. 81.28)

At the ileocecal junction, peritoneal recesses called ileocecal recesses are frequently present. The superior ileocecal recess is present above the terminal ileum. Its anterior boundary is by a vascular peritoneal fold containing the anterior cecal vessels. The inferior ileocecal recess is present below the terminal ileum. The bloodless fold of Treves forms its anterior boundary. The retrocecal recess is present behind the cecum. It is related anteriorly to the cecum and posteriorly to the parietal peritoneum in the right iliac fossa. Usually the retrocecal vermiform appendix occupies this recess.
Orifices in the Interior of Cecum

i. The ileocecal orifice (Fig. 81.29) is the prominent feature of the interior of cecum. It is guarded by valves, which form the upper and lower lips of the orifice. The lips of the valves are transversely disposed. They extend laterally as frenula of the valve on either side of the orifice. The ileocecal valve regulates the flow of ileal contents into the cecum. The tightening of the frenula prevents the reflux of the cecal contents into the ileum, by drawing the lips of the valve closer in distended cecum.

ii. A small appendicular opening is situated about one to two centimeter below the ileocecal orifice on the posteromedial wall of the cecum. An insignificant valve (of Gerlach) guards this opening.

Blood Supply (Fig. 81.30)
The anterior and posterior cecal branches of ileocolic branch of the superior mesenteric artery supply the cecum. The veins of the cecum follow the arteries and drain in the portal venous system.

Lymphatic Drainage
The lymph vessels from the cecum drain into ileocolic lymph nodes and finally in the superior mesenteric nodes.

Vermiform Appendix
The vermiform appendix is worm like in appearance. Its length is variable, the average being eight to nine centimeter. The wall of the appendix contains large aggregations of lymphatic tissue hence the appendix has been termed the abdominal tonsil.

Parts
i. The appendix has a base, which is attached to the cecum, two centimeter or less, below the ileocecal junction. The position of the base is constant. The taeniae coli of the cecum become continuous with the complete longitudinal coat of the appendix at the base. The appendix opens into the posteromedial wall of the cecum by its base.

ii. The apex of the appendix is free and its position is variable.
iii. The lumen is very narrow. If the lumen is blocked, a small mass of intestinal contents gets isolated in it, which predisposes to inflammation.

Peritoneal Relation

The appendix is intra-peritoneal organ. Its mesentery is called the meso-appendix, which is part of the mesentery of the terminal part of the ileum. It is very transparent in childhood. The appendicular artery runs through the meso-appendix.

Surface Marking

The base of the appendix is represented on the anterior abdominal wall by a point, which is two centimeters (or less) below the ileocecal junction (a point of intersection of transtubercular and right lateral lines). In this connection, it is worthy of note that this point and the McBurney’s point do not exactly coincide anatomically though they are in close topographical proximity. This may be the reason for equating the surface marking of the base to McBurney’s point for practical purposes (described as “useful surgical approximation”).

Positions of the Tip of Appendix (Fig. 81.32)

The various positions of the appendix are, retrocecal (60%), pelvic (30%), subcecal (2%), paracecal (1%), promontoric (1%), preileal (1%) and postileal (5%).
thrombosed first so that tip becomes gangrenous and may perforate. The appendicular vein drains into the portal venous system.

**Nerve Supply**
The sympathetic afferent fibers in lesser splanchnic nerve via the superior mesenteric plexus carry the pain sensations to the T10 segment of the spinal cord. Therefore, appendicular pain is referred to the skin of umbilical region.

### Clinical insight ...

**Acute Appendicitis**
Acute appendicitis is a surgical emergency. Typically, the pain is felt initially in the umbilical region. This visceral pain is due to distension and spasm of the muscularis of the appendicular wall. Gradually, the pain is localized to the right iliac fossa. This is due to the inflammation of parietal peritoneum in the right iliac fossa. Usually, vomiting and fever accompany the pain. On palpation of the abdominal wall, an area of maximum tenderness is found at the McBurney’s point. Irritation of the parietal peritoneum also gives rise to abdominal rigidity and muscle guarding. Some complications of appendicitis include perforation, gangrene and appendicular abscess. Atypical presentation like the appendicitis mimicking the symptoms of acute cholecystitis is due to inflammation of subhepatic appendix.

**Anatomical Basis of Steps in Conventional Appendicectomy (Figs 81.33A to C)**
The incisions for appendicectomy is called gridiron (shape of a cross beam) incision. It is placed at right angles to the McBurney’s point in the plane of cleavage lines.

i. The three flat muscles are identified and split along the direction of their fibers.
ii. The branches of deep circumflex iliac artery and iliohypogastric nerve are identified in the neurovascular plane so as not to injure them.
iii. The transversalis fascia and parietal peritoneum are incised together.
iv. The cecum is identified by presence of taenia coli and is withdrawn from its bed.
v. The base of appendix is located by tracing the anterior taenia coli of the cecum.
vi. The appendicular artery is ligated in the mesoappendix.
vii. The appendix is incised from its base.
viii. The site of attachment to cecum is sutured.
ix. The skin incision is sutured.

### Ascending Colon
The average length of the ascending colon is 15 cm. It begins from the cecum at the level of ileocecal orifice and reaches the hepatic flexure of the colon below the liver, where the ascending colon becomes the transverse colon. The ascending colon lies in the right lumbar and iliac regions in the retroperitoneal position.

**External Features**
The ascending colon has all the three characteristics of the large intestine. The taeniae coli are anterior, posteromedial and posterolateral in position.

**Relations**
Anterior to the ascending colon there are coils of small intestine and greater omentum. The posterior relations
can be divided into two parts. Above the iliac crest the transversus abdominis and quadratus lumborum muscles and iliohypogastric and ilioinguinal nerves are the posterior relations. The lower pole of the right kidney is also related posteriorly. Below the iliac crest the iliacus muscle and lateral cutaneous nerve of thigh are the posterior relations.

**Transverse Colon**

The transverse colon extends from the hepatic flexure to the splenic flexure of colon, where it continues as the descending colon. The average length of the transverse colon is 50 cm. Its right end, which is below the level of transpyloric plane, is fixed. Its left end is above the transpyloric plane in the left hypochondrium and is fixed. The intervening part of the transverse colon is suspended from the posterior abdominal wall by the transverse mesocolon. The intermediate mobile part usually extends to the level of umbilicus but it may reach down as far as the pelvis. Thus, the transverse colon is shaped like a U with limbs of unequal lengths. The anterior surface of transverse colon is closely related to the anterior abdominal wall. This makes the exposure of this part of the colon simple for the surgeon who wants to perform transverse colostomy (making an opening in the transverse colon).

**External Features**

Since, the transverse colon is suspended by a mesentery the position of the taeniae is different. It has anterior, superior and posterior taeniae.

**Relations**

The posterior surface of its right extremity is devoid of peritoneum and hence is fused to the anterior surface of the second part of duodenum and the head of pancreas. The other posterior relations are the upper end of the mesentery, the duodenojejunal flexure and the coils of jejunum and ileum. Anteriorly, the transverse colon is related to the greater omentum with which it is fused. The greater omentum separates it from anterior abdominal wall. Superiorly, it is related to the liver, gallbladder, greater curvature of stomach and the lateral end of spleen from the right to the left.

**Transverse Mesocolon**

The transverse mesocolon is attached by two layers of peritoneum to the anterior border of the body of pancreas. The anterior surfaces of the transverse colon and the mesocolon are fused with the posterior layers of greater omentum. This gives an impression of two peritoneal folds being attached to the transverse colon, the mesocolon to its upper border and the greater omentum to its lower border. The contents of transverse mesocolon are, the transverse colon, middle colic vessels, ascending branches of left colic vessels, marginal artery, lymph nodes, lymphatics and nerve plexuses embedded in loose areolar tissue with variable amount of fat.

**Comparison of Hepatic and Splenic Flexures**

i. The hepatic flexure is located in the right lumbar region and the splenic flexure is deep in the left hypochondrium.

ii. The hepatic flexure is below the transpyloric plane whereas the splenic flexure is above.

iii. The vertebral level of the hepatic flexure is L2 and that of splenic flexure is T12.

iv. The angulation of the hepatic flexure is wider compared to that of the splenic flexure.

v. The splenic flexure is attached to the diaphragm by phrenicocolic ligament.

vi. The vagus supplies the hepatic flexure whereas the pelvic splanchnic nerve supplies the splenic flexure.

vii. The hepatic flexure develops from midgut and hence is supplied by right colic branch of superior mesenteric artery. The splenic flexure develops from the hindgut. It is supplied by the marginal artery formed by the left colic branch of the inferior mesenteric artery and the middle colic branch of superior mesenteric artery. Therefore, the splenic flexure is at the junction of the territories of the superior and inferior mesenteric arteries and hence is more prone to ischemia. The critical point of the gut is said to be located at the splenic flexure.

**Descending Colon**

The descending colon is longer, narrower and more deeply placed than the ascending colon. It starts at the splenic flexure in the left hypochondrium and descends through the left lumbar and iliac regions to become continuous with the sigmoid colon at the medial margin of left psoas major in front of the left external iliac vessels at the left pelvic brim. Its average length is 25 cm. It is retroperitoneal.

**Relations**

i. Anteriorly, its upper part is covered with the terminal part of transverse colon and the coils of intestine. The lower part of the descending colon is in the left iliac fossa so it is related anteriorly to the anterior abdominal wall when distended with gas or fecal matter and can be palpated above the inguinal ligament.
ii. Posteriorly, the upper part of the descending colon is related to the anterior surface of the lower lateral part of left kidney. Below the level of iliac crest the posterior relations are, the iliacus and psoas major muscles, lateral cutaneous nerve of thigh, femoral and genitofemoral nerves, external iliac artery and testicular vessels in male. The loaded descending colon may compress the left testicular vein. This is one of the predisposing factors for the causation of varicocele (enlarged and dilated pampiniform plexus) on left side.

**Blood Supply of Colon**
Refer to chapter 83.

**Lymphatic Drainage**
The lymphatic drainage of colon is important since carcinoma of colon spreads by lymphatic route. There are numerous colic lymph nodes collecting the lymph from the colon. The colic lymph nodes are arranged in four groups. The minute epicolic nodes are located on the colonic wall. The paracolic nodes lie very close to the marginal arterial anastomosis. The intermediate colic nodes lie along the right, middle and left colic arteries and the preterminal nodes lie along the trunks of superior and inferior mesenteric arteries.

**Nerve Supply**
The superior and inferior mesenteric nerve plexuses supply the colon.

**Parasympathetic Supply**
   i. The vagus nerve supplies the part of colon that develops from the midgut (ascending colon and right two-thirds of transverse colon).
   ii. The pelvic splanchnic nerve or nervi erigentes (S2, S3, S4) supplies the colon that develops from the hindgut (left one-third of transverse colon, descending colon and the sigmoid colon).

**Afferent Nerve Supply**
The visceral pain sensation from the ascending colon and the transverse colon travels through the lesser splanchnic nerve to the T10 and T11 segments of the spinal cord hence pain is referred to the umbilical and hypogastric regions. The pain from the descending and sigmoid colon is carried in the lumbar splanchnic nerves to L1 and L2 segments of spinal cord hence pain from these parts is referred to inguinal region and thigh.

**Clinical insight ...**
   i. The barium enema radiography is used for visualizing the colon (Fig. 81.34). The typical pattern of colon due to sacculations is very clearly seen.
   ii. The carcinoma of colon is slow growing. Initially, the cancer spreads by lymphatics but later, it spreads to the liver via the portal circulation. If diagnosed early hemicolectomy (partial removal of colon) and resection of all the lymph nodes of the colon are the effective measures. Advanced cancer causes obstruction of bowel. To overcome the obstruction in the colon (in inoperable cases) an artificial opening is made in the transverse colon (colostomy). The artificial opening is brought to the anterior abdominal wall to drain out the fecal matter.
The pancreas is a soft, finely lobulated and elongated gland. It is located behind the peritoneum on the posterior abdominal wall. Due to its deep position, the pancreas is not easily accessible for direct clinical examination. Therefore, the diagnosis of pancreatic diseases is assisted by ultrasound scan, CT scan and special investigations for visualization of pancreatic and biliary ducts in addition to biochemical tests.

**Functions**

Functionally the pancreas consists of two parts, exocrine and endocrine. The exocrine pancreas secretes digestive enzymes in a bicarbonate rich fluid. The daily secretion of pancreatic juice amounts to one liter. The exocrine cells secrete lipase, amylase and trypsin while the epithelium of the ducts secretes bicarbonate, which protects the duodenum from gastric acid and ensures optimum pH for activity of digestive enzymes. The endocrine cells of the pancreas (islets of Langerhans) secrete insulin and glucagon, which control blood glucose level. They also secrete pancreatic gastrin and somatostatin.

**General Features**

The pancreas is about 12 to 15 cm long and extends from the duodenum to the spleen. It consists of head, neck, body and tail (Fig. 82.1). The pancreas is retroperitoneal except for its tail, which lies in the lienorenal ligament. The head lies opposite the first two lumbar vertebrae, the body lies more or less in transpyloric plane and the tail is at the level of T12 vertebra.

**Embryologic insight (Fig. 82.2A)...**

The pancreas develops from the dorsal and ventral endodermal pancreatic buds, which originate from the caudal end of the foregut during the fourth week of intrauterine life. The ventral bud arises in common with hepatic bud but the dorsal bud arises singly. The fusion of the two buds takes place in the seventh week.
**Fig. 82.1:** Main parts of pancreas (head, neck, body and tail)

Contd...

i. The dorsal bud gives rise to the acini and ductules of tail, body, neck and upper part of the head.

ii. The ventral bud gives rise to acini and ductules of lower part of the head and uncinate process.

iii. The pancreatic ducts develop as follows. An anastomotic communication is established between the ducts of ventral and dorsal buds. The main pancreatic duct develops from the distal part of the duct of dorsal bud, anastomotic channel and the duct of ventral bud. The accessory pancreatic duct develops from the proximal part of the duct of the dorsal bud.

iv. The islets of Langerhans develop (during third month of intrauterine life) from the detached acinar cells. These detached cells form clusters of cells around sinusoids.

**Congenital Anomalies**

i. Annular pancreas is a ring of pancreatic tissue around the second part of duodenum (Fig. 82.2B) causing duodenal obstruction. It results if the ventral pancreatic bud splits into two parts and one remains posterior to and the other goes anterior to the duodenum to meet the dorsal bud.

ii. Pancreas divisum is a condition in which the duct of the ventral bud does not fuse with duct of the dorsal bud. The body and tail of pancreas drain through minor duodenal papilla by duct of dorsal bud and the head drains through major duodenal papilla by duct of ventral bud.

iii. Sometimes the pancreatic tissue is spilled in ectopic locations, such as, the greater omentum or Meckel’s diverticulum. Digestive enzymes in ectopic pancreas may destroy normal tissues resulting in ulceration and perforation.

**Surface Marking**

The surface marking of the duodenum marks the head of pancreas. For the body of the pancreas two lines, approximately 2.5 to 3 cm apart are drawn from the head towards the left for a distance of about 10 cm on the transpyloric plane but with an upward slant. The two lines meet at the left end above the transpyloric plane and their meeting point represents the tail.
Relations of Head (Fig. 82.3)
The head of the pancreas lies in the C-shaped concavity of the duodenum. A blunt uncinate process arises from the lower part of the head and turns to the left behind the superior mesenteric vessels.

i. Anteriorly, the head is related from above downwards to the first part of duodenum, transverse colon and coils of jejunum.

ii. Posteriorly, it is intimately related to the common bile duct. The other posterior relations are, IVC and the termination of the right and left renal veins in to it.

iii. Above, below and to the right the head is in close relation to the duodenum. The pancreaticoduodenal arterial arcades lie in the groove between the duodenum and head of pancreas.

iv. The uncinate process is related anteriorly to superior mesenteric vessels and posteriorly to the abdominal aorta. This vascular relationship is described as a vascular nutcracker formed by the abdominal aorta and its superior mesenteric branch.

Relations of Body
The body is triangular with three borders and three surfaces. The anterior surface lies between the anterior and superior borders. The inferior surface lies between the anterior and inferior borders. The posterior surface is between the superior and inferior borders.

Relations of Borders
i. The anterior border gives attachment to transverse mesocolon. In fact, in the embryological stage, this border gives attachments to two posterior layers of greater omentum and two layers of transverse mesocolon (Fig.80.5).

ii. The right end of the superior border, which is in contact with lesser omentum, is called tuber omentale. At this point, the superior border is related to the celiac trunk. The tortuous splenic artery runs to the left along the rest of the superior margin (Fig. 81.13).

iii. The inferior border is in relation to the superior mesenteric vessels as they emerge from the head to cross the uncinate process. The inferior mesenteric vein passes deep to this margin to reach the splenic vein.

Relations of Surfaces
i. The anterior surface is part of the stomach bed (Fig.81.2). It is separated from the posterior surface of the stomach by the lesser sac (omentum bursa).

ii. The inferior surface is in contact with duodenojejunal flexure, coils of jejunum and left colic flexure.

iii. The posterior surface is related from right to left, to the abdominal aorta at the origin of superior mesenteric artery, left crus of diaphragm, left renal vessels, left kidney and left suprarenal gland. A very intimate relation of the posterior surface is the splenic vein, which runs from the hilum of the spleen to the neck of pancreas.

![Fig. 82.3: Relations of head of pancreas](image)

![Fig. 82.4: Main pancreatic duct and accessory pancreatic duct](image)
Tail of Pancreas

The tail is the tapering left end of the pancreas. It reaches the hilum of the spleen through the lienorenal ligament along with the splenic vessels (Fig. 82.21). Therefore, the tail of the pancreas is part of the splenic pedicle. The islet cells are usually numerous in the tail. During splenectomy, the tail of pancreas is likely to be injured unless identified and excluded from the ligature for splenic vessels. Failure to do so may cause diabetes mellitus (insufficiency of insulin). Additionally, the injured tail may leak out pancreatic enzymes causing destruction surrounding tissues (leading to chemical peritonitis or pancreatic fistula).

Pancreatic Ducts (Fig. 82.4)

i. The main pancreatic duct or duct of Wirsung runs in the entire length of the gland. It begins in the tail and gradually increases in size as it gathers more and more tributaries, which are arranged in a herringbone pattern. In the body of pancreas, the duct lies nearer the posterior surface. At the junction of head and neck, the duct turns sharply in inferior direction and then to the right to enter the second part of duodenum. It usually joins the common bile duct just outside or inside the duodenal wall. The two ducts unite to form a hepatopancreatic ampulla just before opening on the major duodenal papilla (which is 8 to 10 cm distal to pylorus). The hepatopancreatic sphincter surrounds the ampulla. The pancreatic and biliary ducts are surrounded by sphincter pancreaticus and sphincter choledochus respectively near their site of fusion (Fig. 81.19). Thus, the sphincter of Oddi consists of three parts.

ii. The accessory pancreatic duct or the duct of Santorini starts in the lower part of the head and then travels up crossing in front of the main duct. It opens in the second part of the duodenum at the summit of minor duodenal papilla, two cm proximal to the major duodenal papilla. It communicates with the main duct while crossing it.

Radiological Examination of Ducts

i. Endoscopic retrograde cholangiopancreatography (ERCP) is a procedure, in which the dye is injected into the ampulla of Vater through an endoscope introduced through the stomach and duodenum. The dye outlines the pancreatic duct system and the common bile duct.

ii. Magnetic resonance cholangiopancreatography (MRCP) is a noninvasive method of visualizing the ducts (refer to extrahepatic biliary apparatus).

Microscopic Structure

The parenchyma of the gland consists mainly of the acini and ducts interspersed with islets of Langerhans. The acinar cells show characteristic bipolar staining (infranuclear basophilic cytoplasm and supranuclear acidophilic cytoplasm). The basal cytoplasm contains numerous rough endoplasmic reticulum and the supranuclear cytoplasm contains the membrane bound zymogen granules. The narrow intercalated ducts lined by centroacinar cells begin inside the acini. The simple cuboidal or columnar epithelium lines the larger ducts. The islets are present as clusters of small, scattered pale cells. There are of three types of cells, α (alpha) cells secrete glucagon, β (beta) cells secrete insulin and δ (delta) cells secrete pancreatic gastrin and somatostatin.

Arterial Supply (Figs 81.13 and 81.20)

i. The head is supplied by the anastomotic arcades between the superior and inferior pancreaticoduodenal arteries.

ii. The neck, body and tail are supplied by the splenic artery.

Venous Drainage

The veins from the pancreas drain into splenic, superior mesenteric and portal veins.

Lymphatic Drainage

The head and body drain into pyloric and pancreatico-splenic nodes, which ultimately drain into preaortic nodes. The tail drains into the splenic nodes.

Nerve Supply

The celiac plexus supplies both sympathetic and parasympathetic nerves to the pancreas. The visceral afferent fibres travel in the greater and lesser splanchnic nerves. The segmental level of innervation is T7 to T11. The searing pancreatic pain typically radiates to the middle of the back and is due to irritation of the parietal peritoneum covering the pancreas.

Clinical insight ...

i. Inflammation of pancreas is called pancreatitis. It may occur as a complication of mumps. The symptoms of pancreatitis include loss of appetite, nausea, typical pancreatic backache and fever. These are usually accompanied with bulky and fat filled stools. Acute pancreatitis is characterised by rise in serum amylase level four times its normal value. Recurrent pancreatitis (due to any cause) predisposes to stasis of pancreatic juice in the ducts leading to calculi formation in the pancreas.

ii. The omental bursa (lesser sac) is anteriorly related to the anterior surface of the body of pancreas. Therefore, inflammatory fluid collects in the omental bursa in pancreatitis. Such a swelling gives a false impression of a cyst arising from pancreas hence the name, pancreatic pseudocyst.
LIVER

The liver is the largest gland associated with the digestive system. It is situated below the diaphragm mainly in the right hypochondrium, extending across the epigastrium to the left hypochondrium. The liver descends with inspiration and ascends with expiration. It is an extremely vascular organ, which makes it a soft, reddish-brown and friable organ in the living state. The liver is wedge-shaped. It is the heaviest organ in the body. Its weight in adult is 1200 to 1500 g.

Development
The hepatic bud arises from the endoderm of the caudal end of the foregut (Fig. 82.2A). It divides into a larger cranial part (pars hepatica) and a smaller caudal part (pars cystica). The pars hepatica invades the septum transversum and rapidly proliferates to give rise to the right and left lobes of the liver. Glisson’s capsule and the sinusoids of the liver develop from the septum transversum. The hepatocytes start secreting bile at about twelfth week.

Surfaces
The liver has five surfaces as listed below.

i. Anterior
ii. Superior
iii. Posterior
iv. Inferior (visceral)
v. Right lateral.

The anterior, posterior, superior and right lateral surfaces are continuous with each other without definite margins. These four surfaces together make a large diaphragmatic surface. The anterior and inferior surfaces are demarcated by sharp inferior margin, which is palpated while examining the liver in a patient.

Surface Marking (from anterior aspect)

1. The inferior margin is drawn as a curved line by joining the following five points beginning from the right side.
   (Note: The inferior margin is felt by palpation of anterior abdominal wall in the clinical examination of liver in a patient).
   i. The first point corresponds to the right tenth costal cartilage in the midaxillary line.
   ii. The second point is at the tip of right ninth costal cartilage.
   iii. The third point lies in on the transpyloric plane in the median plane.
   iv. The fourth point corresponds to the tip of left eighth costal cartilage at the left costal margin.
   v. The fifth point lies on the left fifth rib at the midclavicular line.

2. The superior margin is indicated by joining the following points from left to right.
   i. First point corresponds to a point on the left fifth rib at midclavicular line.
   ii. The second point is at xiphisternal joint.
   iii. The third point is at point of intersection of midclavicular line on the right fifth rib.

3. The right margin is convex to the right and is indicated by a line that joins the right ends of the superior and inferior margins.

Relations

i. The line of attachment of falciform ligament divides the anterior surface (Fig. 82.5) into larger right lobe and smaller left lobe. This surface is related to anterior abdominal wall and xiphoid process in the midline. On either side it is related to the diaphragm. On either side of falciform ligament the respective anterior surfaces of the lobes are related to right and left intraperitoneal subphrenic spaces.

ii. The superior surface of right and left lobes is convex for tight fitting with the respective domes of diaphragm. A depressed area between the two convexities is related to the central tendon of diaphragm and is known as the cardiac impression. The cardiac impression is related to base of right lung, pericardium and part of the base of left lung.

iii. Carcinoma of the head of pancreas produces symptoms due to compression of the surrounding structures. The compression of common bile duct results in obstructive jaundice, that of the portal vein in ascites and that of second part of duodenum in intestinal obstruction.

Fig. 82.5: Features of anterior surface of liver
iii. The right lateral surface extends from the seventh rib above to the eleventh rib below (Fig. 82.6). It is related to the diaphragm and through it, to the right lung and pleura in the upper one-third, the right costodiaphragmatic recess in the middle third and the tenth and eleventh ribs in the lower third. For taking biopsy, the liver is approached at the midaxillary line in the ninth or tenth intercostal space.

iv. The features of posterior surface, from right to left are, the bare area of liver, groove for inferior vena cava (caval groove), the caudate lobe, fissure for ligamentum venosum and a shallow impression for esophagus and stomach fundus.

**Details of Posterior Surface (Fig. 82.7)**

i. The bare area of liver is triangular. Its base is formed by groove for IVC, the apex by the right triangular ligament, upper margin by the superior layer of coronary ligament and lower margin by the inferior layer of the coronary ligament. The bare area is in direct contact with the diaphragm. The right suprarenal gland is related to its inferomedial part. The bare area of liver is surgically important as it encloses the right extraperitoneal space. In amoebic hepatitis, the pus may collect in this space and form an abscess, which may burst through the diaphragm in to the right pleural cavity.

ii. The inferior vena cava grooves the posterior surface of the liver. The floor of this groove is devoid of peritoneum. The hepatic veins pierce the floor of the groove to open into the IVC.

iii. The caudate lobe belongs to the right lobe of the liver. Its boundaries are the groove for IVC on the right, fissure for ligamentum venosum on the left and porta hepatis inferiorly. The caudate lobe has two processes, the papillary process arises from the left side and the caudate process connects it to the rest of the right lobe. The caudate lobe is unique because it is the only part of the liver that is covered by
peritoneum of the lesser sac (Fig. 80.5A). In fact, the caudate lobe projects into the superior recess of the lesser sac.

iv. The fissure for ligamentum venosum is a deep cleft on the posterior surface of the liver, having a floor and right and left walls. Its floor is in contact with the ligamentum venosum, which is a fibrous remnant of the ductus venosus of fetal circulation. This fissure gives attachment to two layers of the vertical limb of lesser omentum (Fig. 80.5A) and the same two layers are reflected respectively on the right and left walls of the fissure.

v. The abdominal part of esophagus is related to posterior surface of left lobe on the left side of the upper end of the fissure for ligamentum venosum.

Inferior or Visceral Surface (Fig. 82.7)

The fissure for the ligamentum teres extends from the notch on the inferior border of the liver to the left end of porta hepatis. The fissure lodges the ligamentum teres, which is a fibrous remnant of the left umbilical vein. It demarcates the right and left lobes on the inferior surface.

Inferior Surface of Left Lobe

i. The gastric impression on left lobe is a large area in contact with anterosuperior surface of stomach.

ii. The tuber omentale is a slight elevation of the left lobe near the left side of the lower end of fissure for ligamentum venosum. It comes in contact with the lesser omentum and hence the name.

Inferior Surface of Right Lobe

The prominent features on this surface are the quadrate lobe and the fossa for gallbladder.

i. The boundaries of the quadrate lobe are fossa for gallbladder to the right, fissure for ligamentum teres to the left, the porta hepatitis above and the inferior margin of liver below. The quadrate lobe is related to pyloric end of stomach and the first part of duodenum.

ii. The fossa for gallbladder occupies a large part and is non-peritoneal.

iii. Colic impression for right colic flexure is closer to inferior margin and is to the right of the fossa for gallbladder.

iv. Posterior to the colic area, there is a large renal impression for the right kidney.

v. The duodenal impression (for the junction of its first and second parts) is to the right of the posterior end of the fossa and behind the colic impression.

vi. The porta hepatitis (gateway of liver) lies between the posterior limit of the quadrate lobe and the caudate process. The structures entering the porta are the hepatic artery, portal vein and nerve plexuses. The structures leaving the porta are, right and left hepatic ducts and the lymph vessels. The arrangement of these structures is as follows. The hepatic ducts are anterior. The hepatic artery lies in the middle and the portal vein and its branches are posterior.

Peritoneal Ligaments

The liver is covered with peritoneum except at certain non-peritoneal areas. The bare area of the liver on its posterior surface is the largest nonperitoneal area. A few other non-peritoneal sites include porta hepatitis, groove for IVC and fossa for gallbladder. The peritoneum is reflected from the liver via five peritoneal ligaments, namely, the lesser omentum, coronary ligament, right and left triangular ligaments and falciform ligament. These ligaments are described in chapter 80.

Subphrenic Spaces (Fig. 80.10)

Out of the five surgically important subphrenic spaces in close relation to liver, four are intraperitoneal and one is extraperitoneal (for details of their boundaries refer to chapter 80).

i. The right subphrenic or right anterior intraperitoneal space is related to anterior, superior and right lateral surfaces of the right lobe.

ii. The left subphrenic or left anterior intraperitoneal space is related to anterior and superior surfaces of left lobe.

iii. The right subphrenic or right posterior intraperitoneal space of Morison is related to right half of visceral surface.

iv. The superior recess of the omental bursa (part of left posterior subphrenic space) is related to the caudate lobe.

v. The right extraperitoneal space or bare area of liver is related to the posterior surface of the right lobe.

Blood Supply

The blood supply of the liver is unique because it consists of arterial supply, portal venous supply and venous drainage. The liver receives 20% of its blood through hepatic artery and 80 percent through portal vein. These two separate blood streams mix-up at the level of hepatic sinusoids.

i. The hepatic artery proper divides into right and left branches just before entering the porta hepatitis. These branches supply the respective lobes of the liver. Their interlobular branches pass through the portal triads or portal areas to open into hepatic sinusoids.
ii. The portal vein brings blood, which contains products of digestion of proteins and carbohydrates from the intestine and products of erythrocyte breakdown (bilirubin and iron) from the spleen. Its tributaries open into the hepatic sinusoids. The intrahepatic ramifications of the portal vein closely follow the arterial pattern.

iii. The venous ends of the liver sinusoids join the central veins (belonging to systemic veins). The central veins unite to form sublobular veins. Ultimately three large-sized hepatic veins (right, middle and left) emerge from the liver by piercing the floor of the groove for IVC. The hepatic veins immediately open into the inferior vena cava so they do not have extrahepatic existence.

**Anatomical Lobes**

The plane dividing the liver into a large right and a small left lobe passes through the line of attachment of falciform ligament on the anterior surface, the fissure for ligamentum teres on the inferior surface and fissure for ligamentum venosum on the posterior surface. According to this subdivision the caudate and quadrate lobes belong to right lobe of liver.

**Functional Lobes (Figs 82.8A and B)**

The functional or physiological subdivision of liver into right and left lobes is based on the area of drainage of bile by the right and left hepatic ducts. The line of demarcation passes through middle of the fossa for gallbladder and the left side of the groove for IVC. This plane (Cantie’s line) roughly falls along the middle hepatic vein. According to this subdivision, the quadrate lobe belongs to the left lobe of the liver and the caudate lobe belongs to both right and left lobes.

**Couinaud’s Segments (Fig. 82.9)**

According to the nomenclature of Couinaud the liver is divided into eight segments numbered I to VIII. Each segment has independent artery, bile duct, tributary of hepatic vein and the portal tributary (Table 82.1).

**Left Hemiliver**

The segments I to IV make up the left hemiliver. The line of attachment of falciform ligament separates the segments II and III on the left side from the segment IV on the right side. The segment IV corresponds to quadrate lobe.

**Right Hemiliver**

The segments V to VIII make up the right hemiliver. The segment I or posterior segment corresponds to the caudate lobe, which is unique because it receives blood from right and left branches of hepatic artery and portal
vein and it drains directly into IVC. Moreover it pours bile into both right and left biliary ducts.

**Lymphatic Drainage**

A large volume of lymph from the liver reaches the thoracic duct. The lymphatic vessels of the liver begin as blind sacs in the space of Mall around the vessels and ducts in the portal canals.

i. The superficial lymph vessels emerge from all over the liver and join the retrosternal, phrenic and mediastinal lymph nodes. Some parts of liver drain into hepatic lymph nodes in the porta hepatis. The posterior surface of the left lobe drains into paracardiac nodes near the lower end of esophagus. A few lymph vessels from right lobe drain directly into celiac nodes.

ii. The deep lymph vessels form two trunks. The ascending trunk enters the thorax through the vena caval opening and terminates into the nodes around the IVC. The descending trunk empties into the hepatic nodes in porta hepatis.

**Microscopic Structure**

The parenchyma of the liver consists of hepatocytes, sinusoids, bile canaliculi and portal triads or canals (consisting of a radicle of bile duct, hepatic artery and of portal vein). The liver sinusoids are lined by highly fenestrated endothelium. The Kupffer cells lie within the sinusoids attached to the endothelial surface. The hepatocytes are very active cells and possess a remarkable capacity to regenerate. The space of Disse is present between the sinusoids and the hepatocytes. It contains reticulin fibers and Ito cells (perisinusoidal cells), which secrete collagen for the repair and maintenance of hepatic laminae and store vitamin A. The spaces of Disse are continuous with spaces of Mall situated in the portal canals at the periphery of the hepatic lobule (Fig. 82.10).

i. The hepatic lobule is a hexagonal unit of liver parenchyma arranged around the central vein. The hepatocytes are arranged in radiating and anastomosing laminae. The portal triads or canals are located at the periphery of the hepatic lobule.

ii. The portal lobule is a triangular unit of liver parenchyma bounded by three central veins of adjacent hepatic lobules. In this unit the central veins are at the periphery and portal triad is in the center. The portal lobule collects bile from the adjacent hepatic lobules.

iii. The portal acinus (hepatic acinus) is a diamond shaped unit of liver parenchyma confined to two adjacent hepatic lobules. The central veins are located at the diametrically opposite angles and portal triads are located at the other two diametrically opposite angles of the diamond. The portal acinus shows three zones depending on oxygen supply of the parenchyma. The hepatocytes at the periphery (in zone I) are richly supplied with oxygen. The hepatocytes close to central

**Fig. 82.10:** Hexagonal hepatic lobule, triangular portal lobule and diamond-shaped portal acinus of Rappaport

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**Table 82.1: Equivalent terms for functional and surgical hepatic segments**

<table>
<thead>
<tr>
<th>Lobes of liver</th>
<th>Functional segments</th>
<th>Couinaud’s surgical segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left hemiliver</td>
<td>Caudate lobe</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Lateral superior</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td>Lateral inferior</td>
<td>III</td>
</tr>
<tr>
<td></td>
<td>Medial (Quadrate lobe)</td>
<td>IV</td>
</tr>
<tr>
<td>Right hemiliver</td>
<td>Anterior inferior</td>
<td>V</td>
</tr>
<tr>
<td></td>
<td>Posterior inferior</td>
<td>VI</td>
</tr>
<tr>
<td></td>
<td>Posterior superior</td>
<td>VII</td>
</tr>
<tr>
<td></td>
<td>Anterior superior</td>
<td>VIII</td>
</tr>
</tbody>
</table>
vein (in zone III) have poor oxygen supply. These cells are the first to undergo necrosis due to ischemia or drug reaction. The hepatocytes in the intermediate area are in zone II.

**Functions**

i. The liver is a seat of metabolism of carbohydrates, proteins and fats.

ii. Most serum proteins except the immunoglobulins are synthesized in liver. Decrease in albumin level because of liver disease may be a cause of edema and ascites.

iii. Blood clotting depends on production of prothrombin and fibrinogen by the liver. Liver failure results in defective clotting leading to bleeding tendencies.

iv. Liver is a storage site for glycogen, triglycerides, iron, copper and fat-soluble vitamins.

v. Hepatocytes secrete bile, which is needed for emulsification of fats. Lack of bile affects digestion of fatty food leading to excretion of fat-filled light stools (steatorrhea).

vi. Amongst the catabolic functions of the liver, deamination of amino acids is important. Thus, liver is the site of urea formation. It also detoxifies hormones and drugs.

vii. Reticuloendothelial cells (Kupffer cells) of the liver kill the pathogens and other particulate matters reaching the liver through portal vein from the intestinal tract and from the hepatic artery.

viii. Maintenance of body temperature is also attributed to liver because it generates lot of heat during the various metabolic reactions.

**Liver Biopsy**

A bit of liver tissue is drawn out for the purpose of histopathological study. Usually the right ninth intercostal space in the midaxillary line is chosen to insert the biopsy needle. After the skin and fasciae, the needle passes through the external oblique and the intercostal muscle and then the right costodiaphragmatic recess, diaphragm and the right anterior subphrenic space.

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**Clinical insight ...**

i. In liver biopsy a bit of liver tissue is drawn out for the purpose of histo-pathological study. Usually the right ninth intercostal space in the midaxillary line is chosen to insert the biopsy needle. After the skin and fasciae, the needle passes through the external oblique and the intercostal muscles and then the right costodiaphragmatic recess, diaphragm and the right anterior subphrenic space.

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**Contd...**

ii. The liver may be ruptured by overlying fractured ribs or by stab injury. Due its vascularity, the liver bleeds profusely, when ruptured. To control bleeding from liver the surgeon uses a simple pincer technique called Pringle’s maneuver (in which the hepatic artery in the free margin of lesser omentum is pressed between the thumb and index finger).

iii. Cirrhosis of liver is the scarring or fibrosis of liver parenchyma due to toxic effects of ingested substances or drugs. Alcohol is the most common cause of cirrhosis. In alcoholic liver disease the cytoplasm of hepatocytes is filled with large lipid droplets. This results in fatty liver, which is enlarged. There is increase in the formation of fibrous septa which entrap the clusters of hepatocytes. When these trapped hepatocytes proliferate nodular liver typical of alcoholic liver disease is formed (Fig. 82.11).

iv. In congestive cardiac failure the pressure in hepatic veins is raised, which leads to venous congestion in liver and cardiac cirrhosis.

v. In biliary cirrhosis, there is prolonged obstruction to the biliary ducts.

vi. The cirrhosis of liver leads to portal hypertension due to obstruction in intrahepatic portal radicles. This causes stasis of blood in portal circulation resulting in massive enlargement of spleen and fatal hematemesis.

vii. Hepatic carcinoma is the primary malignancy of liver parenchyma. The secondary malignancy of liver occurs due to spread from primary cancer elsewhere (in the gastrointestinal tract) via the portal vein. The malignant cells from breast, lung or pelvic organs may also reach the liver.

viii. Viral hepatitis is a common inflammatory disease of liver, which manifests by appearance of jaundice. The hepatitis A virus enters the body through contaminated water and hepatitis B virus enters through the contaminated needles from the blood of the infected person or after blood transfusion from a carrier or from the body fluids of a carrier.

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**Fig. 82.11:** Nodular liver due to cirrhosis as a result of consumption of alcohol.
**BILIARY APPARATUS**

The biliary apparatus consists of intrahepatic and extrahepatic parts. The function of the intrahepatic part is to drain bile secreted by the hepatocytes outside the liver and that of extrahepatic part is to store the bile in the gallbladder and carry it to the second part of the duodenum as and when necessary.

### Intrahepatic Part

This consists of a series of bile canaliculi, bile ductules and interlobular bile ducts. The interlobular ducts of right and left lobes of the liver unite to form the right and left hepatic ducts respectively.

### Extrahepatic Parts (Fig. 82.12)

The extrahepatic biliary apparatus consists of the right and left hepatic ducts, common hepatic duct, gallbladder, cystic duct and the common bile duct. It collects bile from the liver, stores it in the gallbladder and transmits it to the second part of the duodenum.

#### Right and Left Hepatic Ducts

The right and left hepatic ducts emerge from the porta hepatis, where the arrangement of structures from behind forwards is, branches of portal vein, branches of hepatic artery and hepatic ducts.

#### Common Hepatic Duct

The common hepatic duct (about 3.5 cm long) is formed by the union of right and left hepatic ducts at the right end of the porta hepatis. It unites with the cystic duct (from gallbladder) at an acute angle after descending about 2 cm or so to form the common bile duct. It forms the left boundary of Calot’s triangle. Its function is to carry the bile to the cystic duct for storage in the gallbladder.

#### Gallbladder

The gallbladder is the reservoir of bile. It is a pear-shaped organ having a slate blue color. It is 7 to 10 cm in long and 3 cm in broad at its widest. It is capable of considerable distension. Its functions are the storage of the bile and concentration of the bile to about ten times. The simple columnar epithelium of the gallbladder is adapted for absorption of a considerable amount of water and electrolytes.

- **Capacity**
  - The normal capacity of gallbladder is 30 to 50 ml.

- **Location**
  - It is normally present in the right hypochondrium. It situated in the shallow fossa on the inferior surface of the right lobe of liver. It extends anteriorly from the right end of the porta hepatis to the inferior margin of the right lobe of the liver.

- **Parts**
  - The gallbladder consists of three parts—fundus, body and neck.

#### Fundus of Gallbladder

The fundus is the most anterior and expanded part of the gallbladder, which projects beyond the inferior margin of the liver. It is related anteriorly to the anterior abdominal wall. Its surface marking is important. The fundus corresponds to the tip of the right ninth costal cartilage (point of intersection of the right linea semilunaris and the transpyloric plane). The pressure on the tip of the right ninth costal cartilage (with patient in sitting position and while taking deep breath) gives sharp pain in cholecystitis. This is known as Murphy’s sign.

#### Body of Gallbladder

The body of gallbladder is in contact with the inferior surface of the liver at the fossa for gallbladder. The body
The gallbladder continues as the neck near the right end of the porta hepatis. Its superior surface is in contact with the liver. Its inferior surface is related to the transverse colon, second part of duodenum and the first part of duodenum from before backwards (Fig. 82.13). This relationship is important because sometimes the stones in the gallbladder ulcerate through its wall into the duodenum or the transverse colon.

**Neck of Gallbladder**

The neck is the narrow part of the gallbladder, which continues from the body. At first it curves upwards and forwards and then abruptly backwards and downwards to become the cystic duct. Inferiorly the neck is related to the first part of duodenum. The lumen of the neck has spiral valve. The neck shows a small projection from its right side called Hartman’s pouch or infundibulum. Gall stones lodged in the pouch may cause adhesions with duodenum and perforation.

**Peritoneal Relations**

The superior surface of gallbladder is nonperitoneal and is connected to the inferior surface of right lobe of liver by connective tissue. The inferior surface is covered with peritoneum. The fundus of gallbladder is completely covered with peritoneum.

**Cystic Duct**

The cystic duct is described as S-shaped. It is three to four centimeter long. It begins in the neck of the gallbladder and passes backwards, downwards and to the left to join the common hepatic duct to form common bile duct. Its lumen shows mucous folds, which form the spiral valve like that of the neck of gallbladder. The cystic duct is a two-way passage. The gallbladder receives bile through the cystic duct from the common hepatic duct and sends bile out through the cystic duct to the common bile duct.

**Common Bile Duct**

The common bile duct (CBD) (also known as bile duct) is usually 7.5 to 8 cm long and less than 6 to 7 mm in diameter. The cystic duct unites with common hepatic duct to form the common bile duct. It descends in the free margin of the lesser omentum and then passes behind the first part of the duodenum. On its way to the second part of the duodenum it passes posterior to the head of pancreas.

**Subdivisions**

Its course is divided into four parts, supraduodenal, retroduodenal, and infraduodenal and intraduodenal (intramural).

i. The supraduodenal part lies in the free margin of lesser omentum along with portal vein and hepatic artery proper, constituting the hepatic pedicle. In this location the common bile duct lies anterior to the portal vein and to the right of the hepatic artery proper.

ii. The retroduodenal part is behind the first part of the duodenum. The gastroduodenal artery lies on its left aspect and the portal vein is on its posterior aspect.

iii. The infraduodenal part lies in the concavity of the duodenum embedded in the posterior aspect of the pancreatic head. The inferior vena cava is its posterior relation and the second part of duodenum is on its right side.

iv. The intramural part is the narrowest part. It is inside the wall of the second part of the duodenum, where the bile duct is in close relation to the main pancreatic duct. The two ducts unite to form hepatopancreatic ampulla in the wall of the duodenum very close to the summit of the major duodenal papilla. The ampulla is surrounded by sphincter of Oddi (Fig. 81.19), which is also called the hepatopancreatic sphincter. The sphincter is composed of circular muscle around the terminal part of the common bile duct, including the ampulla and the terminal part of pancreatic duct. The release of bile from the gallbladder is under hormonal control. The arrival of acid or fat in the second part of duodenum causes liberation of cholecystokinin (CCK) in the blood. The muscle of the gallbladder contracts under the influence of CCK. There is rise in pressure in the gallbladder. This is a stimulus for the sphincter of Oddi to relax. The bile now can flow in the second part of duodenum.
Arterial Supply of Extrahepatic Biliary Apparatus (Fig. 82.14)

i. The gallbladder receives blood from the cystic artery, which arises from the right branch of the hepatic artery. A few small arterial twigs from the liver through the fossa for gallbladder form an additional source.

ii. The arterial supply of the common bile duct is clinically important. Its upper part receives twigs from the descending branches of the cystic artery and its lower part from the ascending branches of the superior pancreaticoduodenal artery. If the anastomosis between the superior and inferior pancreaticoduodenal arteries is poor, the ligation of the superior pancreaticoduodenal artery during surgery may cause stricture or gangrene of the common bile duct (postoperative complication).

iii. Hepatic artery proper or its right branch provides a minor source to the middle part of CBD.

Venous Drainage

The cystic veins draining the gallbladder vary in their mode of termination. Those coming out of the superior surface of the gallbladder directly enter the liver substance and open into the hepatic veins. The remaining veins from the gallbladder join to form one or two cystic veins, which usually enter the liver directly. A few veins, which accompany the cystic artery, open into the right branch of the portal vein. Thus, the gallbladder drains in both the systemic and portal veins.

Lymphatic Drainage

The lymphatic vessels originate in the rich lymphatic plexuses in the subserosal and submucosal locations in the gallbladder. Majority of these vessels end in cystic node of Lund located in Calot’s triangle. Efferent vessels from this node end in the hepatic group. A few vessels on the superior surface of gallbladder make connections with the subcapsular lymph channels of the liver. The common bile duct drains into the hepatic nodes and pancreaticosplenic nodes.

Nerve Supply

The gallbladder receives both sympathetic and parasympathetic nerves from the celiac plexuses. Fibers from the right phrenic nerve reach the gallbladder through communications between the phrenic plexus and celiac plexus. This is the explanation of referred pain to the right shoulder in gallbladder inflammation. The sympathetic supply is from T7 to T9 segments. This explains why gallbladder pain is referred to inferior angle of right scapula.

Radiology of Biliary Apparatus

i. Cholecystography consists of the contrast radiography of biliary apparatus after ingestion of contrast medium. Nowadays this method is replaced by intravenous cholecystography.

ii. Ultrasonography is a noninvasive method to inspect the parts of the biliary apparatus.

iii. Endoscopic retrograde cholangiopancreatography (ERCP) is the procedure in which the fiber optic duodenoscope is used to inspect the duodenal opening of the hepatopancreatic ampulla. Then the ampulla is cannulated and the bile and pancreatic ducts are visualized, after injecting water-soluble contrast.

iv. Magnetic resonance cholangiopancreatography (MRCP) is a special type of MRI procedure that produces good images of hepatobiliary and pancreatic ducts (Fig. 82.15).
Abdomen, Pelvis and Perineum

Fig. 82.15: MRCP (magnetic resonance cholangiopancreatography) image of biliary tree showing stone (shown by arrow) in CBD

The spleen is a large hemolymphoid organ consisting of vascular and lymphatic tissue. It has friable texture due to its rich vascularity. Direct trauma to the overlying ribs can rupture the spleen and cause bleeding into the peritoneal cavity.

Clinical insight...

Gall Stones

i. Gallstones or cholelithiasis is a very common clinical condition. Gallstones may cause biliary colic as a result of impaction of stone in the cystic duct. The biliary pain radiates typically to the inferior angle of scapula. The pain of peritoneal irritation is felt over the right shoulder.

ii. The obstruction of CBD is usually due to impaction of gallstones, pancreatic cancer, bile duct cancer, enlarged hepatic lymph nodes and congenital biliary atresia. The obstruction to bile flow results in jaundice, which is called obstructive or surgical jaundice. The treatment consists of the surgical removal of the obstruction.

iii. Calot’s triangle or cystohepatic triangle is an arbitrary triangle, which a surgeon must identify during surgery on gallbladder. The boundaries of Calot’s triangle are the cystic duct inferiorly, the common hepatic duct medially and the inferior surface of liver above (Fig. 82.16). The right hepatic artery, cystic artery and the cystic lymph node of Lund are its contents. During cholecystectomy (removal of gallbladder) the surgeon locates the artery behind the lymph node. The cystic artery and cystic duct are clamped and cut is given in Figure 82.17. Severe bleeding due to injury to cystic artery is the most feared complication during cholecystectomy. The bleeding is controlled by compressing the hepatic artery proper between the finger and thumb, where it lies in the free margin of the lesser omentum (Pringle’s manoeuvre).

Congenital Anomalies of Gallbladder

i. Floating gallbladder is the one with a mesentery.

Contd...

ii. Phrygian cap is a radiologically seen anomaly in which the gallbladder resembles the cap worn by people of Phrygia (an ancient country of Asia Minor), due to a constriction between the fundus and the body.

iii. Sessile gallbladder is a condition in which the cystic duct is absent.

Contd...
Location
The spleen is located in the left hypogastrium between the fundus of the stomach and the diaphragm, opposite the left ninth to eleventh ribs. Its long axis lies in the plane of the long axis of the left tenth rib. The spleen moves with respiration.

Size and Measurements
The size of the spleen roughly corresponds to the cupped hand or fist of the subject. In the adult, the spleen is 12 cm long, 7 cm broad and 3 cm thick and its weight varies from 80 to 150 gm.

Surfaces, Borders and Poles
The spleen has diaphragmatic and visceral surfaces, the superior and inferior borders and anterior (lateral) and posterior (medial) ends or poles (Fig. 82.18).

i. The posterior (medial) end is rounded and lies 4 to 5 cm from the midline at the level of the spine of tenth thoracic vertebra.

ii. The anterior (lateral) end is expanded. It lies in the midaxillary line on the tenth rib.

iii. The superior border separates the diaphragmatic surface from the visceral surface. It is sharp and bears two or three notches near its lateral end. The developmental importance of the notches is that they are indicative of development of spleen by fusion of separate masses. Its clinical importance is that in an enlarged spleen the notching is exaggerated. This feature distinguishes the splenic swelling from other swellings in the abdominal cavity.

iv. The inferior border separates the diaphragmatic and the visceral surfaces. It is more rounded than the superior border and corresponds in position to the lower margin of the eleventh rib.

v. The visceral surface (Fig. 82.19) bears the hilum of the spleen, through which splenic vessels and nerve plexuses enter or leave the spleen. The lienorenal and gastrosplenic ligaments are attached to the hilum. The area between the superior border and the hilum is the gastric area. The part between the inferior border and the hilum is related to the anterior surface of the left kidney. There is a raised margin separating the gastric and renal areas. The colic impression (left colic flexure) is below the hilum. The tail of pancreas is related to the hilum just above the colic impression.

vi. The diaphragmatic surface is convex and faces posterosuperiorly and to the left. It lies in contact with the inferior surface of diaphragm, which separates it from the left lung and left costodiaphragmatic recess (Fig. 82.20).
Surface Marking

The outline of the spleen is drawn on the lower posterior thoracic wall on the left side. A point about 4 to 5 cm away from the midline at the level of the spine of tenth thoracic vertebra represents the upper or posterior or medial end. A point on the tenth rib in the midaxillary line represents the lateral end. The superior border is indicated by joining the two points by a convex line along the upper border of the ninth rib. The inferior border is indicated joining the same points by a line, which passes along the lower margin of the eleventh rib.

Peritoneal Relations (Fig. 82.21)

The spleen is completely covered with peritoneum. It gives attachments to two peritoneal folds.

Blood Supply

The highly tortuous splenic artery enters the hilum of the spleen and breaks-up into 4 or 5 branches, which travel along the splenic trabeculae. The splenic vein emerges out of the hilum and joins the superior mesenteric vein behind the neck of the pancreas to form the portal vein.

Lymphatic Drainage

As the spleen filters blood and not the lymph, it receives no afferent lymphatic vessels. However, the efferent vessels from the stroma and capsule terminate in the pancreatico-splenic lymph nodes. The cancer cells rarely spread to the spleen because it lacks afferent lymph vessels and its microenvironment does not favor implantation and growth of malignant cells.

Know More ...

Splenic Circulation

The terminal branches of splenic artery enter the hilum of spleen and follow the trabeculae to ramify inside the spleen. Once these arteries narrow to the arteriolar dimensions, they enter the white pulp of spleen, where the arterioles lose their connective tissue adventitia and acquire the periarterial lymphatic sheath (PALS). At places, PALS are enlarged to form lymphatic follicles called Malpighian follicles. Inside the lymphatic follicle the central arteriole is typically in eccentric position. PALS and the Malpighian follicles constitute the white pulp of the spleen. The central arteriole comes out of the white pulp to enter the red pulp, where it abruptly divides into 3 to 5 straight penicillar arterioles. A sheath of macrophages called ellipsoid surrounds the terminal part of each penicillar arteriole. These sheathed arterioles terminate in arterial capillaries. Beyond this the venous side of splenic circulation starts. In close splenic circulation, the arterial capillaries communicate with venous sinusoids by direct arteriovenous connections. In open splenic circulation, the arterial capillaries discharge their blood in the spaces of red pulp and thence to the venous sinusoids. The components...
of the red pulp are the cords of Billroth (made of macrophages and reticulocytes, RBCs, WBCs, platelets and plasma cells) and the splenic sinusooids, which are lined by elongated endothelial cells. The venous sinusooids congregate to form venules, which join to form trabecular veins, which approach the hilum of the spleen and unite at or just outside the hilum to form the splenic vein. Since the periarterial lymphatic sheath is T-cell dominant and Malpighian corporcles are B cell dominant areas, the main function of the white pulp is to produce lymphocytes and plasma cells. In inflammatory conditions, the white pulp is antigenically stimulated. As a result, the lymphatic follicles develop germinal centers and become big in size causing increase in the size of the spleen. The macrophages of red pulp destroy worn out and damaged erythrocytes. Similarly, they phagocytose granulocytes, platelets, bacterial pathogens, particulate matter and parasites, e.g. malarial parasite. The red blood corporcles are broken down heme and globin. The heme contains iron and bilirubin. The iron is sent to bone marrow for reutilization or to liver for storage. Amino acids from hydrolysis of globin are returned to the amino acid pool of the body. The end product of hemoglobin breakdown (bilirubin) enters the liver via the splenic and portal veins. The hepatocytes process the bilirubin and add it to the bile.

**Clinical insight...**

i. A normal spleen is not palpable. Only when enlarged almost twice its normal size, the spleen becomes clinically palpable under the left costal margin. The spleen does not enlarge in a vertically downward direction due to the presence of phrenicocolic ligament. It enlarges along the spinoumbilical line, which extends from the right anterior superior iliac spine to the umbilicus. In massive enlargement the spleen may reach the right iliac fossa. Therefore, palpation of the spleen follows the spinoumbilical line towards the left costal margin.

ii. Splenomegaly is the term used for enlarged spleen. A few causes of splenomegaly include, portal hypertension, malaria, typhoid fever, hemolytic anemia and leukemia.

iii. Asplenia is absence of spleen. It is also known as right isomerism, in which bilateral right sidedness occurs. People born with right isomerism present following features, bilateral right atria, bilateral right lungs, centrally placed liver and asplenia.

iv. Polysplenia or left isomerism presents with bilateral left atria, bilateral left lungs and polysplenia.

v. Figure 82.22 shows massive splenomegaly in a child suffering from rare cancer called splenic lymphangiomatosis for which splenectomy (surgical removal of spleen) is performed. In this operation the gastrosplenic and lienorenal ligaments are dissected carefully to isolate, clamp and cut the splenic blood vessels (preserving the tail of pancreas).
BLOOD SUPPLY OF DIGESTIVE TRACT

The abdominal aorta gives origin to the three unpaired arteries for the supply of the derivatives of foregut, midgut and hindgut. The celiac trunk is the artery of foregut. The superior mesenteric artery is the artery of midgut. The inferior mesenteric artery is the artery of hindgut.

Celiac Trunk (Fig. 83.1)
The celiac trunk is a very short artery (1 cm long) as it immediately divides into left gastric, common hepatic and splenic arteries, which diverge in three directions. The celiac trunk is surrounded by celiac plexus of nerves.

Celiac Arteriography
This is a radiological procedure to visualize the celiac artery and its branches. The radiopaque dye is injected through a catheter that passes in succession through the femoral artery, external iliac artery, common iliac artery and the abdominal aorta.

Left Gastric Artery
The left gastric artery at first runs upwards and to the left behind the parietal peritoneum to the cardiac end of the stomach. Then it enters the left end of the lesser omentum. Before entering the lesser omentum it gives esophageal

Fig. 83.1: Branches of celiac trunk (artery)
branches to the lower end of the esophagus. Inside the lesser omentum, it anastomoses with the right gastric artery along the lesser curvature of the stomach.

**Common Hepatic Artery**

The common hepatic artery passes at first to the right behind the parietal peritoneum. On its way to the lesser omentum, it first gives origin to right gastric artery and then to gastroduodenal artery.

i. The right gastric artery passes to the left and enters the lesser omentum to anastomose with left gastric artery.

ii. The gastroduodenal artery descends posterior to the first part of duodenum and divides into right gastroepiploic and superior pancreaticoduodenal arteries at its lower margin. The ulcer on the posterior wall of the first part of duodenum may perforate and erode the gastroduodenal artery causing massive bleeding in the peritoneal cavity. Hence, this artery is called the “artery of duodenal hemorrhage”. It may give rise to supraduodenal artery of Wilkie and it frequently supplies retroduodenal branches to the first part of duodenum.

The right gastroepiploic artery enters the greater omentum where it anastomoses with the left gastroepiploic artery. The superior pancreaticoduodenal arteries are two in number, anterior and posterior. They course along the junction of pancreatic head and second part of duodenum to anastomose with corresponding branches of inferior pancreaticoduodenal artery. The superior pancreaticoduodenal arteries give twigs to the head of pancreas and supply the duodenum up to the major duodenal papilla.

**Hepatic Artery Proper**

The common hepatic artery continues as hepatic artery proper after it gives origin to the gastroduodenal artery. The superior pancreaticoduodenal arteries are two in number, anterior and posterior. They course along the junction of pancreatic head and second part of duodenum to anastomose with corresponding branches of inferior pancreaticoduodenal artery. The superior pancreaticoduodenal arteries give twigs to the head of pancreas and supply the duodenum up to the major duodenal papilla. The cystic artery usually arises from the right branch of the hepatic artery. The right and left hepatic branches enter the porta hepatis to supply the corresponding lobes of liver.

**Splenic Artery**

The splenic artery is the largest branch of the celiac trunk. It is tortuous to allow for the expansion of the stomach as the artery is one of the constituents of the stomach bed. It runs retroperitoneally towards the left along the superior margin of the pancreas. After reaching the front of left kidney, it enters the lienorenal ligament along with the tail of pancreas. It supplies several pancreatic branches that arise along the superior margin of the pancreas. A few short gastric arteries and the left gastroepiploic artery arise near the hilum of the spleen and reach the stomach via the gastrosplenic ligament. The terminal splenic branches enter the spleen via the hilum.

**Superior Mesenteric Artery (Fig. 83.2)**

The superior mesenteric artery (SMA) arises from the front of the abdominal aorta about 0.5 cm below the celiac trunk at the level of the disc between L1 and L2 vertebrae behind the body of pancreas. From its origin until its entry into the root of the mesentery, the artery lies on the posterior abdominal wall. Since the artery angles acutely in the first part of its course it forms a nutcracker with the aorta (Fig. 81.18). The structures enclosed inside the vascular nutcracker are, left renal vein, uncinate process of pancreas and third part of duodenum. The unusual venous relation at its origin is the splenic vein embedded in the posterior surface of body of pancreas in front and the left renal vein behind.

**Course**

From behind the pancreas the superior mesenteric artery emerges anteriorly by passing between the uncinate process and body of the pancreas. It crosses in front of the third part of the duodenum to enter the root of the mesentery, in which it travels downwards and to the right to reach the ileocecal junction.

**Surface Marking**

The upper point is in the midline just above the transpyloric plane. The lower point lies at the intersection of right lateral and transtubercular planes. The line joining the two points has a slight convexity to the left.

**Branches (Fig. 83.2)**

i. The inferior pancreaticoduodenal artery may arise from the superior mesenteric artery or its first jejunal branch. Its anterior and posterior branches make anastomoses with the corresponding branches of superior pancreaticoduodenal artery. This anastomosis is the only communication among the branches of celiac and superior mesenteric arteries (arteries of the foregut and midgut).

ii. The jejunal and ileal branches are several in numbers and arise from the left side of the superior mesenteric artery. These arteries pass through the mesentery to reach the gut.

iii. The ileocolic artery is actually the continuation of the superior mesenteric artery. It divides into ascending and descending branches. The ascending branch
anastomoses with descending branch of right colic artery. The descending branch supplies terminal ileum by its ileal branch, cecum by anterior and posterior cecal branches, appendix by appendicular branch and the lower part of ascending colon by colic branch.

iv. The right colic artery arises from the right side and travels on the posterior abdominal wall behind the peritoneum. On reaching the ascending colon it divides into ascending and descending branches, which anastomose with branches of ileocolic and middle colic arteries to form marginal artery.

v. The middle colic artery arises from the right side of superior mesenteric artery. It enters the transverse mesocolon and divides in right and left branches that anastomose with branches of right colic and left colic arteries to complete the marginal artery. The anastomosis between left colic and middle colic at the level of marginal artery may be deficient. This break in the marginal artery is usually compensated by presence of an artery called an arc of Riolan between the trunk of middle colic artery and ascending branch of left colic artery. In case, the arc of Riolan is not developed the blood supply of left colic flexure is in danger.

**Intestinal Angina**

Stenosis of superior mesenteric artery may produce colicky abdominal pain referred to the umbilicus (intestinal angina).

**Superior Mesenteric Arteriography**

The artery and its branches can be visualized by injecting a radiopaque dye in it. For this purpose the artery is approached via the femoral artery, external iliac artery, common iliac artery and the abdominal aorta.

**Inferior Mesenteric Artery**

The inferior mesenteric artery (IMA) arises from the aorta at the level of L3 vertebra posterior to the third part of duodenum. It courses down on the front of aorta and then on the posterior abdominal wall on the left side of the aorta. It continues as the superior rectal artery.

**Surface Marking**

The upper end of the artery is in the midline 4 cm below the transpyloric plane. The lower end lies 4 cm below the umbilicus and 4 cm to the left of the midline.

**Branches (Fig. 83.3)**

i. Left colic artery runs upwards and to the left behind the peritoneum and divides into ascending and descending branches. The descending branches communicate with sigmoid arteries and ascending branches meet the left branches of middle colic artery and thus form the marginal artery.

ii. Sigmoid arteries enter the left limb of sigmoid mesocolon and their branches take part in completing the marginal artery. It has been observed that there is a constant anastomosis between the lowest sigmoid artery and a branch of superior rectal artery.

iii. Superior rectal artery is the continuation of inferior mesenteric artery in the true pelvis. It descends in
the right limb of the sigmoid mesocolon. At the level of third piece of sacrum, it divides into two branches. These branches course down on either side of rectum and give twigs that pierce the rectal wall to supply the mucous membrane of the rectum and that of anal canal up to the level of pectinate line, where they anastomose with branches of inferior rectal arteries.

**Inferior Mesenteric Arteriography**

It is possible to visualize the artery by injecting a radioopaque dye in it. The approach is similar to that for the superior mesenteric artery.

**Marginal Artery of Drummond (Fig. 83.4)**

The marginal artery is a circumferential arterial channel located close to the colon and extending from the ileocecal junction to the rectosigmoid junction. It is an anastomotic channel formed by colic branches of superior and inferior mesenteric arteries. It supplies vasa longa and vasa brevia to the wall of the colon. In the event of a block in the inferior mesenteric artery, the blood reaches the left side of the colon through the marginal artery. If the superior mesenteric artery is occluded, the marginal artery becomes enormously dilated since it supplies the entire small intestine through the connection between the ileal branches of ileocolic and ileal branches of superior mesenteric artery. It is observed that at the junctional area of the supply of the superior and inferior mesenteric arteries, the anastomosis may not be sufficient. This area is the splenic flexure, where the ascending branch of left colic artery may fail to communicate with the left branch of middle colic artery (at the level of marginal artery). There is another anastomosis connecting the trunk of middle colic artery with the ascending branch of left colic artery. This anastomosis is called arc of Riolan. If by any chance this anastomosis is not well developed then the arterial supply of the splenic flexure is endangered in case of obstruction of any one of the two parent arteries. This explains the relative frequency of ischemic lesions in the region of splenic flexure. Therefore, the critical point on the gut is said to exist at the splenic flexure.

**Venous Drainage**

The veins accompanying the ileocolic, right colic and middle colic arteries join the superior mesenteric vein while the veins accompanying the branches of inferior mesenteric artery join the inferior mesenteric vein. Both the veins ultimately drain into portal circulation.

**Portal Vein**

The portal vein is an important venous channel that collects blood from the abdominal and pelvic parts of digestive tract (excluding lower part of anal canal), pancreas, spleen and gallbladder. It carries products of digestion of carbohydrates and proteins and other nutrients from the intestines and also products of hemoglobin catabolism from the spleen to the liver sinusoids. The portal vein begins like a vein in the capillary bed and terminates in the hepatic sinusoids like an artery. Since it passes through two sets of exchange vessels, the portal pressure is higher than systemic venous pressure. The normal portal pressure is 5 to 15 mm of Hg. The portal vein and its tributaries are valve less. They act as reservoir of blood since they contain up to one-third of the total volume of blood in the body.

**Formation (Fig. 83.5)**

The portal vein is formed posterior to the neck of pancreas by the union of superior mesenteric and splenic veins at the level of L2 vertebra.

**Parts**

It is extrahepatic and intrahepatic parts (vide infra).

**Termination**

The portal vein terminates into right and left branches at the right end of porta hepatitis.
Extrahepatic Course

The extrahepatic part, about 8 to 10 cm long, is divided into three parts, infraduodenal, retroduodenal and supraduodenal.

i. The infraduodenal part lies below the first part of the duodenum. It is related anteriorly to the neck of pancreas, posteriorly to the inferior vena cava and on its right to common bile duct.

ii. The retroduodenal part lies posterior to the first part of duodenum. It is related anteriorly to first part of duodenum with common bile duct and gastroduodenal artery separating the two. Posteriorly, it is related to inferior vena cava.

iii. The supraduodenal part is located into free margin of lesser omentum. The common bile duct and hepatic artery proper are related to it anteriorly, the artery being medial to the duct. The epiploic foramen is related posteriorly. The foramen separates the portal vein and the inferior vena cava.

Intrahepatic Course

At the right edge of porta hepatis, the portal vein divides into two terminal branches. The right branch is shorter and wider and may receive a cystic vein before entering the right lobe of liver. The longer left branch enters the left lobe. Three structures join the left branch inside the liver (ligamentum teres, ligamentum venosum and paraumbilical veins).

Blood Flow in Portal Vein (Fig. 83.5)

The portal vein contains two sluggish streams of blood probably due to the wide angle of union between the superior mesenteric and splenic veins. The right stream carries blood from the superior mesenteric vein and the
left stream carries blood from the splenic vein. The right branch of the portal vein distributes blood to the right lobe of liver from the intestine up to the right two-thirds of the transverse colon. The left branch of the portal vein distributes blood to the left lobe of liver (including the caudate and quadrate lobes) from the stomach, spleen, pancreas and the large intestine (including left one-third of transverse colon, rectum and anal canal up to the pectinate line). Therefore, primary cancer or infective emboli from the sigmoid colon deposit in the left lobe and that from the cecum in the right lobe of liver.

**Tributaries (Fig. 83.7)**

i. The direct tributaries of the portal vein are, superior mesenteric, splenic and right and left gastric veins.

ii. The tributaries of the superior mesenteric vein are, ileocolic, right colic, middle colic, jejunal, ileal and right gastroepiploic veins.

iii. The tributaries of the splenic vein are, short gastric, left gastroepiploic and inferior mesenteric veins.

iv. The tributaries of the inferior mesenteric vein are superior rectal, sigmoid and left colic veins.

**Paraumbilical, Cystic and Prepyloric Veins**

i. The paraumbilical veins extend from the anterior abdominal wall along the ligamentum teres to the left branch of portal vein. They are connected to superficial veins of abdominal wall by potential anastomoses.

ii. A few cystic veins open in the right branch of portal vein.

iii. The prepyloric veins of Mayo are the anterior relation to the pylorus of the stomach. During surgery on pylorus, these veins are helpful in identification of the pylorus. They ascend in front of the pylorus and drain into the right gastric vein.

**Know More**

**Measurement of Portal Pressure**

i. Direct method consists of splenic puncture through which the pressure of the splenic pulp is measured.

ii. An indirect method of measuring the portal pressure is to record the hepatic vein pressure under radiographic control. The catheter passes in succession through the right median cubital, basilic, axillary, subclavian, and brachiocephalic veins and then through the SVC to the right atrium. It is further advanced to the IVC until it reaches the hepatic veins. When the tip of the catheter is wedged in the smaller tributaries of the hepatic vein, pressure is recorded.

**Radiological Examination**

To study the portal venous anatomy on a radiograph a contrast material is injected in the spleen (splenoportography).

**Clinical insight ...**

The obstruction of portal vein leads to portal hypertension. The causes of obstruction may be divided into intrahepatic and extrahepatic. Among the intrahepatic causes, the most common is the cirrhosis of liver. Among the extrahepatic causes, portal vein thrombosis is one of the causes. The obstruction to blood flow leads to stasis and rise in portal pressure. The effects of portal hypertension are splenomegaly (enlargement of spleen), ascites and those due to enlarged portosystemic collateral channels. The blood in portal circulation is diverted to the systemic circulation through portosystemic communications because of which the veins at such sites are dilated.

**Sites of Portosystemic Anastomoses (Fig. 83.8)**

i. At the lower end of esophagus the left gastric vein (a portal vein tributary) and the esophageal veins (the hemiazygos vein—a systemic vein tributary) anastomose in the submucosa. This submucosal venous plexus is dilated and tortuous in portal hypertension giving rise to esophageal varices. The rupture of the varices leads to vomiting of blood (hematemesis).

ii. Around the umbilicus, the paraumbilical veins (portal tributary) anastomose with the superficial tributaries of superior epigastric and inferior epigastric veins.
Fig. 83.8: Sites of portosystemic anastomoses. (A) Umbilicus; (B) Lower end of esophagus; (C) Pectinate line of anal canal

Contd...

(systemic veins). Enlargement of the radiating veins in portal hypertension produces a characteristic pattern of dilated veins around the umbilicus (caput medusae).

iii. At the level of pectinate line in the anal canal submucosal venous plexus contains potential anastomoses between the superior rectal vein (a portal vein tributary) with inferior rectal veins (systemic vein tributary) below the pectinate line. The enlargement of this venous plexus gives rise to internal piles, which may cause bleeding per rectum, on injury.

iv. At bare area of liver, the hepatic portal radicals directly communicate with inferior phrenic veins.

v. Retroperitoneal areas of posterior abdominal wall are the areas in relation to retroperitoneal organs like ascending or descending colon. Here, the portal vein tributaries draining these organs may communicate with the systemic veins of posterior abdominal wall.
LUMBAR FASCIA

The lumbar fascia (thoracolumbar fascia) is the deep fascia of lumbar region between the iliac crest and the twelfth rib. It is divisible into three layers, the posterior, middle and anterior (Fig. 84.1).

Posterior Layer
i. Medially, it is attached to the tips of spines of the lumbar vertebrae and the supraspinous ligaments.
ii. Laterally, it fuses with the middle layer along the lateral margin of erector spinae.
iii. Above, it is continuous with the deep fascia on the posterior thoracic wall.
iv. Below, it is continuous with the deep fascia over the sacral region.

Middle Layer
i. Medially, it is attached to the tips of transverse processes of lumbar vertebrae.
ii. Laterally, it fuses with the posterior layer along the lateral margin of the erector spinae muscle.
iii. Above, it is attached to the lower border of the twelfth rib.
iv. Below, it is attached to the posterior part of the iliac crest.

Anterior Layer
i. Medially, it is attached to the middle of the anterior surface of transverse processes of lumbar vertebrae.
ii. Laterally, it fuses with the fused middle and posterior layers lateral to the quadratus lumboorum.
iii. Above, it is attached to the lower border of twelfth rib.
iv. Below, it is attached to the iliolumbar ligament and iliac crest.

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- LUMBAR PLEXUS
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Fig. 84.1: Vertebral attachments of layers of lumbar fascia (Note the muscles enclosed by and taking origin from lumbar fascia)
Abdomen, Pelvis and Perineum

Muscles Attached to Lumbar Fascia

i. The posterior layer gives origin to the latissimus dorsi and serratus posterior inferior muscles.

ii. The lateral margin of the fused layers of the fascia gives origin to transversus abdominis and internal oblique muscles.

iii. The upper margin of the anterior layer (lateral arcuate ligament) gives origin to the diaphragm.

Special Relations of Anterior Layer

The anterior layer lies immediately behind the posterior surface of the kidney. Its upper margin is thickened to form lateral arcuate ligament, which extends from the front of the transverse process of first lumbar vertebra to the last rib. The quadratus lumborum muscle lies between the anterior and middle layers of lumbar fascia. The subcostal nerve and vessels, iliohypogastric and ilioinguinal nerves pass between the quadratus lumborum muscle and the anterior layer of lumbar fascia.

MUSCLES OF POSTERIOR ABDOMINAL WALL

Quadratus Lumborum (Fig. 84.2)

The quadratus lumborum is the most lateral muscle of the posterior abdominal wall. It extends between the iliac crest and the twelfth rib.

- It arises from the iliolumbar ligament, the adjacent part of the iliac crest and second to fourth lumbar transverse processes.

- It is inserted into the anterior aspect of the medial part of the twelfth rib and in the upper four lumbar transverse processes posterior to its own slips of origin.

Nerve Supply

The muscle receives nerve supply from the direct branches of upper lumbar nerves and subcostal nerve.

Relations

The relations of quadratus lumborum are important during surgery on kidney by lumbar route. The muscle is enclosed within the anterior and middle layers of thoracolumbar fascia. The muscle is related anteriorly to the posterior surface of the respective kidney. The subcostal nerve and vessels and ilioinguinal and iliohypogastric nerves are in close relation to its anterior surface.

Actions

The quadratus lumborum helps in inspiration by fixing the twelfth rib in lower position, when the diaphragm contracts. Acting singly the muscle is a lateral flexor of lumbar vertebral column. Acting together the two muscles extend the lumbar vertebral column.

Psoas Major (Fig. 84.3)

This muscle is located on posterior abdominal wall and in the femoral triangle.

Origin

It has a wide origin from the anterior surfaces of medial parts of transverse processes of all lumbar vertebrae, sides of bodies of all lumbar vertebrae and of twelfth thoracic vertebra, intervertebral discs between twelfth thoracic and fifth lumbar vertebrae and four tendinous arches between adjacent bodies of lumbar vertebrae.

Insertion

It is inserted by a tendon on the lesser trochanter of femur along with the iliacus.

Know More ...

Psoas minor muscle, if present lies anterior to the psoas major and is confined to abdomen only. It has a common origin with psoas major from the twelfth thoracic and first lumbar vertebrae and is inserted in the iliopubic eminence.
Relations of Psoas Major in Abdomen

As the lumbar plexus is located inside the muscle, the branches of the plexus emerge from the psoas major as follows (Fig. 84.3). The iliohypogastric nerve, ilioinguinal nerve, lateral cutaneous nerve of thigh, and the femoral nerve emerge from its lateral margin. The genitofemoral nerve emerges from its anterior surface and the obturator nerve emerges from its medial margin.

The psoas major muscle is enclosed in the psoas sheath, which is open only at its upper end. The upper margin of the psoas sheath is thickened to form the medial arcuate ligament, which gives origin to muscle fibers of the diaphragm.

Relations in Femoral Triangle

The psoas major lies in the floor of the femoral triangle, where it is related anteriorly to the femoral artery. Posteriorly, it is related to the capsule of hip joint. The pectineus and femoral vein are on its medial side and the femoral nerve and iliacus are on the lateral side.

Nerve Supply

The psoas major is supplied by the ventral rami of upper four lumbar spinal nerves and psoas minor is supplied by first lumbar ventral ramus.

Actions

i. The main action along with the iliacus is flexion of thigh at hip joint.

ii. It is a medial rotator of thigh as its insertion is situated lateral to the axis of rotation, which passes through the head of femur.

iii. The muscles help in flexion of the trunk as in getting up from the supine position.

iv. In fracture of the neck of femur, it rotates the thigh laterally because the axis of rotation passes through the shaft of femur (medial to the insertion of psoas major).

Testing Function of Psoas Major

In the sitting position with lower limb at right angles to the trunk, the subject is asked to lift the limb (flexion at the hip is tested).

Clinical insight...

i. Right psoas major muscle is related to the retrocecal vermiform appendix. An inflamed appendix causes spasm of psoas major muscle. So to reduce pain the patient keeps the right thigh in the flexed and medially rotated position. The anatomical relation of right psoas major to pelvic appendix is the basis of psoas test in appendicitis. In this test on asking the patient to extend the thigh pain is experienced due to the stretch on the muscle.

ii. Psoas abscess is accumulation of pus inside the psoas sheath. Since the sheath is open superiorly, the pus from tuberculous thoracic vertebrae can enter it giving rise to abscess, which may track down along the sheath and appear as a swelling in the femoral triangle.

Iliacus Muscle (Fig. 84.3)

The iliacus is a triangular muscle that arises mainly from the iliac fossa. The iliacus and psoas major muscles have a common insertion at the lesser trochanter of femur. The abdominal part of the muscle is covered with fascia iliaca. This fascia merges medially with psoas sheath and is attached to the iliopectineal eminence. Inferiorly, in the region of the femoral vessels the fascia iliaca forms the posterior wall of the femoral sheath. The cecum is related to the anterior surface of right iliacus whereas the descending colon is related to left iliacus.

Nerve Supply

The femoral nerve supplies the iliacus in the iliac fossa.

Actions

The actions of iliacus are same as psoas major.

Lumbar Plexus

The lumbar plexus of nerves is formed on the posterior abdominal wall in the substance of psoas major muscle.
The lumbar plexus is formed from the upper three ventral rami of lumbar nerves and the upper part of the fourth lumbar ventral ramus. The lower part of the fourth and the fifth rami unite to form the lumbosacral trunk. Because the ventral ramus of fourth lumbar nerve bifurcates to take part in the lumbar plexus and the lumbosacral trunk, it is called the nervus furcalis. All the ventral rami receive gray rami communicantes (GRC) carrying postganglionic fibers from the sympathetic ganglia. The ventral rami of first and second lumbar nerves are connected to sympathetic ganglia by white rami communicantes (WRC), which carry preganglionic fibers to the sympathetic chain from the spinal cord.

**Formation**

i. The upper larger division of first lumbar ventral ramus bifurcates into iliohypogastric nerve (L1) and ilioinguinal nerve (L1).

ii. The lower smaller division of first lumbar ventral ramus unites with a branch from the second lumbar ventral ramus to form the genitofemoral nerve (L1, L2).

iii. The second, third and fourth ventral rami divide into dorsal and ventral divisions.

iv. The dorsal divisions of second and third ventral rami give off smaller branches, which unite to form the lateral cutaneous nerve of thigh (L2, L3).

v. The remaining parts of the dorsal divisions of second, third and the entire dorsal division of the fourth rami unite to form femoral nerve (L2, L3, L4).

vi. The ventral divisions of L2, L3 and L4 unite to form obturator nerve (L2, L3, L4).

The accessory obturator nerve, if present, receives fibers from the third and fourth ventral divisions.

**Iliohypogastric and Ilioinguinal Nerves**

The iliohypogastric and ilioinguinal nerves (L1) come out of the lateral margin of psoas major muscle and then descend laterally on the front of quadratus lumborum. They enter the neurovascular plane of the anterior abdominal wall at the lateral border of quadratus lumborum muscle. Their further course and distribution are described in chapter 79.

**Genitofemoral Nerve**

The genitofemoral nerve (L1, L2) emerges from the anterior surface of the psoas major muscle. It pierces the psoas sheath and then ends by dividing into genital and femoral branches at a variable distance above the inguinal ligament.

i. The genital branch enters the deep inguinal ring in the fascia transversalis and traverses the inguinal canal to come out through the superficial inguinal ring. It supplies the cremaster muscle and is sensory to the scrotal skin in male and skin of mons pubis and labium majus in female.

ii. The femoral branch descends posterior to the inguinal ligament and enters the femoral sheath lateral to the femoral artery. It pierces the anterior wall of the femoral sheath and fascia lata to supply the skin of the upper part of femoral triangle.

**Lateral Cutaneous Nerve of Thigh**

The lateral cutaneous nerve of thigh is also known as the lateral femoral cutaneous nerve. It emerges from the lateral margin of psoas major muscle and descends on the iliacus muscle. In the iliac fossa, it is posterior to the lower part of descending colon on left side and cecum on the right side. It enters the thigh by passing behind or through the lateral end of inguinal ligament and is distributed to the skin of the anterolateral surface of the thigh. At the site where it passes through inguinal ligament, the nerve is liable to compression causing meralgia paresthetica.

**Obturador Nerve**

The obturator nerve (L2, L3, L4) takes origin from the lumbar plexus from the ventral divisions of ventral rami of lumbar second to fourth spinal nerves. It has an abdominal and intrapelvic course before it reaches the obturator foramen, through which it enters the medial compartment of the thigh.

i. The obturator nerve emerges from the medial border of the psoas major muscle and enters the true pelvis behind the common iliac vessels and in front of the sacroiliac joint.

ii. In its intrapelvic course, the obturator nerve travels forwards on the medial surface of the obturator internus along the lateral wall of the true pelvis. The obturator vessels accompany the obturator nerve lying below it.

iii. At the obturator foramen, the nerve divides into anterior and posterior divisions.

iv. The relation of the obturator nerve to the ovarian fossa deserves special mention. The lateral surface of the ovary is in contact with the parietal peritoneum of ovarian fossa. The obturator nerve and vessels are retroperitoneal structures in this location. The inflammation of ovary may produce localized peritonitis in the ovarian fossa and consequent irritation of the obturator nerve. The patient experiences pain along the medial side of thigh and knee.

v. The course and distribution of the obturator nerve in the thigh is described in the medial compartment of thigh (chapter 95).
Chapter Vertebrae Extent
It extends from the lower border of the twelfth thoracic vertebra to the fourth lumbar vertebra.

Termination
The aorta bifurcates into the right and left common iliac arteries a little to the left of the midline.

Surface Marking
The abdominal aorta can be indicated on the anterior abdominal wall by a 2 cm wide band drawn in the midline at the level of a point, which is 2.5 cm above the transpyloric plane. A point 1 cm below and to the left of umbilicus denotes the lower level of this band.

Aortic Pulssations
The aortic pulsations can be felt or may be visible just below and slightly to the left of the umbilicus in thin individuals, when the abdominal muscles are relaxed.

Histological Peculiarity
The infrarenal abdominal aorta is composed of following three layers.

i. The tunica intima endothelium, subendothelial tissue and internal elastic lamina (which is fenestrated).

ii. Tunica media contains stacks of fenestrated elastic laminae.

iii. The tunica adventitia contains vasa vasorum (vessels feeding vessels) along with loose connective tissue. The vasa vasorum of infrarenal aorta do not penetrate the tunica media hence the entire burden of supplying nourishment to aortic wall falls on diffusion from luminal blood. When tunica intima thickens due to atherosclerosis (as age advances) diffusion from luminal blood is reduced. This leads to weakening of the wall of aorta. This is the reason why abdominal aneurysms occur in infrarenal part of abdominal aorta.

Radiological Visualization

i. Abdominal aortography is the radiological procedure to visualize the aorta and its branches. The contrast is injected via a catheter passed in the femoral artery and extended via the external and common iliac arteries in to the aorta.

ii. The ultrasound, CT scan and MRI are the other tools for visualizing the aorta.

Relations of Abdominal Aorta

i. The anterior relations from above downward are the celiac trunk and its three branches, the origin of
superior mesenteric artery, splenic vein, left renal vein, origin of inferior mesenteric artery, third part of duodenum and the root of the mesentery.

ii. The posterior relations are the vertebral column, the dorsal branches of aorta (lumbar arteries and median sacral artery) and the left third and fourth lumbar veins.

iii. On the right side, it is related to the right crus of diaphragm and right celiac ganglion in the upper part. Below the level of second lumbar vertebra inferior vena cava is the right relation.

iv. On the left side, there are left crus of diaphragm and left celiac ganglion in the upper part. At the level of second lumbar vertebra the duodenojejunal junction is on the left side. Below this, the inferior mesenteric vessels are on the left side.

### Branches of Abdominal Aorta with Vertebral Level of Origin

<table>
<thead>
<tr>
<th>No.</th>
<th>Branch</th>
<th>Type</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inferior phrenic arteries</td>
<td>Paired and parietal</td>
<td>T12</td>
</tr>
<tr>
<td>2</td>
<td>Celiac trunk</td>
<td>Unpaired visceral</td>
<td>T12</td>
</tr>
<tr>
<td>3</td>
<td>Superior mesenteric artery</td>
<td>Unpaired visceral</td>
<td>L1</td>
</tr>
<tr>
<td>4</td>
<td>Middle suprarenal arteries</td>
<td>Paired visceral</td>
<td>L1</td>
</tr>
<tr>
<td>5</td>
<td>Renal arteries</td>
<td>Paired visceral</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Gonadal ovarian or testicular</td>
<td>Paired visceral</td>
<td>L2</td>
</tr>
<tr>
<td>7</td>
<td>Inferior mesenteric artery</td>
<td>Unpaired visceral</td>
<td>L3</td>
</tr>
<tr>
<td>8</td>
<td>Four lumbar arteries</td>
<td>Paired parietal</td>
<td>L1 – L4</td>
</tr>
<tr>
<td>9</td>
<td>Median sacral</td>
<td>Unpaired parietal</td>
<td>L4</td>
</tr>
<tr>
<td>10</td>
<td>Common iliac arteries</td>
<td>Paired terminal</td>
<td>L4</td>
</tr>
</tbody>
</table>

### Clinical insight ...

- Leriche syndrome is due to chronic atherosclerosis of the distal abdominal aorta below the origin of the renal arteries. The atherosclerosis gradually occludes the abdominal aorta near its bifurcation and encroaches on the common iliac arteries. The claudication (pain on exercise) characteristically involves lower back, buttocks, thighs and calves. This may cause impotence in males if the internal iliac arteries are occluded. The clinical findings include bilateral absence of femoral pulses and the detection of audible bruit on the abdomen below the umbilicus.

- The sudden occlusion in the distal abdominal aorta occurs as a result of occlusive embolus usually arising from the heart. This gives rise to acute pain in the lower limbs accompanied by coolness and pallor. Gangrene of the lower limb is the dreaded complication of this condition.

- The aneurysm of abdominal aorta (Fig. 84.5) due to atherosclerosis is common. It presents as a pulsatile, palpable nontender mass just below the umbilicus.

### Common Iliac Arteries

The right and left common iliac arteries are the terminal branches of the abdominal aorta arising at the level of the fourth lumbar vertebra. The common iliac arteries divide into external and internal arteries at the level of the disc between sacrum and the fifth lumbar vertebra in front of the sacroiliac joints.
Formation (Fig. 84.7)
The IVC is formed by the union of the right and left common iliac veins on the front of the body of the fifth lumbar vertebra about 2 cm to the right of the midline. The IVC has no valves.

Length
The IVC is 20 to 23 cm long (almost double the length of the abdominal aorta).

Surface Marking
The IVC is represented by a band 2.5 cm wide drawn to the right of the median plane. The left margin of the band is

Branches
The common iliac arteries give a few peritoneal and ureteric branches besides the terminal branches.

Angiography of Common Iliac Arteries
The atherosclerosis of these arteries endangers the arterial supply of the lower limb. To examine the arteries aortic angiography is done. If narrowing is found, stenting (Figs 84.6A and B) is the method of choice to dilate the artery and restore circulation to the lower limb.

External Iliac Artery
It is larger terminal branch of common iliac artery. It is the major artery supplying the lower limb. It descends along the medial margin of psoas major muscle to the midinguinal point, where it continues as the femoral artery.

Surface Marking
The external iliac artery is represented by lower two-third of a broad line joining the point of aortic bifurcation to the midinguinal point.

Branches
  i. Deep circumflex iliac artery
  ii. Inferior epigastric artery.

Internal Iliac Artery
The internal iliac artery enters the true pelvis by crossing the pelvic brim on each side. The description of its branches in the male and female is given in chapter 86.

INFERIOR VENA CAVA (IVC)
This largest vein drains the blood from the body below the level of diaphragm. It extends from the right of the fifth lumbar vertebra to the level of eighth thoracic vertebra, where it pierces the central tendon of diaphragm. It opens in the right atrium immediately thereafter.

Figs 84.6A and B: (A) Angiographic appearance of occluded (arrow) left common iliac artery; (B) Restoration of blood flow in the same artery after stenting
Abdomen, Pelvis and Perineum

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1 cm from the median plane and the right margin is 3.5 cm from the median plane. The lower limit of the band corresponds to a line just below the transtubercular plane and its upper limit is at the sternal end of the right sixth costal cartilage.

Relations of IVC

i. The anterior relations, starting from its commencement to its opening in the diaphragm are the right common iliac artery, root of mesentery, third part of duodenum, head of pancreas, bile duct and portal vein, epiploic foramen and the vena caval groove on the posterior surface of the liver.

ii. The posterior relations are the bodies of lumbar vertebrae, right psoas major muscle, right crus of diaphragm and the anteromedial surface of the right suprarenal gland.

iii. To the left of IVC runs the abdominal aorta and to its right are the second part of duodenum and medial margin of right kidney.

Tributaries of IVC

i. Four pairs of lumbar veins drain blood from the abdominal wall and the vertebral venous plexus. In front of the roots of the transverse processes of the lumbar vertebrae the lumbar veins join each other by a vertical channel called the ascending lumbar vein, which joins the azygos vein. There is another vertical channel called lumbar azygos vein, which lies parallel and medial to the ascending lumbar vein. The first and second lumbar veins open into either the ascending lumbar vein or the azygos lumbar vein. The third and fourth lumbar veins directly open into the IVC.

ii. Inferior phrenic veins open directly in the IVC.

iii. Right gonadal vein (testicular or ovarian) is a direct tributary.

iv. Renal veins are the direct tributaries.

v. Right suprarenal vein is a direct tributary.

vi. Hepatic veins are extremely short. As soon as they emerge in the groove for IVC they open into IVC.

Know More...

Collateral Circulation

If there is obstruction to the IVC, the blood from below the level of obstruction is carried to the right atrium through SVC via collateral anastomotic channels at the following sites.

i. In the anterior abdominal wall, the tributaries of the inferior epigastric veins (tributaries of external iliac veins) are in communication with the lateral thoracic veins (tributaries of axillary veins) by thoraco-epigastric veins. So, the blood from femoral vein goes to the external iliac vein and from there is carried by the inferior epigastric vein to the thoraco-epigastric vein and thence to the axillary vein for onward passage to SVC. There are dilated and tortuous veins in the lateral part of anterior abdominal wall in obstruction of IVC (Fig.79.5A).

ii. The lumbar veins communicate in the anterior abdominal wall with lower intercostal, subcostal, inferior epigastric and iliolumbar veins. The posterior parts of lumbar veins receive intervertebral veins, which make communications with vertebral venous plexus. Similarly, the lateral sacral veins carry blood from pelvic organs to the vertebral venous plexus. In obstruction of IVC, the lumbar veins and the lateral sacral veins carry the blood in reverse direction to the vertebral venous plexus, the cranial venous sinuses and ultimately via the internal jugular vein to the SVC. This venous route is responsible for secondary deposits of cancer cells (from the primary in pelvic organs) to the vertebral column and cranial bones.

iii. The azygos system of veins forms an important alternate venous pathway. The ascending lumbar, lumbar azygos and subcostal veins are dilated to carry additional load of blood from the anterior and posterior abdominal walls to the azygos vein, which empties in to the SVC. (Note: In obstruction to SVC same anastomotic channels open up except that the blood flows from above downwards so that blood from obstructed SVC is brought to IVC for carrying to right atrium)
LYMPH NODES OF ABDOMEN AND PELVIS

The main lymph nodes of the abdomen are retroperitoneal. They are located on posterior abdominal wall close to the abdominal aorta. These nodes are called lumbar nodes and are divisible into three groups.

i. Preaortic group comprising of intercommunicating celiac, superior mesenteric and inferior mesenteric nodes
ii. Right lateral aortic or para-aortic group
iii. Left lateral aortic or para-aortic group

Preaortic Lymph Nodes

The preaortic lymph nodes are located in front of the abdominal aorta around the origin of its three midline branches. They receive lymph from the alimentary canal below the diaphragm and from the associated glands.

i. The celiac lymph nodes are closely related to origin of celiac artery. They receive lymph from the regional nodes lying along the branches of celiac trunk. Three main groups fall under this category, namely, gastric, hepatic and gastrosplenic. These are further subdivided into outlying nodes associated with specific viscera. The efferent vessels from the celiac group unite to form intestinal trunks, which empty into the cisterna chyli.

ii. The superior and inferior mesenteric nodes are located around the origin of the arteries of the same names. They receive lymph from regional nodes draining the digestive tract from duodenojejunal flexure to the pectinate line of anal canal. The regional lymph nodes comprise of 100 to 150 mesenteric, ileocolic, colonic and pararectal nodes.

Lateral Aortic (para-aortic) Lymph Nodes

These nodes receive lymph from the viscera and other structures supplied by the lateral and dorsal branches of aorta and from the nodes in relation to the iliac vessels in the pelvis. Their efferent vessels form right and left lumbar trunks, which open into cisterna chyli. These nodes receive the lymph vessels directly from the kidney, suprarenal gland, abdominal ureter, posterior abdominal wall, gonad, uterine tube and upper part of uterus. They also receive lymph from regional nodes, namely, common, external and internal iliac nodes. Thus, the para-aortic nodes receive lymph from both the lower limbs and the pelvis.

Pelvic Lymph Nodes

i. The common iliac lymph nodes are present around the common iliac vessels and receive lymph from the external and internal iliac nodes and drain into para-aortic nodes.

ii. The external iliac nodes collect lymph from the inguinal nodes, deeper layers of infravenous anterior abdominal wall, adductor region of thigh, membranous urethra, prostate, base of urinary bladder, cervix and upper vagina. Their efferent vessels pass to the common iliac nodes.

iii. The internal iliac nodes receive lymph from all the pelvic viscera, deeper parts of perineum, gluteal region and posterior part of the thigh. They receive lymph from sacral nodes found along the median sacral and lateral sacral vessels. The efferent vessels from the internal iliac nodes reach the common iliac nodes.

iv. There are other groups called obturator and sacral nodes.

Cisterna Chyli (Fig. 33.2)

This is a thin-walled elongated lymphatic sac located in front of the first two lumbar vertebral bodies. It lies on the right side of abdominal aorta and is normally overlapped by the right crus of diaphragm. In this situation, it is very deeply placed on the posterior abdominal wall. It receives the intestinal trunks from the celiac lymph nodes and the right and left lumbar lymph trunks from the para-aortic lymph nodes. The cisterna chyli continues superiorly as the thoracic duct.

Abdominopelvic Part of Autonomic Nervous System

The efferent nerves of the autonomic nervous system supply the smooth muscles of the abdominal viscera, smooth muscles of the blood vessels and the glands. The afferent nerves carry sensation of distension of viscera to the CNS. The organs receive the nerve supply by means of the periarterial nerve plexuses, which arise in the central autonomic plexuses surrounding the major blood vessels situated on the posterior abdominal and lateral pelvic walls. The autonomic plexuses are composed of both afferent and efferent fibers belonging to sympathetic and parasympathetic systems.

Sympathetic Part

The following preganglionic visceral branches of the sympathetic chain take part in the central autonomic plexuses.

i. The greater, lesser and least splanchnic nerves arise from the thoracic sympathetic chain.

ii. The lumbar splanchnic nerves arise from the lumbar sympathetic chain.

iii. The sacral splanchnic nerves arise from the sacral sympathetic chain.
Parasympathetic Part

i. The right and left vagus nerves bring preganglionic fibers, which terminate on postganglionic neurons in the wall of the viscera via the plexuses.

ii. The pelvic splanchnic nerves from sacral parasympathetic outflow carry preganglionic fibers, which terminate on the postganglionic neurons in the walls of the viscera.

Sympathetic Chains in Abdomen and Pelvis

The thoracic parts of the right and left sympathetic chains enter the posterior abdominal wall behind the respective medial arcuate ligaments to continue as the lumbar parts. Each lumbar sympathetic chain descends along the medial margin of psoas major muscle and usually possesses four ganglia. The lumbar part continues as the sacral part of the chain as it passes behind the common iliac vessels the crossing the pelvic brim. Each chain lies in front of the sacrum medial to anterior sacral foramina and behind the rectum. The sacral part of the chain presents four or five ganglia. At their lower ends, the two chains converge in front of the first piece of coccyx to unite and form the ganglion impar.

Branches of Lumbar Part of Sympathetic Chain

i. Gray rami communicantes join each lumbar nerve for the pilomotor, sudomotor and vasomotor supply.

ii. White rami communicantes from first and second lumbar ventral rami are given to the first two lumbar ganglia.

iii. Four lumbar splanchnic nerves carry preganglionic fibers to the abdominal and pelvic plexuses.

Branches of Sacral Part of Sympathetic Chain

i. Gray rami communicantes join each sacral and coccygeal nerve for the pilomotor, sudomotor and vasomotor supply.

ii. Sacral splanchnic nerves carry preganglionic sympathetic fibers to the inferior hypogastric plexuses.

Intra-abdominal Branches of Vagus Nerves

The gastric, celiac, hepatic and renal branches of the two vagus nerves join the autonomic plexuses in the abdomen.

Intrapelvic Branches of Sacral Parasympathetic Outflow

The pelvic splanchnic nerves or nervi erigentes are composed of the preganglionic parasympathetic fibers that arise in S2 to S4 segments of spinal cord. They leave the spinal cord through the second, third and fourth ventral roots of sacral nerves and unite outside the sacral canal to form the pelvic splanchnic nerve (nervi erigentes) on each side. They join the inferior hypogastric plexuses for supply of the digestive tract from the splenic flexure downwards up to the upper part of anal canal and for the supply of other pelvic viscera.

Celiac Plexus (Solar Plexus)

The celiac plexus is the largest autonomic plexus in the abdomen. It is a dense network surrounding the celiac artery and the root of superior mesenteric artery. Its main constituents are the right and left celiac ganglia and nerve fibers. The celiac ganglia are irregular masses made of postganglionic neurons situated on the crus of diaphragm on either side of the celiac trunk. They are grouped as collateral ganglia of sympathetic system. The lower part of each ganglion is detached to form aorticorenal ganglion. The greater splanchnic nerve (T5 to T9 sympathetic ganglia) ends in celiac ganglion for relay. The lesser splanchnic nerve (T10 to T11 ganglia of sympathetic chain) ends in the aorticorenal ganglion for relay.

Constituents

i. Postganglionic sympathetic fibers from the celiac ganglia.

ii. Preganglionic parasympathetic fibers from the right and left vagus nerves.

iii. Afferent fibers from the abdominal viscera.

iv. Phrenic nerves bring sensory fibers.

Secondary Plexuses from Celiac Plexus

i. The phrenic plexus receives the branches of the phrenic nerve. On the right side at the junction of phrenic nerve and the plexus, there is a small ganglion called phrenic ganglion, which distributes branches to IVC, suprarenal gland and hepatic plexus.

ii. The hepatic plexus receives fibers from both vagus nerves and from the right phrenic nerve.

iii. The left gastric plexus accompanies the left gastric artery and receives the vagal gastric branches.

iv. The splenic plexus is continued from the celiac plexus along the splenic artery. The parasympathetic fibers are distributed along the branches of splenic artery to the stomach and pancreas. The spleen receives sympathetic innervation only for its blood vessels and smooth muscle of capsule and trabeculae.

v. The suprarenal plexus receives a massive connection from the celiac plexus. The sympathetic fibers are
preganglionic from the greater and lesser splanchnic nerves, which pass through the celiac ganglion uninterrupted and synapse on the chromaffin cells in the suprarenal medulla.

vi. The renal plexus is quite dense, being composed of a few small ganglia and fibers from the celiac ganglion and plexus, parasympathetic fibers from vagus, aorticorenal ganglion, least splanchnic nerve, and first lumbar splanchnic nerve. The renal plexus enters the kidney along with branches of renal artery. It gives connections to ureteric and gonadal plexuses.

vii. The testicular or ovarian plexuses receive fibers from renal and aortic plexuses and travel along the testicular or ovarian artery to the target organs. The efferent sympathetic fibers are from T10 and T11 segments of spinal cord. The afferent fibers reach the same segments of spinal cord. The connections with inferior hypogastric plexus bring pelvic parasympathetic fibers responsible for vasodilatation.

viii. The superior mesenteric plexus is a downward continuation of the celiac plexus and accompanies the superior mesenteric artery into the mesentery. It supplies the viscera along the branches of superior mesenteric artery.

ix. The intermesenteric or abdominal aortic plexus is located on the sides and front of abdominal aorta between the origin of superior and inferior mesenteric arteries. It is formed from celiac plexus and from contribution of first and second lumbar splanchnic nerves.

x. The inferior mesenteric plexus is continuous above with the aortic plexus and receives additional branches from second and third lumbar splanchnic nerves. The preganglionic parasympathetic fibers reach the plexus indirectly (through branches of pelvic splanchnic nerves to the inferior hypogastric plexus travelling up to the superior hypogastric plexus) or by direct branches from the pelvic splanchnic nerves to the inferior mesenteric plexus. The plexus gives parasympathetic supply to the derivatives of hindgut by following the inferior mesenteric artery and its branches.

Superior Hypogastric Plexus
This plexus lies anterior to aortic bifurcation, the body of fifth lumbar vertebra and promontory of sacrum. It was earlier referred to as presacral nerve though it is never a single nerve and its main position is in front of the fifth lumbar vertebra rather than in front of sacrum. It is mainly derived from the downward continuation of aortic plexus. It is joined by third and fourth lumbar splanchnic nerves and ascending fibers of pelvic splanchnic nerves. The afferent sympathetic fibers carry pain sensation from pelvic viscera to the dorsal root ganglia of lower thoracic and upper two lumbar spinal nerves. The superior hypogastric plexus supplies branches to ureteric, testicular, ovarian and common iliac plexuses. It divides in to right and left hypogastric nerves, which descend into the pelvis to become the inferior hypogastric plexus.

Inferior Hypogastric Plexus
This plexus is present along the lateral wall of pelvis on each side of midline pelvic viscera.

 Constituents of Inferior Hypogastric Plexus
i. Pelvic splanchnic nerves carry preganglionic parasympathetic fibers.

ii. Hypogastric nerves provide preganglionic and postganglionic sympathetic fibers from thoracic tenth to twelfth and first two lumbar segments of the spinal cord.

iii. Sacral splanchnic nerves are derived from sacral part of the sympathetic chain.

The pelvic viscera are supplied through several secondary plexuses arising from the inferior hypogastric plexus. The secondary plexuses reach the viscera along the branches of internal iliac arteries.

Secondary Plexuses from Inferior Hypogastric Plexus
i. The middle rectal plexus surrounds the middle rectal branch of internal iliac artery and supplies the smooth muscle of the rectum and anal canal.

ii. The vesical plexus goes along the vesical arteries or artery depending on the sex to supply bladder, and terminal parts of ureters. In males. it also gives twigs to seminal vesicles.

iii. The prostatic plexus supplies the prostate, seminal vesicles and ejaculatory ducts. It extends as cavernous nerves of penis for supply of cavernous tissue of bulb and crura of the penis.

iv. The uterovaginal plexus follows the uterine and vaginal arteries and is located in the base of the broad ligaments. The plexus supplies the uterus, cervix, vagina, and the erectile tissue of the vestibule and the clitoris.
SUPRARENAL GLANDS

The suprarenal or the adrenal gland is located in close proximity to the superomedial part of the respective kidney on the posterior abdominal wall. The suprarenal gland and kidney are enclosed in a common fascial sheath called the renal fascia but they occupy separate compartments inside the fascial sheath.

Parts
The suprarenal gland is composed of an outer cortex and an inner medulla, which are developmentally, structurally and functionally distinct from each other. Hence, the cortex and medulla are regarded as two separate endocrine glands.

Embryologic insight ...

i. The cortex of the suprarenal gland develops from the proliferation of coelomic epithelium on either side of the root of dorsal mesentery. Hence, cortex is mesodermal.

Anomalies of Suprarenal Gland

i. Accessory suprarenal tissue may be found around the main gland, in greater omentum, or in broad ligament of uterus.

ii. In the female fetus, the hyperplasia of cortex leads to excess production of androgens, due to which the external genitalia resemble that of male (female pseudohermaphroditism).

iii. If the developing kidney fails to ascend to the lumbar region, the suprarenal gland develops in its normal position.

Weight and Shape
Each gland weighs about 4 to 5 g and measures 50×30×10 mm. The right and left suprarenal glands differ in shape.
The right gland is an irregular tetrahedron (having four surfaces) and the left gland is of semilunar or crescentic shape.

**Relations of Right Suprarenal Gland (Fig. 85.1)**

i. The right gland has three borders (anterior, medial and lateral) and three surfaces (anteromedial, anterolateral and posterior), a base and an apex.

ii. The anterior border bears a hilum nearer the apex. A very short and wide right suprarenal vein comes out of the hilum to open into the inferior vena cava immediately.

iii. The anteromedial surface is related to the inferior vena cava.

iv. The anterolateral surface is related to the right lobe of liver. The upper part of this surface is in direct contact with bare area of liver while the lower part is related to visceral surface of right lobe.

v. The upper part of posterior surface is related to diaphragm and lower part to the upper pole of right kidney.

**Relations of Left Suprarenal Gland (Fig. 85.1)**

i. The left gland has anterior and posterior surfaces, lateral and medial borders and upper and lower poles.

ii. The anterior surface bears the hilum nearer the lower end. The hilum gives exit to the left suprarenal vein, which is longer than but as wide as the right suprarenal vein.

iii. The upper part of the anterior surface is related to the posterior aspect of cardiac end of the stomach and the lower part to the body of pancreas with splenic vessels (left suprarenal gland is part of the stomach bed).

iv. The posterior surface is in contact with the left crus of diaphragm medially and medial margin and adjacent upper pole of left kidney laterally.

**Hormones of Suprarenal Cortex**

The suprarenal cortex is divisible into three zones, which secrete three different hormones.

i. The zona glomerulosa secretes aldosterone or mineralocorticoids responsible for maintenance of water and electrolyte balance.

ii. The zona fasciculata secretes glucocorticoids responsible for maintenance of carbohydrate balance and immune mechanism.

iii. The zona reticularis secretes androgens and other sex steroids.

The cortex is essential to life. Its complete removal is fatal without replacement therapy.

**Clinical insight ...**

i. Deficiency of aldosterone leads to Addison’s disease.

ii. Adrenal hyperplasia with excessive aldosterone secretion results in Conn’s syndrome, which is characterized by hypertension, edema due to sodium and water retention and hypokalemia.

iii. Adrenal hyperplasia with excessive secretion of sex steroids leads to feminization of male and masculanization of female.

iv. Adrenal hyperplasia with excessive glucocorticoid secretion leads to Cushing’s syndrome, which is characterized by moonshaped face, hirsutism, acne, hypertension, central distribution of fat, weakness and wasting of limbs and purple skin striae.

**Hormones of Suprarenal Medulla**

The medulla consists of chromaffin cells or pheochromocytes, which are the modified sympathetic ganglion cells. They synapse with the preganglionic sympathetic fibers and secrete epinephrine and norepinephrine in blood circulation. Under normal conditions very small quantity of the hormones is released but under stress situations the output is increased.

**Clinical insight ...**

**Pheochromocytoma**

Pheochromocytoma is the tumor of adrenal medulla. It releases excessive quantity of catecholamines in the blood circulation. Typically this produces paroxysms of palpitation, perspiration, pallor, headache and hypertension.

**Arterial Supply (Fig. 85.2)**

The suprarenal gland receives arterial supply from three sources.

i. The inferior suprarenal artery is a branch of the renal artery.
ii. The middle suprarenal artery is a branch of the abdominal aorta.

iii. The superior suprarenal artery is a branch of inferior phrenic artery.

### Venous Drainage (Fig. 85.1)

Only one vein emerges from the hilum of each suprarenal gland.

i. The right suprarenal vein is extremely short. As soon as it emerges from the hilum on the anterior border, it opens into the IVC. This may pose difficulty during surgical removal of the right suprarenal gland.

ii. The left suprarenal vein is longer. It emerges from the hilum on the anterior surface and opens into the left renal vein. The surgical removal of left suprarenal gland is easier because the identification and clamping of the left suprarenal vein is easy.

### Nerve Supply

i. The postganglionic sympathetic innervation to cortex and medulla is vasomotor in function.

ii. The medulla receives preganglionic sympathetic fibers from the greater and lesser splanchnic nerves via the suprarenal plexus, (which is the extension of celiac plexus). They make synaptic contacts with each and every chromaffin cell of the medulla.

### Radiology of Suprarenal Gland

The suprarenal glands are deeply located hence difficult to visualize on plain radiograph. On CT scan of abdomen the suprarenal gland resembles the alphabet Y. Hence, it is described as the Mercedes Benz sign (Mercedes Benz car’s makers have Y as their symbol).
Collecting Part

The collecting part develops from the ureteric bud (arising from mesonephric duct). The ureteric bud undergoes dichotomous divisions in the metanephric blastema. The dilated upper end of the ureteric bud forms the pelvis of kidney. Its first divisions become the major calyces. The subsequent 2 to 4 generations are fused to form minor calyces and the rest of divisions give rise to all the collecting ducts and collecting tubules.

Nephrogenesis

The process of development of nephrons is called nephrogenesis. The metanephric tissue is induced to form nephrons by the inductive influence of the growing tip of each division of the ureteric bud. The solid clump of metanephric cells is converted into a circular metanephric vesicle. One end of this tube is invaginated by the tuft of capillaries. The rest of the tube differentiates into PCT, loop of Henle and DCT. The crucial stage in nephrogenesis is to establish the luminal continuity between the developing nephron and the collecting tubule.

Ascent of Kidney

Since, the kidney begins development inside the pelvis it undergoes ascent to gain its definitive position in the lumbar region. With each new position on the body wall a new artery, which is higher in location supplies the kidney. This is a physiological necessity because a direct branch from the aorta maintains a high-pressure head in the glomerular capillaries.

Rotation of Kidney

To begin with the hilum of the kidney faces anteriorly. As development progresses the kidney undergoes 90° rotation in medial direction so that the hilum faces medially.

Function of Fetal Kidney

The fetal kidney becomes functional at the end of first trimester. Urine is passed in the amniotic cavity. It mixes with the amniotic fluid, which is swallowed by the fetus. From the intestinal tract the fluid is absorbed in the blood and brought back to the kidneys. The fetal kidneys are believed to play some role in the regulation of volume of the amniotic fluid. In cases of renal agenesis, volume of the amniotic fluid is small.

Congenital Renal Anomalies (Figs 85.4A to D)

i. Agenesis of kidney can be unilateral or bilateral. Bilateral agenesis is incompatible with life. Unilateral kidney undergoes compensatory hypertrophy so a person can live a normal life.

ii. Lobulated kidney means the retention of fetal lobulation (Fig. 87.13) in postnatal life. After birth the growth of nephrons and connective tissue evens the kidney surface. So the cause of the lobulated kidney is failure of postnatal growth in the kidney.

iii. Pelvic kidney is an unascended kidney (Fig. 85.5). It receives arterial supply from the common iliac or internal iliac artery. The pelvic kidney has a short ureter.

iv. Crossed renal ectopia is a condition in which both kidneys are located on one side. The two kidneys may fuse or remain separate.

v. Malrotated kidney is the one in which the hilum faces anteriorly or laterally.

vi. Horseshoe kidney results when the lower poles of the right and left kidneys are fused to each other by an isthmus. The inferior mesenteric artery arrests the ascent of the horseshoe kidney. Since the ureters cross in front of the isthmus there is likelihood of urinary obstruction.

vii. The aberrant renal artery usually is due to failure of one of the lower arteries to regress as the kidney ascends. The aberrant artery entering the lower pole may cause compression of pelviureteric junction producing hydronephrosis.

viii. Congenital polycystic kidney results if there is failure in establishing luminal continuity between the nephrons and collecting tubules. The glomeruli continue to function and the filtrate accumulates in the tubules for lack of outlet. Thus the tubules show cystic enlargement.
Figs 85.4A to D: Congenital renal anomalies (A) Pelvic kidney; (B) Horseshoe kidney; (C) Crossed ectopia; (D) Unilateral aberrant renal arteries

Fig. 85.5: Radiological appearance (MRI urogram) of pelvic kidney (arrow) (failure to ascend from pelvis to lumbar region)

Gross Anatomy of Kidneys

The kidneys are reddish-brown in color and present a smooth and glistening appearance in the living.

Measurements

Each kidney in the adult measures about 11 to 12 cm in length, 6 cm in breadth and 3 cm in thickness. Its weight ranges from 130 to 170 g.

Position

Each kidney is located on the posterior abdominal wall in the paravertebral gutter. It is retroperitoneal. The position of the kidney varies with respiration and the posture of the body. The upper extent of the right kidney approximately, corresponds to the twelfth rib and that of left kidney to the eleventh rib. The transpyloric plane passes through the lower part of the hilum of the left kidney and upper part of the hilum of the right kidney. This is because the liver pushes the right kidney slightly downwards.
Surfaces and Borders (Fig. 85.6)
Each kidney has two poles, two surfaces and two borders. The bulge of the vertebral column and the adjacent psoas major muscle affect the orientation of the kidney. The longitudinal axis of the kidney runs obliquely downward and laterally and hence the upper pole is situated 2.5 cm and the lower pole 7.5 cm away from the midline. The transverse axis of the kidney runs laterally and backwards, hence its medial border faces slightly anteriorly. The anterior surface faces anterolaterally and posterior surface posteromedially. The lateral border of the kidney is smoothly convex while the concave medial border shows the depression of hilum at its middle.

Hilum of Kidney
The hilum gives passage to the renal vessels and the pelvis of the ureter. It is situated five cm away from the midline. The arrangement of the structures at the hilum in anteroposterior order is, renal vein, renal artery and renal pelvis. If the renal artery divides at the hilum into its two main divisions then the order of the structures at the hilum is, renal vein, anterior division of renal artery, renal pelvis and posterior division of renal artery.

Surface Marking
The kidneys can be marked on the anterior and posterior aspects of the trunk. The point to note while marking the width of the kidney is that on the surface of the body, the projected width is reduced compared to its actual width due to the obliquity of the transverse axis of the kidney. Hence in the surface drawings of the kidney the width is taken as 4.5 cm.

Surface Marking on the Back of Trunk (Fig. 85.6)
A quadrilateral or parallelogram is drawn (named after Morris) in which the outline of the kidney is mapped.

Fig. 85.6: Morris’ parallelogram illustrating surface marking of kidneys on the back

Renal Angle
It is an angle between the lower margin of twelfth rib and lateral margin of erector spinae muscle. At this angle, the kidney lies close to the body surface.

Clinical insight ...

Importance of Renal Angle
i. Renal pain is usually felt at the renal angle as a dull ache.
ii. The perinephric abscess causes swelling and tenderness at the renal angle.
iii. The lower border of pleura runs horizontally, crossing the twelfth rib at the lateral margin of erector spinae muscle. Hence, the upper end of the skin incision for approaching the kidney by the lumbar route should begin below the renal angle. Any upward extension of the incision will injure the pleura.

Coverings of Kidney (Fig. 85.7)
Each kidney has four coverings. From within outward they are:
i. True capsule (fibrous capsule)
ii. Fatty capsule (perinephric fat)
iii. Fascial capsule (false capsule, renal fascia or fascia of Gerota)
iv. Paranephric fat.

True Capsule
The true capsule is composed mainly of collagen fibers, a few elastic fibers and smooth muscle fibers. In a healthy kidney the true capsule is easily stripped off. It gives the shining appearance to the kidney. The capsule becomes adherent in renal disease.

Fatty Capsule
The fatty capsule is a layer of adipose tissue, which is traversed by a number of fibrous strands connecting the true and false capsules.
Section

Fascial Capsule

The fascial capsule or renal fascia forms a common covering to the kidney and the suprarenal gland. Its anterior layer is called fascia of Toldt and posterior layer is called fascia of Zuckerkandl.

i. On horizontal tracing (See Fig. 84.1), the two layers fuse along the lateral border of kidney to become continuous with the transversalis fascia. Medially, the anterior layer passes in front of the renal vessels and becomes continuous with the anterior layer of the opposite side in front of the abdominal aorta and inferior vena cava while the posterior layer blends with the psoas fascia and is attached to the bodies of the lumbar vertebrae.

ii. On vertical tracing, the two layers fuse above the suprarenal gland and become continuous with the diaphragmatic fascia. Inferiorly, the two layers continue downwards along the ureter and merge with the fascia iliaca. Thus, the fascial capsule is open inferiorly.

Clinical insight...

i. In nephroptosis, the kidney descends to a very low level through the lower opening. The renal vessels alone form the support of such a displaced kidney. This causes kinking of ureter and urinary obstruction.

ii. The perinephric abscess, pus collects in the space between the true and fascial capsules. It tends to descend along the periureteral sheath downwards and may reach pelvic cavity.

Paranephric Fat

The paranephric fat, which is part of the retroperitoneal fat, lies outside the false capsule and is abundant on the posterior aspect.

Supports of Kidney

The kidney moves minimally with regular breathing. But on deep inspiration it descends vertically by about 2 to 2.5 cm. The factors that maintain the kidney in position are the fatty capsule, fascial capsule and the renal vessels. If the fatty capsule is entirely absent the weight of the kidney is borne by the renal pedicle and hence the kidney tends to fall down, which is known as nephroptosis (floating kidney).

Relations of Kidney

The anterior relations of the kidneys are different on right and left sides whereas their posterior relations are similar.

Anterior Relations of Right Kidney (Fig. 85.8)

i. The right suprarenal gland is related to the superior pole and the adjacent part of medial border.
i. The visceral surface of right lobe of liver is in contact with a large area below the upper pole.
iii. The second par of duodenum is related to the area adjacent to the medial margin near the hilum.
iv. The hepatic flexure and coils of jejunum are related to the lower part.

Anterior Relations of Left Kidney (Fig. 85.8)

i. The left suprarenal gland is related to a small medial area.

ii. The spleen is related to the upper two-thirds of lateral half of anterior surface.

Fig. 85.7: Four coverings of kidney
(Note that fascial capsule is open inferiorly as shown by the arrow)

Fig. 85.8: Visceral relations of anterior surface of right and left kidneys
iii. The body of pancreas is related to the central rectangular area.
iv. The stomach is related to a small triangular area bounded by suprarenal, splenic and pancreatic areas.
v. The splenic flexure and descending colon are in contact with a narrow strip near the lateral margin.
vi. The duodenojejunal flexure and coils of jejunum are related below the pancreatic area.

**Posterior Relations (Fig. 85.9)**

i. The upper part is related to the diaphragm.
ii. The right kidney is related to twelfth rib while left kidney is in relation to the eleventh and twelfth ribs.
iii. Below the twelfth rib the posterior surface is related to three muscles from medial to lateral they are, the psoas major, quadratus lumborum and the transversus abdominis. Between the quadratus lumborum and the posterior surface of kidney, the subcostal nerve and vessels, iliohypogastric and ilioinguinal nerves pass inferolaterally.

**Gross Appearance of Kidney in Coronal Section (Fig. 85.10)**

The kidney is composed of outer cortex and inner medulla. The sinus of the kidney is a large area lateral to the hilum surrounded by the kidney substance. The walls of the sinus are lined with the continuation of the capsule in the interior. The sinus contains the branches of renal artery, accompanying veins, major and minor calyces, pelvis of kidney, nerve plexuses and fatty tissue. The cortex is pale and granular while the medulla is dark and striated in appearance. The cortex is composed of about a million or more nephrons per kidney. The medulla consists of about 6 to 12 pyramids, but this number is variable. The cortical tissue that extends in between the adjacent pyramids in the medulla is known as renal columns.

The apex of each pyramid extends into the minor calyx as a small projection called the renal papilla. The pyramid is composed of collecting ducts and the apparatus for concentration of urine. The base of the pyramid is directed toward the cortex. The cortical area that caps the base of a pyramid is called the cortical arch. This unit of cortical arch and adjacent pyramid is called the renal lobe. The renal calyces are of two orders, greater or major and lesser or minor. Calyx is the Latin word for glass or cup. The minor calyces receive the papillae of pyramids. One minor calyx may receive one papilla or more than one. Therefore, the number of the pyramids need not coincide with the number of minor calyces, which is very variable. There is a structural continuity between the papilla and the minor calyx. The major calyces are less in number, usually two to three and are formed by fusion of minor calyces. The major calyces unite to form the pelvis of kidney. The combined volume of the pelvis and calyces is nearly 8 ml.

**Functional Correlation to Histology**

The cortex consists of nephrons, which are the structural and functional units of the kidney. The nephrons consist of four parts, renal corpuscle, proximal convoluted tubule (PCT), loop of Henle and distal convoluted tubule (DCT). The renal corpuscles filter the blood and the other components of the nephrons are involved in selective resorption from the glomerular filtrate.
Abdomen, Pelvis and Perineum

Section

i. The renal corpuscle consists of central glomerulus (lobulated tuft of capillaries) and Bowman’s capsule, which is the blind expanded end of the nephrons. The endothelium of the glomerular capillaries is fenestrated. The glomerulus invaginates in the Bowman’s capsule, as a result of which the latter is divided into a parietal layer and a visceral (glomerular) layer enclosing a capsular space. The visceral layer closely invests the capillary endothelium. The cells of the visceral layer are called podocytes since they are attached to the basal lamina by numerous pedicles or footplates. The filtration barrier between capillary lumen and the capsular space is composed of, endothelial cells, fused basement membranes of the endothelial cells and podocytes and discontinuous footplates of the podocytes.

ii. The PCT begins at the lower end of the renal corpuscle. It is lined by simple columnar cells. The apical aspects of the cells present striated or brush border, which is made of microvilli. The basal aspects of the cells show infoldings of the plasma membrane and plenty of mitochondria. These histological features are indicative of the active absorption by the PCT. The PCT helps in absorption of water, sodium, potassium, bicarbonates, glucose and amino acids from the glomerular filtrate back into the peritubular capillaries.

iii. The loop of Henle begins as the continuation of PCT and extends into the medulla. The simple squamous cells line the descending limb of the Henle’s loop. There is passive ionic transfer across these cells. The ascending loop of Henle is lined by cuboidal cells, which help in transfer of the chloride and sodium from the tubules in to the medulla. It is impermeable to water. The countercurrent multiplier system in the ascending and descending limbs of Henle’s loop builds up high concentration of sodium and chloride in medullary interstitial spaces. The countercurrent exchange system between the vasa recta, which run parallel to the Henle’s loops help to conserve the high osmotic pressure in the medulla.

iv. The distal convoluted tubules (DCT) are located in the cortex. Their lining epithelium is of low cuboidal type without microvilli. The water absorption from DCT is under the influence of antidiuretic hormone. Thus, the isotonic filtrate is passed on to the collecting tubules. While passing through the high osmotic pressure in the interstitial spaces of medulla, the collecting tubules let out more water into the medulla so that finally the urine becomes hypertonic.

### Juxtaglomerular Complex (Fig. 85.11)

The juxtaglomerular (JG) complex consists of three parts:

i. Macula densa of DCT

ii. Juxtaglomerular cells of afferent arteriole

iii. Extraglomerular mesangial cells.

Each glomerulus has a vascular pole consisting of an afferent arteriole and an efferent arteriole. At its beginning each distal convoluted tubule is very close to the afferent arteriole. The lining cells of the adjacent wall of the DCT and the afferent arteriole show structural modification. The modified cells of the DCT in this location have secretory granules and are called macula densa. The adjacent smooth muscles of the afferent arteriole undergo epithelioid change, contain secretory granules and are called, the juxtaglomerular cells.

#### Function of JG Complex

The fluid pressure in the DCT activates the cells of macula densa to secrete some substances, which activate the JG cells to secrete renin. The renin has the property to convert
angiotensinogen in the blood circulation to angiotensin I, which is changed to angiotensin II in pulmonary endothelial cells. The final effect is rise in blood pressure.

**Arterial Supply of Kidney**

The renal arteries are the direct branches of abdominal aorta. Each renal artery divides into an anterior and posterior division near the hilum. The primary branches of these two divisions are segmental arteries, which are the end arteries and supply renal vascular segments. The anterior division passes in front of the renal pelvis and subdivides into four segmental arteries. The posterior division passes behind the pelvis and continues as one segmental artery.

**Intrarenal Course of Segmental Arteries**

i. The segmental arteries travel inside the renal sinus and divide into lobar arteries, which further divide into interlobar arteries.

ii. The interlobar arteries pass through the renal columns in the medulla (Fig. 85.12).

iii. At the corticomedullary junction each interlobar artery divides into two arcuate arteries, which arch over the bases of adjacent pyramids.

iv. The arcuate arteries give origin to interlobular arteries (at right angles) and radiate towards the capsule by passing through the cortical substance.

v. Each interlobular artery gives off a number of afferent arterioles, which feed the glomerular capillary plexuses.

vi. The glomerular capillary plexus (filtration apparatus) is unique in that it is the only capillary plexus in the body, which is fed by an arteriole and drained by an arteriole and moreover the efferent arteriole is narrower in diameter than the afferent. This specialization is necessary to maintain high hydrostatic pressure in the glomerular capillaries.

vii. The efferent arterioles from the glomeruli are unique as they begin in capillaries and end in capillaries.

viii. The efferent arterioles from the cortical glomeruli break up into peritubular capillary plexuses around the proximal and distal tubules.

ix. The efferent arterioles from juxtamedullary glomeruli enter the pyramid and break into straight arterioles called vasa recta. The straight arterioles form bundles of smaller vessels as they pass by the side of loops of Henle and collecting ducts and break-up into capillary plexuses there. Thus it is evident that a major part of renal blood circulates through the cortex and the medulla is dependent for its blood supply on the efferent arterioles of juxtamedullary glomeruli.

x. Thus the kidney shows two types of circulations (Fig. 85.12). The larger circulation operates in the cortex, where it is concerned with filtration of blood. The smaller circulation operates in medulla, where it is responsible for the concentration of urine.

**Renal Artery Angiography**

Radiologically one can visualize the renal artery and its branches by angiography or by ultrasound. Figure 85.13 depicts the aneurysm of renal artery found out on renal angiography.
Venous Drainage

The interlobular veins drain the peritubular plexuses in the cortex, which drain in succession into arcuate, interlobular, interlobar, segmental and lastly the renal vein.

Vascular Segments (Fig. 85.14)

Based on the distribution of the five segmental arteries each kidney is divided into five vascular segments.

i. Apical
ii. Upper anterior
iii. Middle anterior
iv. Lower
v. Posterior.

Apical segment occupies both anterior and posterior surfaces. The upper anterior segment is confined to the anterior surface only. The middle anterior segment is confined to the anterior surface only. The lower segment occupies the entire inferior pole and includes both anterior and posterior surfaces. The posterior segment occupies the posterior surface only (corresponding to the upper and middle anterior segments). The segmental resection of diseased parts of kidney is undertaken to preserve the healthy parenchyma.

Lymphatic Drainage

There are rich lymphatic plexuses in the renal parenchyma. The lymphatic vessels accompany the renal vessels and terminate in lateral aortic (para-aortic) lymph nodes near the origin of renal arteries.

Nerve Supply

The renal plexus supplies both sympathetic and parasympathetic innervation to the kidney. The sympathetic supply is vasomotor in function. Parasympathetic supply is through the vagus. The sensory impulses from kidneys reach the spinal cord via the least splanchnic nerve (T12) or lumbar splanchnic nerve (L1). Thus the pain of renal or ureteric origin is referred from the lumbar to the inguinal regions (loin to groin pain).

Palpation of Kidneys

The method of kidney palpation is called bimanual palpation because kidney is palpated using both hands. One hand is placed behind the supine patient in the interval between lower rib and the iliac crest. The other hand is pressed on the lumbar region of the anterior abdominal wall. The inferior pole of an enlarged kidney is felt against the fingers when the patient takes deep inspiration.

Radiology of Urinary Organs

i. The plain radiograph of abdomen (KUB film) is usually inspected to examine kidney, ureter and urinary bladder. A faint soft tissue shadow of kidney is detectable on plain radiograph.

ii. The intravenous pyelography (IVP) consists of injecting the contrast material by intravenous route. The contrast agent (urograffin) is injected intravenously. X-ray films are taken at the interval of one, three, five, ten, fifteen and thirty minutes and postmicturition. The cupping of the minor calyces is distinctly visible in a normal kidney (Fig. 85.15).

iii. In retrograde pyelography the contrast material is introduced in the ureteric orifice. First a cystoscope is passed in urinary bladder through the urethra and then a catheter is passed through the cystoscope in the ureteric orifice in the urinary bladder.

iv. Ultrasound, CT and MRI are useful to detect the pathology of the kidneys.

Clinical insight ...

i. The kidney is usually approached surgically through the lumbar (loin) region; the advantage being it is a retroperitoneal approach. For this approach it is very essential to be familiar with the posterior relations of kidney (Fig. 85.9) and the layers of lumbar fascia (See Fig. 84.1).

ii. Stone formation in kidney is a common cause of renal disease. Small stones pass out through urinary passages without causing symptoms. A very large...
Each ureter is a thick muscular tube, which conveys urine from the renal pelvis to the urinary bladder. The ureter shows active peristaltic contractions.

**URETERS**

- **Location**
  The ureter is a retroperitoneal structure that is placed on posterior abdominal wall and lateral pelvic wall.

- **Length and Diameter**
  The average length of the ureter is 25 cm and its diameter is 3 mm.

- **Extent**
  It extends from the pelviureteric region to the urinary bladder. Usually the pelviureteric region is extrahilar and lies adjacent to the lower part of medial border of the kidney.

- **Parts**
  The ureter is divisible into two parts of equal lengths, abdominal and pelvic. The relations of abdominal part are different on the two sides while the relations of the pelvic parts are different in the two sexes.

- **Sites of Constrictions (Fig. 85.17)**
  i. Pelviureteric region (junction of pelvis of kidney and the ureter) at the level of tip of transverse process of second lumbar vertebra.
  ii. At the pelvic brim (the ureter crosses the sacroiliac joint)
  iii. Inside the pelvic cavity, where the ureter is crossed by vas deferens in male and passes through tunnel in broad ligament in female.
  iv. Intramural or intravesical (passing through wall of bladder) at the level of the tip of ischial spine.
  v. At ureteric orifice in the interior of urinary bladder.
**Surface Marking on Anterior Surface**
Join the tip of the ninth costal cartilage to the pubic tubercle.

**Surface Marking on Posterior Surface**
Take a point about 4 cm lateral to the spine of L2 vertebra and join it to posterior superior iliac spine (indicated by the dimple).

**Abdominal Part of Right Ureter**
Anterior Relations (from above downward)
  i. Horizontal or third part of duodenum
  ii. Right gonadal vessels
  iii. Right colic vessels
  iv. Ileocolic vessels
  v. Root of mesentery
  vi. Coils of ileum.

**Medial Relation**
Inferior vena cava.

**Posterior Relations**
The ureter lies on the psoas major muscle and the right genitofemoral nerve and tips of lumbar transverse processes. At the pelvic brim the ureter crosses in front of the bifurcation of right common iliac vessels.

**Abdominal Part of Left Ureter**
Anterior Relations (from above downward)
  i. Left gonadal artery
  ii. Left colic vessels
  iii. Sigmoid colon
  iv. Sigmoid mesocolon.

**Posterior Relations**
The ureter lies on the psoas major muscle, left genitofemoral nerve and tips of lumbar transverse processes. At the pelvic brim the ureter crosses in front of the bifurcation of left common iliac vessels at the intersigmoid recess.

**Pelvic Part of Ureter in Male**
The pelvic part of ureter is divided into two parts, namely, posterolateral (first part) and anteromedial (second part).
  i. The posterolateral part is in contact with lateral pelvic wall. It is related posteriorly to the internal iliac vessels, lumbosacral trunk and sacroiliac joint from before backwards. Anteriorly it is covered with parietal peritoneum. Laterally it is related to the obliterated umbilical artery, obturator nerve and vessels, inferior vesical vessels and middle rectal vessels from above downwards.
  ii. The anteromedial or second part lies on the floor of the pelvic cavity. It is related superiorly to the parietal peritoneum and inferiorly to the levator ani muscle. Near its termination in the bladder it is crossed by vas deferens anteriorly and is related to the upper end of the seminal vesicle.

**Pelvic Part of Ureter in Female**
i. The posterolateral or the first part is related posteriorly to the internal iliac vessels, lumbosacral trunk and sacroiliac joint. It is covered with parietal peritoneum anteriorly. It forms the posterior boundary of ovarian fossa and hence related to ovary and fimbriated end of uterine tube. In this position the ureter is likely to be injured if clamped along with ovarian vessels in the infundibulopelvic ligament. Lateral to the ureter, are the obliterated umbilical artery, obturator nerve and vessels, uterine and vaginal arteries and middle rectal vessels from above downwards.
ii. The anteromedial or second part of the ureter lies in the extraperitoneal connective tissue along the lower margin of the broad ligament. Here it pierces the transverse cervical ligament, in which it passes through the ureteric canal, (which provides room for the peristaltic movements of the ureter). The uterine artery crosses the ureter in front from lateral to medial at a point nearly 2 to 2.5 cm from the cervix (Fig. 88.31). The ureter is liable to injury during hysterectomy as the ureter may be mistakenly clamped along with uterine vessels. Injury to the ureter may lead to extravasation of urine and peritonitis. Inferiorly the ureter rests on the pelvic floor. Near its termination, the ureter is closely related to the lateral fornix of vagina and then lies on the anterior wall of the vagina.

Intravesical (Intramural) Part of Ureter

The ureter has an oblique course in the wall of the bladder. The ureteric openings are 5 cm apart in a distended bladder and 2.5 cm apart in empty state. The intramural part of the ureter is the narrowest. The oblique passage of the ureter prevents the reflux acting as a flap valve.

Blood Supply

Several arteries supply the ureter since it has a long course. The multiple arteries form longitudinal anastomoses on the wall of the ureter.

i. The abdominal part of ureter receives twigs on its medial side from renal artery, abdominal aorta and gonadal artery.

ii. As the ureter crosses the pelvic brim it receives twigs from common iliac and internal iliac arteries.

iii. Inside the pelvis it receives twigs on lateral aspect from the inferior vesical artery in male and uterine artery in female. The veins correspond to the arteries.

Nerve Supply

i. The sympathetic innervation to the upper part of ureter is through the least splanchnic nerve from T12. Lumbar splanchnic nerve from L1 and L2 supplies the remaining part of abdominal and pelvic ureter through the abdominal autonomic plexuses.

ii. The parasympathetic supply is given from pelvic splanchnic nerve (S2, S3, S4), which reaches the ureter through the autonomic plexuses. Visceral afferents travel along the least splanchnic, lumbar splanchnic and pelvic splanchnic nerves. In distension of the renal pelvis pain is referred to lumbar region. In distension of abdominal ureter the pain is referred to inguinal and pubic regions (a typical loin to groin pain). In distension of pelvic ureter the pain is referred to the perineum.

Ureteric Peristalsis

The contraction waves originate in the smooth muscle of minor calyces. Atypical myocytes in minor calyces at several sites act as pace makers. The contraction waves are propagated away from the kidney towards the urinary bladder so that kidney parenchyma is not subjected to high pressure. It is believed that autonomic innervation does not play a role in the peristaltic activity of ureter.

Skeletal Relations of Ureter (Fig. 85.18)

Knowing the course of the ureter in relation to bony landmarks is useful in identifying the course of the ureter in a plain X-ray of the abdomen and pelvis and in locating tiny stones in the ureter in the plain radiograph of abdomen. The ureter starts at the tip of the transverse process of the second lumbar vertebra and then follows the line of the tips of the transverse processes of the remaining lumbar vertebrae. It crosses in front of the sacroiliac joint. It further courses slightly laterally along the anterior margin of the greater sciatic notch till it reaches the ischial spine. From here it runs medially to enter the urinary bladder about 1.5 to 2.5 cm from the midline.
Development of Ureter
The ureter develops from the ureteric bud arising from the caudal end of the mesonephric duct.

Congenital Anomalies of Ureter (Fig. 85.19A to D)

i. Partial or complete duplication.
ii. Congenital hydroureter due to obstruction to lower end of ureter.
iii. Postcaval ureter (in which the right ureter lies behind the IVC instead of to its right).

Figs 85.19A to D: Congenital anomalies of ureter (as shown by arrow)
The true pelvis or the lesser pelvis has the following boundaries. Its short anteroinferior wall is formed by pubic symphysis and pubic bones. The anterolateral wall is formed by part of hip-bone below the level of arcuate line, pubic crest and the obturator internus muscle. The long and curved posterosuperior wall is composed of sacrum and coccyx and the posterolateral wall has greater and lesser sciatic foramina and the sacrotuberous and sacrospinous ligaments. Superiorly, the walls end in the margins of superior aperture of pelvis. Inferiorly, the walls end in the margins of inferior aperture of pelvis. The pubic symphysis, inferior pubic and ischial rami, ischial tuberosities, sacrotuberous ligaments and coccyx bound the diamond-shaped inferior aperture. The muscles of the pelvic diaphragm and of urogenital diaphragm close the inferior aperture. The muscles of the true pelvis consist of obturator internus, levator ani, coccygeus and piriformis.

Obturator Internus (Fig. 86.1)
This muscle is located on the lateral wall of the pelvis. It takes origin from the inner surface of the obturator membrane and the surrounding parts of ilium, ischium and pubis. A strong tendon emerges from the obturator internus muscle and leaves the pelvis through the lesser sciatic foramen to enter the gluteal region. The superior and inferior gemelli muscles (triceps coxae) are attached to the tendon of obturator internus on either side. These three structures form part of the bed for the sciatic nerve in the gluteal region and together they are inserted on the anterior part of medial aspect of greater trochanter of femur. The tendon turns through 90° and runs laterally behind the hip joint to reach its insertion.

Nerve Supply
The nerve to obturator internus (a branch of sacral plexus) supplies the muscle. It leaves the pelvis through the greater

![Fig. 86.1: Attachments of obturator internus muscle as seen from posterior aspect](image-url)
sciatic foramen and re-enters it through the lesser sciatic foramen to supply the obturator internus and gemellus superior muscles.

**Actions**
The obturator internus muscle is the lateral rotator of the femur in the erect posture. It helps to maintain the head of femur in the acetabulum.

**Obturator Fascia**
The obturator fascia is a dense fascia covering the pelvic surface of the obturator internus muscle. It is fused with the periosteum of the margins of the obturator foramen except at the obturator sulcus, where it leaves a gap for the obturator nerves and vessels to pass through the obturator foramen.

**Arcus Tendinalis**
There is a thickened tendinous arch (arcus tendinalis) in the obturator fascia extending between the body of pubis and the ischial spine. It gives origin to pubococcygeus part of levator ani muscle.

**Parts of Obturator Internus and their Relations**
The obturator internus muscle is located in lateral wall of pelvis and in the lateral wall of ischiorectal fossa. Based on the location it is divisible into following two parts:
1. The part above the tendinous arch forms lateral pelvic wall and obturator nerve and vessels are related to it. This part is related to inferolateral surfaces of urinary bladder. It is related to pelvic appendix (when present) and this relationship is responsible for the obturator sign in pelvic appendicitis. In the female, this part is related to lateral surface of ovary in ovarian fossa and also to the lateral end of uterine tube.
2. The part below the level of the tendinous arch lies below the pelvic floor and forms the lateral wall of the ischiorectal fossa, which is located in the anal triangle of perineum. The obturator fascia covering this part takes part in formation of Alcock’s or pudendal canal (Fig. 89.2). Therefore, the contents of pudendal canal are closely related to obturator internus muscle. In fibrosis of the obturator internus muscle the pudendal nerve in the pudendal canal is likely to be entrapped (Alcock’s canal syndrome).

**Pelvic Diaphragm or Pelvic Floor (Fig. 86.2)**
The pelvic diaphragm is the V-shaped floor of the true pelvis, which separates the pelvis from the perineum. The pelvic floor has evolved with assumption of erect posture by Man to support the pelvic viscera. The urethra and anorectal junction pass through it in the males. In the female, the vagina passes through it in addition to urethra and anorectal junction. The pelvic diaphragm is formed by the right and left levator ani and coccygeus muscles enclosed in the superior and inferior layers of fasciae.

**Levator Ani**
This muscle has a broad origin from the inner side of the pelvis along a line extending from the body of pubis in front to the ischial spine behind. The muscle fibers sweep downwards and backwards to unite in the midline with fibers of the opposite side.

**Broad Subdivisions of Levator Ani**
1. Pubococcygeus
2. Iliococcygeus

![Fig. 86.2: Pelvic diaphragm (levator ani and coccygeus muscles) in female](image-url)
Pubococcygeus
The pubococcygeus arises from the pelvic surface of the body of the pubis and anterior part of tendinous arch in obturator fascia. The fibers arising from the body of pubis (except those forming puborectalis sling) are inserted into perineal body while those arising from tendinous arch are inserted into the anococcygeal ligament and tip of the coccyx.

Subdivisions of Pubococcygeus
i. The fibers that surround the prostate (levator prostatae) in male are inserted into the perineal body (part of this muscle surrounding the urethra is peri-urithralis muscle). Fibers attached to the vaginal wall (pubovaginalis) in female are inserted into the perineal body (part of this muscle surrounding the urethra is peri-urithralis muscle).
ii. The fibers attached to rectum decussate and blend with the longitudinal rectal muscle to form conjoint longitudinal coat of anal canal.
iii. The puborectal parts of the two sides join each other to form a sling at the anorectal junction.
iv. Behind the rectum majority of pubococcygeal fibers are attached to the tip of the coccyx and anococcygeal ligament.

Iliococcygeus
The iliococcygeus arises from the posterior part of the tendinous arch in the obturator fascia and the ischial spine. It is inserted into the anococcygeal ligament and sides of the last two pieces of coccyx.

Coccygeus (Ischiococcygeus)
This muscle is posterior to the levator ani. It arises from the pelvic surface and tip of ischial spine. It is inserted into the anococcygeal ligament and sides of the last two pieces of coccyx.

Nerve Supply
Levator ani is supplied on its pelvic surface by direct branches from the ventral ramus of fourth sacral nerve and on its lower surface by branches from either the perineal branch or the inferior rectal branch of the pudendal nerve. The coccygeus receives twigs from the third and fourth sacral nerves.

Fascia of Pelvic Diaphragm
The pelvic diaphragm is covered on inferior and superior aspects by the fascia. The inferior fascia of pelvic diaphragm is continuous with the obturator fascia laterally and after covering the medial wall of ischiorectal fossa blends with the fascia on sphincter ani externus. The superior fascia of pelvic diaphragm is attached anteriorly to the back of the body of pubis and to the superior ramus of pubis. It is continuous laterally with the obturator fascia and is continuous posteriorly with fascia on the piriformis and the anterior sacrococcygeal ligament.

Relations of Pelvic Diaphragm
The superior relations in the male are the urinary bladder, prostate and rectum while those in the female are the urinary bladder, uterus, vagina and rectum. The inferior relations are the ischiorectal fossae. Laterally, it has bony and fascial attachments. Medially, the pelvic floor gives passage to urethra and anorectal junction in male and in addition the vagina in female.

Actions
i. The most important function of pelvic diaphragm is to support the pelvic viscera. Whenever there is rise in intra-abdominal pressure (due to contraction of thoracic diaphragm and abdominal muscles) the muscles of pelvic diaphragm contract to counter the downward pull on the pelvic viscera.
ii. The puborectalis helps to create anorectal angle by pulling the anorectal junction upwards and forwards. This is an important factor in rectal continence. During defaecation, however, levator ani supports the viscera but the puborectalis relaxes along with the anal sphincters.
iii. The pubovaginalis acts as a vaginal sphincter.
iv. During the second stage of labor the pelvic diaphragm (floor) guides the fetal head into the anteroposterior diameter of the pelvic outlet. As the head passes under the pubic arch the small urogenital hiatus in the anterior part of pelvic diaphragm becomes enormously enlarged. This may cause tear of the anterior fibers of the levator ani (fibers that are inserted into perineal body). The prompt repair of the perineal tears restores the normal function of the muscle.
v. The peri-urithralis muscle contracts for short spells thus helping the sphincter urethrae muscle.

Clinical insight ...
The pelvic diaphragm is likely to be injured during difficult childbirth. This weakens the muscles of the pelvic diaphragm. The weak pelvic floor predisposes to uterine prolapse, cystocele (herniation of bladder into the vagina), urinary stress incontinence (due to alteration in the position of bladder neck and urethra or urethrocele) and prolapse of rectum. Perineal exercises of Kegel are useful in increasing the tone of the muscles of perineum and levator ani.
Piriformis (Figs 86.3 and 87.2)
The piriformis is located on the posterior wall of the pelvis. It is partly intrapelvic and partly extrapelvic. It takes origin from the anterior surface of the sacrum by three digitations (inverted E-shaped origin) and passes inferolaterally to leave through the greater sciatic foramen, which it almost fills. It inserts by a rounded tendon on the upper border of greater trochanter of femur. Inside the pelvis it is related anteriorly to the rectum, sacral plexus and branches of internal iliac artery. Its posterior surface is in contact with the sacrum. The relations of its extrapelvic part are described in chapter 94. The piriformis receives direct branches from L5, S1 and S2 ventral rami inside the pelvis.

Sacral Plexus
The sacral plexus is located in the pelvis in front of the sacrum. The nerves that take part in the sacral plexus are the lumbosacral trunk (L4, L5) and the ventral rami of the S1, S2, S3 and part of S4 spinal nerves.

Formation
All the nerves mentioned above converge towards the greater sciatic foramen and unite to form upper larger band and a lower smaller band. The upper band mainly consists of the nerves forming the two components of sciatic nerve. The ventral rami of L4, L5, S1 and S2 divide into ventral and dorsal divisions while that of S3 remains undivided. The lower band is more plexiform and receives contributions from ventral divisions of S2, S3 and from the undivided S4.

Branches of Communications
i. Each ventral ramus receives a gray ramus communicans from the sympathetic chain, through which each nerve receives postganglionic sympathetic fibers for distribution in their cutaneous territories.
ii. The ventral rami of second to fourth sacral nerves carry preganglionic parasympathetic fibers from S2 to S4 segments of spinal cord. These parasympathetic fibers leave the ventral rami to form the pelvic splanchnic nerve or nervi erigentes, which terminates in the appropriate parasympathetic ganglia located close to the target organs.

Branches from Dorsal Divisions
i. Superior gluteal nerve (L4, L5, S1)
ii. Inferior gluteal nerve (L5, S1, S2)
iii. Perforating cutaneous nerve (S2, S3)
iv. Perineal branch of the fourth sacral nerve
v. Direct branches to piriformis from S1, S2.

Branches from Ventral Divisions
i. Nerve to quadratus femoris (L4, L5, S1)
ii. Nerve to obturator internus (L5, S1, S2)
iii. Direct branches from S4 to levator ani and coccygeus
iv. Pudendal nerve from S2, S3 and S4 ventral divisions.

Branches from Both Divisions
i. Posterior cutaneous nerve of thigh from ventral division of S2 and S3 and dorsal division of S2 and S3.
ii. The common peroneal component of sciatic nerve from L4, L5, S1, S2 dorsal divisions and the tibial component from L4, L5, S1, S2 and S3 ventral divisions.

Except the intrapelvic muscular branches to piriformis, levator ani and coccygeus all the other branches of sacral plexus leave the pelvis through the greater sciatic foramen, where they are arranged in relation to piriformis muscle. Their extrapelvic course and distribution are described along with lower limb and perineum.

Clinical insight ...

i. Cancer may spread to the sacral plexus from the uterus, cervix, or rectum. Severe intractable pain in the lower limb is the most common symptom.
ii. When the fetal head descends into the pelvis during the last trimester of pregnancy, the sacral plexus is likely to be compressed, which results in pain or discomfort.
Coccygeal Plexus

The nerves taking part in this plexus are three in number, a small branch from the fourth sacral, fifth sacral and the coccygeal ventral rami. The three unite to form a common trunk on the surface of the coccygeus. Anococcygeal nerves are the fine filaments, which arise from it. They supply a few twigs to the coccygeus and levator ani. A few filaments pierce the sacrotuberous ligament to supply the skin from the coccyx to the anus.

Blood Vessels of Pelvis

The internal iliac arteries supply the pelvic walls, pelvic viscera, gluteal region, perineum and adductor compartment of thigh. They are the smaller of the two terminal branches of the common iliac arteries. In the fetus the internal iliac arteries give origin to umbilical arteries through which blood reaches the placenta for purification. After birth the entire umbilical artery does not undergo degeneration. Its patent segment forms the superior vesical artery whereas the rest of the umbilical artery (from the superior vesical artery till the umbilicus) is reduced to a fibrous ligament called lateral umbilical ligament.

**Internal Iliac Artery (Fig. 86.4)**

The internal iliac artery begins at the bifurcation of common iliac artery at the level of the disk between fifth lumbar vertebra and the sacrum, in front of the sacroiliac joint. It descends in posterior direction towards superior margin of the greater sciatic notch, where it divides into anterior and posterior divisions. The anterior division gives off both visceral and parietal branches whereas the posterior division gives only parietal branches.

**Visceral Branches of Anterior Division (Figs 86.4 and 86.5)**

The visceral branches of the anterior trunk are three in males and four in females.

In Male

i. The superior vesical artery supplies the urinary bladder and often gives a branch to the ductus deferens.

ii. Inferior vesical artery runs forward to the base of the bladder and supplies the structures related to the base, including a long branch to the ductus deferens.

iii. A smaller middle rectal artery supplies the rectum, prostate and seminal vesicle.

In Female

i. The superior vesical artery supplies the urinary bladder.

ii. The vaginal artery takes the place of the inferior vesical artery. It supplies the urinary bladder, vagina and urethra.

iii. The smaller middle rectal artery supplies the rectum and vagina.

iv. The uterine artery describes a C-shaped course in the pelvis. At first it passes medially along the floor in the root of the broad ligament. On reaching the lateral vaginal fornix (at a distance of two centimeter from the cervix) it crosses the ureter superiorly. This relationship is described as “water under the bridge” by the surgeons. At this level the artery gives off its descending branch for the supply of vagina. The uterine artery now turns forward and then upward in the broad ligament by the side of the uterus to which it supplies numerous branches. Reaching the medial
end of uterine tube the uterine artery turns laterally along the lower margin of uterine tube to end in the mesovarium by anastomosing with ovarian artery. The uterine vessels are tortuous since they are greatly enlarged in gravid state of the uterus.

Parietal Branches of Anterior Division

i. The inferior gluteal artery passes posteriorly between the first and second sacral ventral rami to reach the lower part of the greater sciatic foramen below the piriformis. Inside the pelvis it supplies the muscles of pelvic walls, perirectal fat and the urinary bladder. In males it supplies prostate and seminal vesicle. Its further course is described in the gluteal region.

ii. The obturator artery along with the nerve and vein of the same name (NAV from above downward) passes in anterior and inferior direction towards the obturator canal from where it leaves the pelvis to enter the medial compartment of thigh. In the pelvis it gives three branches, namely, iliac, vesical and pubic. The pubic branch anastomoses with the pubic branch of inferior epigastric artery on the pelvic surface of the body of the pubis.

iii. The internal pudendal artery leaves the pelvis through the lowest part of greater sciatic foramen. It is accompanied by the pudendal nerve and nerve to obturator internus. These three structures enter the gluteal region, wind round the ischial spine to enter the lesser sciatic foramen. The extrapelvic course of the internal pudendal artery is described in gluteal region and perineum.

Branches of Posterior Division

i. The superior gluteal artery is the largest branch. It passes between the lumbosacral trunk and first sacral ramus to reach the uppermost part of the greater sciatic foramen. It is accompanied by corresponding vein and superior gluteal nerve. Its further course is described in gluteal region.

ii. The iliolumbar artery ascends anterior to the sacroiliac joint in close relation to the lumbosacral trunk and obturator nerve. It divides into iliac and lumbar branches and may give rise to the fifth lumbar artery.

iii. The lateral sacral arteries are two on each side. They enter the pelvic sacral foramina to supply the contents of sacral canal.

Veins of Pelvis

The following veins drain blood from pelvic viscera and pelvic walls, internal iliac veins, superior rectal vein (drains the rectum and upper part of anal canal in portal venous system), median sacral vein (draining into the left common iliac vein), gonadal vein (draining into the inferior vena cava on the right side and into the left renal vein on the left side) and pelvic venous plexuses.

Internal Iliac Vein

This is the main vein of the pelvis. It receives tributaries corresponding to the branches of the internal iliac artery. It is formed at the upper end of greater sciatic foramen by the confluence of all the veins accompanying the branches of internal iliac artery except the iliolumbar vein, which drains into the common iliac vein. The internal iliac vein joins the external iliac vein in front of the sacroiliac joint to form the common iliac vein.

Pelvic Venous Plexuses

The pelvic venous plexuses are present around the pelvic viscera. They are thin-walled and intercommunicating.

i. The vesical venous plexus in the male is located in the retropubic space in relation to the inferolateral surfaces of the urinary bladder. It receives communication from the prostatic plexus and drains by inferior vesical veins into the internal iliac vein. Some part of it that travels along the posterior ligament of bladder, drains into the internal vertebral venous plexus (Batson’s plexus). This communication provides a route for spread of prostatic cancer into the vertebral column.

ii. The prostatic venous plexus is present within the fascial sheath of the prostate. It receives the deep dorsal vein of the penis and drains into the vesical plexus.

iii. In the female the vesical plexus surrounds the neck of the bladder and the beginning of the urethra. It receives the dorsal vein of clitoris and drains into the vaginal plexuses.
iv. The uterine plexuses are located inside the broad ligaments. They communicate with ovarian and vaginal plexuses and drain by two veins into the internal iliac veins. The vaginal plexuses, on the sides of vagina and in its mucosa, intercommunicate with uterine, rectal and vesical plexuses and drain by right and left vaginal veins into the respective internal iliac veins.

v. The rectal venous plexuses are of two types—internal and external. The internal plexuses are present in the submucosa of rectum and anal canal up to the pectinate line. The internal plexuses are important site of portocaval anastomosis. They are enlarged in portal hypertension. The superior and inferior rectal veins drain these plexuses. The external rectal plexus lies outside the muscular layer and is drained by all the three rectal veins. The rectal plexuses are in free communications with vesical and other pelvic plexuses.
The sigmoid colon, rectum and urinary bladder are located inside the pelvic cavity.

**SIGMOID COLON**

The sigmoid colon is also called the pelvic colon. It begins at the left brim of the true pelvis and forms a loop of variable length, which normally lies within the true pelvis. It ends at rectosigmoid junction where it becomes the rectum at the level of third sacral vertebra. The sigmoid colon, at first descends in contact with the left pelvic wall, and then crosses the pelvis between the rectum and urinary bladder in male, and between rectum and uterus in female. The average length of the sigmoid colon (Figs 81.25 and 83.4) is 40 cm. It is suspended from the posterior pelvic wall by a mesentery called the pelvic mesocolon.

**Pelvic Mesocolon**

The pelvic mesocolon is attached to the posterior pelvic wall by an inverted V-shaped root. The left limb of the root is attached along the left brim of the pelvis medial to the left psoas major muscle. The right limb is attached to the pelvic surface of sacrum and it ends in the midline on the third piece of sacrum. The apex of the root is located in front of the bifurcation of the left common iliac artery. An intersigmoid peritoneal recess is often found at the apex (its important relation is the left ureter). The pelvic mesocolon contains the sigmoid colon, superior rectal vessels in the right limb, sigmoid branches of inferior mesenteric artery in the left limb, marginal artery, lymph nodes, lymph vessels, nerve plexuses in loose areolar tissue and variable amount of fat.

**Relations of Sigmoid Colon**

On the left side, it is related to structures on the left pelvic wall, namely, external iliac vessels, obturator nerve, and ovary in female and vas deferens in male. On the posterior side, it is related to left internal iliac vessels, sacral plexus, left ureter and piriformis muscle. Inferiorly, it rests on urinary bladder in male and uterus and urinary bladder in female. On the right side, it is related to coils of small intestine.

**Rectosigmoid Junction**

The rectosigmoid junction corresponds to the third sacral vertebra, where the pelvic mesocolon ends. All the distinguishing external features of large intestine (bowel) cease to exist here. There is an acute angulation at this junction, which causes difficulty during passage of an endoscope. The rectosigmoid junction lies at the distance of 15 to 17 cm from the anal orifice. The perforation of bowel at this site may occur during sigmoidoscopy unless care is exercised while negotiating the instrument at this junction.
Sigmoid Colon, Rectum and Urinary Bladder

Chapter

Fig. 87.1: Colonoscopy by which interior of large intestine is inspected and biopsy taken, if necessary

Fig. 87.2: Barium enema radiograph showing aganglionic segment (yellow arrow) and megacolon (green arrow) in Hirschsprung’s disease

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**Clinical insight ...**

1. The diverticulosis is common in sigmoid colon. The small vessels perforate the wall of colon to reach the appendices epiploicae. The passage of the vessels creates weak areas. In cases where intraluminal pressure is quite high, (chronic constipation) the mucosa may herniate through the weak areas forming small diverticula. Inflammation of the diverticula is called diverticulitis.

2. The sigmoid colon is prone to volvulus because of extreme mobility of its mesocolon. Volvulus is a condition in which the peritoneal fold of a viscus rotates and twists around it endangering the blood supply of the viscus concerned.

3. Colonoscopy is used to examine the interior of colon (Fig. 87.1) and to take biopsy for confirming histopathological diagnosis.

4. Hirschspring’s disease or congenital megacolon (Fig. 87.2) is due to non-development of parasympathetic neurons in myenteric plexuses in a segment of large intestine. The reduced peristalsis in the aganglionic segment causes dilatation of proximal colon (hence the name megacolon). The child born with this condition presents following symptoms within a few days after birth. The newborn fails to pass meconium. The meconium is a dark green colored substance (composed of intestinal juices, bile and swallowed amniotic fluid) filling the large intestine of a full term fetus. The abdomen of the new born begins to distend. The treatment consists of operative removal of aganglionic segment.

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**RECTUM**

The rectum is the part of large intestine, which lies between the rectosigmoid and anorectal junctions. It is about 12 to 15 cm long and its diameter is similar to that of the sigmoid colon. The anorectal junction lies about 3 cm in front of and just below the tip of the coccyx.

**Curvatures**

Though the meaning of the word rectum is straight, it is curved in sagittal and coronal (lateral) planes. The upper and lower ends of the rectum are in the midline. The sagittal curvatures are the sacral and perineal. The sacral curvature is the one by which the rectum is moulded to the concavity of sacrum. The perineal curvature is present at the anorectal junction, which is encircled by the puborectalis muscle and shows an acute angulation (120°) with forward convexity. The three coronal curvatures are the upper with convexity to the right, middle with convexity to left and the lower with convexity to the right.
Abdomen, Pelvis and Perineum

Section 7

Structures, base of the urinary bladder, seminal vesicles, vasa deferentia, prostate and terminal parts of ureters (Fig. 87.6). The rectovesical fascia represents the obliterated part of rectovesical peritoneal pouch, which extends right up to the pelvic floor until the fourth month of intrauterine life.

ii. In the female, the rectum is closely related to the posterior wall of vagina (Fig. 87.8).

Anterior Relations (Above the Level of Peritoneal Reflection)

i. In the male, the rectum is related to the rectovesical pouch and its contents.

ii. In the female, the rectum is related to the rectouterine pouch and its contents.

Posterior Relations (Figs 87.4A and B)

The posterior relations are similar in the two sexes. The rectum is attached to the sacrum and coccyx by connective tissue (fascia of Waldeyer) enclosing the lymph nodes, lymphatics and perirectal fat. There are different structures posteriorly in the midline and on either side of midline.

Peritoneal Relations

The upper-third of the rectum is covered with peritoneum on the front and sides. The middle third is covered only on the front and the lower-third is devoid of peritoneal covering. The peritoneum is reflected from the junction of middle and lower-third of rectum to the urinary bladder in the male to form rectovesical pouch (Fig. 87.7). In the female, the peritoneum is reflected from the same level to the posterior fornix of vagina to form a deeper rectouterine pouch (Fig. 87.9).

The coils of small intestine and the sigmoid colon are the usual contents of the peritoneal pouches in both the sexes.

Anterior Relations (Below the Level of Peritoneal Reflection)

i. In the male, the rectovesical fascia (Denonvillier’s fascia) separates the rectum from the following structures, base of the urinary bladder, seminal vesicles, vasa deferentia, prostate and terminal parts of ureters (Fig. 87.6). The rectovesical fascia represents the obliterated part of rectovesical peritoneal pouch, which extends right up to the pelvic floor until the fourth month of intrauterine life.

ii. In the female, the rectum is closely related to the posterior wall of vagina (Fig. 87.8).

Fig. 87.3: Extent of rectum and its internal features

Fig. 87.4A and B: (A) Posterior relations of entire rectum whereas; (B) Posterior relations of upper one-third of rectum in transverse section (Numbers indicate sacral segments or sacral pieces)
Midline Structures (Posteriorly)

i. Lower three pieces of sacrum and coccyx.
ii. Ganglion impar (formed by the union of the lower ends of the sympathetic trunks).
iii. Median sacral artery.

Structures on Either Side (Posteriorly)

i. Piriformis, coccygeus and levator ani
ii. Sympathetic chain
iii. Sacral plexus
iv. Coccygeal nerve
v. Pelvic splanchnic nerve (nervi erigentes)
vi. Terminal branches of superior rectal artery and lower lateral sacral vessels.

Lateral Relations
Muscles of the pelvic diaphragm intimately surround the lower part of the rectum to provide support.

Fascial Relations
The pelvic fascia around the rectum is thicker in consistency and is organized in different parts, which collectively can be grouped as rectal supports. These fascial supports of the rectum are divided during surgical removal of the rectum.

i. The fascia of Waldeyer is a strong condensation on the posterior aspect, which connects the lower part of anterior surface of the sacrum to the anorectal junction.
ii. The lateral rectal ligament is the fascial thickening around the middle rectal vessels. It extends from the lateral pelvic wall to the rectum.

Rectal Support
The puborectalis sling maintains the angulation at the anorectal junction. The pelvic diaphragm and the fascial supports are important in maintaining the position of the rectum. The weakness of the supports predisposes to rectal prolapse.

Arterial Supply of Rectum (Fig. 87.5)
The arterial supply is separate for the mucosa and for the wall of the rectum.

1. The arterial supply of the mucosa of the rectum is by the superior rectal artery, which is a continuation of inferior mesenteric artery. The superior rectal artery courses behind the rectum and divides into right and left branches at the level of third piece of sacrum. These terminal branches give off twigs which, pierce the rectal wall at various points and supply the entire mucosa of the rectum via the submucous plexuses.

2. The arterial supply of the wall of the rectum is from three sources.
   i. The superior rectal artery supplies the upper rectal wall.
   ii. The middle rectal artery (a branch of the anterior division of the internal iliac artery) supplies the lower rectal wall.
   iii. The median sacral artery (a branch of abdominal aorta) supplies the back of the anorectal junction.

Venous Drainage of Rectum
i. The veins in the rectal mucosa form internal rectal venous plexuses, which drain via the superior rectal vein into the portal vein.
ii. The veins of the wall of the rectum form external rectal venous plexus, which drains into the internal iliac vein via the middle rectal veins or the inferior rectal veins.

Lymphatic Drainage (Fig. 87.6)
The lymph vessels along the superior rectal vessels reach the superior rectal lymph nodes (pararectal nodes of Gerota), which lie in close contact with the posterior wall of the rectum. The pararectal nodes drain into the inferior mesenteric nodes. The lymph vessels along the middle rectal vessels end in middle rectal nodes, from which the lymph drains in the internal iliac nodes.

Nerve Supply
The rectum receives both sympathetic and parasympathetic innervation.
Abdomen, Pelvis and Perineum

Section

URINARY BLADDER

The urinary bladder is a hollow muscular organ, which acts as a temporary reservoir of urine brought to it by the ureters. The stored urine is passed out through the urethra, when the bladder is distended enough to feel the desire to micturate.

Position

The position of the urinary bladder varies with age.

i. At birth the bladder is an abdominal organ, the internal urethral meatus being at the level of the upper border of symphysis pubis.

ii. The bladder starts descending at the age of six years and becomes a pelvic organ shortly after puberty, when the internal urethral meatus is just above the plane of the inferior margin of the symphysis pubis.

iii. In adult, the empty bladder is entirely in the pelvic cavity but a distended bladder rises in the abdominal cavity.

iv. The position of the empty bladder in the adult is described as lying on the front part of pelvic floor, below the peritoneum and behind the pubic symphysis.

Shape and Capacity

The shape of the urinary bladder is tetrahedral when empty and globular or ovoid when distended. The capacity of the bladder varies from 120 to 250 ml. The maximum capacity is 500 ml when tension builds up in the bladder wall and pain is experienced. The pain is referred to cutaneous areas supplied by T11 to L2 and S2 to S4 segments of the spinal cord.
Surfaces, Borders and Angles (Fig. 87.7)
The urinary bladder has four triangular surfaces, four borders and four angles. The borders are anterior, right and left lateral (inferolateral) and posterior. The surfaces are superior, right and left inferolateral and posterior (base or fundus). The posterior surface is an inverted triangle with its narrow end pointed inferiorly and its broad end (posterior border) superiorly. The apex or anterior angle is the meeting point of superior and inferolateral surfaces. It gives attachment to the median umbilical ligament. The neck or inferior angle is the lowest and most fixed part of the bladder and is the meeting point of inferolateral surfaces and the narrow end of the posterior surface. The urethra begins at the neck. The right and left lateral angles are located at the meeting points of inferolateral, posterior and superior surfaces. This coincides with the lateral ends of the posterior border and the ureter opens at this angle on each side.

Relations in Male (Fig. 87.8)
i. The peritoneum covers the superior surface completely and is reflected from the upper part of the base on to the anterior surface of the rectum forming the rectovesical pouch. Anteriorly, the peritoneum is reflected on the anterior abdominal wall. The superior surface is in relation to coils of small intestine and sigmoid colon. As the bladder rises with the distension, its superior surface and the covering peritoneum are raised. As a consequence of this, the anterior line of peritoneal reflection is lifted up and the peritoneum is peeled off the infraumbilical abdominal wall. In this way, more and more of inferolateral surfaces come in direct contact with the anterior abdominal wall. So, an extraperitoneal approach for suprapubic cystotomy (making an opening in the urinary bladder) is possible if the bladder is distended.

ii. The inferolateral surfaces face downwards and laterally and the anterior border intervenes between the right and left surfaces. The retropubic space or cave of Retzius with its pad of fat separates them from the pelvic surface of pubis and puboprostatic ligaments. On a slight posterior plane, these surfaces are in contact with fascia covering the levator ani and obturator internus.

iii. The base or the posterior surface has important relations. On either side, it is intimately related to the seminal vesicle and ductus deferens. A triangular area of the base bounded above by the line of peritoneal reflection, and by the right and left vasa deferentia on the sides is called the external trigone (Fig. 87.9). The external trigone is closely related to the rectum, the only structure intervening between the two is rectovesical or Denonvillier’s fascia.

Relations in Female (Fig. 87.10)
i. The superior surface of the bladder is not completely covered with peritoneum. Anteriorly, the peritoneum is reflected on the anterior abdominal wall as in the case of male. Posteriorly, the peritoneum is reflected from the superior surface on to the isthmus of uterus to form a shallow uterovesical pouch. The peritoneum covered superior surface is related to coils of small intestine, sigmoid colon and body of uterus. A small non-peritoneal posterior part of superior surface is in contact with the cervix of uterus.
Section

urethral meatus. At the neck, the circular fibers of detrusor muscle show slight aggregation to form internal sphincter of the bladder. In males, the neck is in direct contact with the base of the prostate while in female it rests on the pelvic fascia.

Ligaments
The ligaments of the bladder are divided into true and false. The true ligaments are the condensations of the pelvic fascia around the base and neck of the bladder or fibrous bands mixed with a few fibers of smooth muscles or the developmental remnants. The false ligaments are the peritoneal folds.

True Ligaments
i. The median umbilical ligament extends from the apex of the bladder to the umbilicus. It is the remnant of urachus.

ii. The medial and lateral puboprostatic (male) or pubovesical (female) ligaments are composed of both smooth muscle fibers and condensation of pelvic fascia. The medial puboprostatic or pubovesical ligaments extend from the neck of bladder to the pubic symphysis while the lateral ligaments attach the neck to the anterior end of the tendinous arch of obturator fascia. The puboprostatic or pubovesical ligaments form the floor of cave of Retzius. These ligaments are of surgical importance because of their intimate relation to the vesical venous plexus. Hence, when they are divided, it is advisable to cut as laterally as possible and as close to the pubis as possible.

iii. The lateral true ligaments are condensation of pelvic fascia and extend from the inferolateral surface to the tendinous arch.

iv. The posterior true ligaments are condensations of the pelvic fascia. They attach the neck and the base of the bladder to the lateral pelvic wall along the internal iliac vein and contain the vesical venous plexus.

False Ligaments
i. The median umbilical fold is a peritoneal fold raised due to median umbilical ligament.

ii. The medial umbilical folds are the peritoneal folds raised due obliterated umbilical arteries.

iii. The lateral false ligaments are the reflections of peritoneum from the urinary bladder to the lateral pelvic wall.

iv. The posterior false ligaments are the sacrogenital folds, which are the peritoneal folds from the sides of the urinary bladder to the sacrum.

Neck of the Bladder
The neck of the bladder alters very little with varying positions of the bladder or rectum. It is pierced by the internal

Fig. 87.9: Relations of base (posterior surface) of urinary bladder in male

Fig. 87.10: Peritoneal relations of urinary bladder in female
Interior of Bladder
In the living, the mucous membrane of bladder is smooth and pale in color. It is very loosely attached to the submucosa hence is thrown up in folds, when the bladder is empty.

Internal Trigone (Fig. 87.11)
i. The internal trigone is a triangular area on the posterior surface of the bladder interior, where the mucosa is pink in color and is firmly attached to the underlying muscle layer (the submucosa being absent at the internal trigone).

ii. It is shaped like an equilateral triangle. The interureteric ridge of Marcier, which is formed by fibers of the inner longitudinal muscle coat of the ureter, forms the upper margin of the trigone. The other two sides of the trigone are formed by uretero-urethral ridges, which are produced by the longitudinal muscle of ureter. The orifices of the ureters form the superolateral angles while the internal urethral orifice forms the inferior angle of the trigone.

iii. In the male, the internal urethral orifice is guarded by an elevation of the trigone called uvula vesicae produced by the projection of the median lobe of the prostate. The hypertrophy of the median lobe blocks the internal urethral meatus causing retention of urine.

iv. The mucosa of the trigone is more vascular and more sensitive compared to the mucosa of rest of the bladder. It is mesodermal in development (compared to the endodermal mucosa of the rest of the bladder).

v. The calculi in the urinary bladder eroding the trigone or cancer involving the mucosa of trigone cause extreme pain, which radiates to the perineum mainly to the tip of penis or clitoris.

Blood Supply
i. In the male, the urinary bladder receives branches mainly from the superior vesical and inferior vesical arteries. Additional branches are derived from obturator and inferior gluteal arteries.

ii. In the female, the branches of superior vesical arteries and of the vaginal arteries (in place of inferior vesical arteries) are the major sources. Additional branches arise from uterine arteries.

iii. The veins form a complicated plexus of veins lying on the inferolateral surfaces. These vesical venous plexuses pass backwards along the posterior true ligaments to open into the internal iliac veins. They are in communication with the internal vertebral venous plexus.

Lymphatic Drainage
The lymphatic vessels of the bladder leave it at various points but all ultimately converge to the external iliac lymph nodes.

Nerve Supply (Fig. 87.12)
Both parasympathetic and sympathetic nerves supply the urinary bladder through the vesical plexus of nerves.

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**Fig. 87.11:** Internal trigone of urinary bladder and internal features of prostatic urethra

**Fig. 87.12:** Nerve supply of urinary bladder, sphincter vesicae and sphincter urethrae
i. The pelvic splanchnic nerve or nervi erigentes (S2, S3, S4) bring preganglionic parasympathetic fibers to the postganglionic neurons in the bladder wall. The postganglionic fibers are motor. On stimulation, they cause contraction of detrusor and relaxation of the internal sphincter. So, parasympathetic is described as “nerve of emptying or voiding”.

ii. The sympathetic fibers arise from lower thoracic and upper two lumbar segments of spinal cord. They synapse in the inferior hypogastric plexus, from where postganglionic fibers reach the bladder via the vesical plexus. It is regarded as mainly vasomotor. Its action on the detrusor is either inhibitory or it has no action on it but it closes the internal sphincter. So the sympathetic efferent fibers mainly act on the muscle surrounding the bladder neck.

iii. The afferent fibers from the bladder carry pain impulse from the mucosa and the sense of awareness of bladder filling. The pain impulse is carried by both parasympathetic and sympathetic nerves to the spinal cord. The pain from the endodermal bladder is referred to the hypogastric region but that from trigone is referred to the tip of the penis or clitoris. The pelvic splanchnic nerves carry the sensation of awareness of bladder filling to the sacral second to fourth segments of the spinal cord.

iv. The pelvic splanchnic nerves form both the afferent and the efferent limbs of the micturition reflex. The center of the reflex arc is intermediolateral cells of sacral second to fourth spinal segments (spinal micturition center). The ventral horn cells of these segments control the voluntary component of the micturition through the nerve supply of the external urethral sphincter by the pudendal nerve (S2, S3, S4). The spinal micturition center is governed by cortical micturition center in paracentral lobule.

Visualization of Urinary Bladder

i. Cystoscopy is used to examine the interior of the bladder with a help of a cystoscope passed through the urethra. It is possible to pass the catheter in the ureteric orifice through the cystoscope for retrograde pyelography or for collecting urine samples directly from the ureter. The pale interureteric ridge is a visible landmark, which helps in guiding the catheter in the ureteral orifice.

ii. Cystogram is the radiograph of the urinary bladder after instilling contrast medium.

iii. The ultrasound and CT scans are the methods to observe the urinary bladder.

Clinical insight ...

i. The urinary bladder may rupture in the fracture of the pubic bone causing intraperitoneal or extraperitoneal extravasation of urine.

ii. The retention of urine may be due to enlarged prostate or stricture of urethra. In these conditions, the obstruction to urine outflow is slow and progressive. The bladder musculature hypertrophies and results in enlarged and trabeculated bladder. Gradual back pressure builds up, which affects the ureter and the entire collecting system of the kidney resulting in hydrourerter and hydronephrosis.

iii. Cystitis means the inflammation of urinary bladder. It gives rise to frequency and urgency of urination with suprapubic discomfort.

iv. The transitional cell carcinoma of the urinary bladder is usually due to chemical cause. The incidence of bladder cancer is more common in workers in aniline dye factories.

v. The suprapubic cystotomy provides an extraperitoneal surgical approach to urinary bladder. For this procedure first the bladder is filled with distilled water so that its non-peritoneal inferolateral surfaces come in contact with anterior abdominal wall. This approach is used in removal of vesical calculi and the prostate.

vi. The spinal cord injuries affect the function of the urinary bladder. The automatic reflex bladder is seen in spinal cord injury above the level of spinal micturition center. Due to injury at this level, the cortical control or voluntary control is lost. As a result, the bladder fills and empties reflexly every one to four hours. The autonomous bladder is the condition produced due to destruction of S2 to S4 segments of spinal cord (located at level of the first lumbar vertebra). Here, both voluntary and reflex control over micturition is lost. The bladder capacity is greatly increased because of loss of tone of detrusor muscle. The bladder overfills and then overflows.

Embryologic insight ...

Developmental Sources of Urinary Bladder (Fig. 87.13)

i. The epithelium lining the trigone of urinary bladder is derived from mesoderm of the absorbed parts of mesonephric ducts.

ii. The epithelium lining the rest of the urinary bladder develops from the endoderm of the vesicourethral part of urogenital sinus.

Contd...
Fig. 87.13: Sources of development of urinary bladder
(Note that endoderm and mesoderm contribute to the development of mucosa of urinary bladder)

Contd...

iii. The detrusor muscle of bladder develops from splanchnopleuric mesoderm.

**Congenital Anomalies of Urinary Bladder**

i. Ectopia vesicae is the condition in which the infraumbilical abdominal wall and the anterior wall of bladder are deficient. As a result, the trigone of the bladder is exposed to the surface.

ii. Congenital vesicovaginal or rectovesical fistula occurs due to incomplete septation of endodermal cloaca by defective urorectal septum.

iii. Urachal cyst and fistula occur due to partial or complete patency of allantois.

iv. Umbilical urinary fistula occurs due to complete patency of urachus (Fig. 79.12).
When the reproductive organs make their appearance in the embryonic stage they are similar in both sexes. This is referred to as indifferent stage of development. Later on development proceeds either on the path of male reproductive organs or on the path of female reproductive organs.

**Male Reproductive Organs**

The male reproductive organs include testes, epididymis, ductus deferens, seminal vesicles and prostate (Fig. 88.1).

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**Development of Testis from Indifferent Gonad**

The genital ridge is formed on each side by proliferation of coelomic epithelium on the dorsal body wall of the embryo during fifth week (Fig. 88.2). The primordial germ cells migrate in to the genital ridge in the sixth week from endoderm of the yolk sac. Under the influence of TDF (testis determining factor) on SRY gene on the short arm of Y chromosome the indifferent gonad differentiates into testis. The cells of coelomic epithelium form the seminiferous tubules. The primordial germ cells give rise to the spermatogonia (germ cells). Thus testis develops from mesoderm and endoderm.
Differentiation of Genital Ducts in Male

Two genital ducts develop in indifferent stage. As shown in Figure 88.3 the indifferent gonad is located medial to the mesonephric tubules and mesonephric duct (or Wolffian duct). The paramesonephric duct or Müllerian duct (formed by the invagination of the coelomic epithelium) is located lateral to the mesonephric duct. The right and left paramesonephric ducts fuse at their caudal ends. Their fused end abuts on the posterior wall of the urogenital sinus to produce a bulge in the interior of the latter. This bulge is called Müllerian tubercle. Under the influence of the testosterone secreted by the Leydig cells (of fetal testes) the mesonephros and the mesonephric ducts become functionally linked to the testes. Simultaneously, under the influence of Müllerian inhibiting substance secreted by Sertoli cells (of fetal testes) the paramesonephric ducts regress.

Duct System of Testis Derived from Mesonephric Tubules and Genital Ducts (Fig. 88.4)

i. The cranial 12 to 15 mesonephric tubules become the vasa efferentia or efferent ductules of the testis.

ii. The mesonephric duct gives rise to the epididymis, ductus deferens, seminal vesicle and ejaculatory duct.

Embryological Remnants in Male (Fig. 88.4)

i. A few cranial mesonephric tubules become the superior aberrant ductules and a few caudal mesonephric tubules become the inferior aberrant ductules and the paradidymis.

ii. The cranial end of the mesonephric duct becomes the appendix epididymis. It is a small pedunculated structure on the head of the epididymis.

iii. The remnants of paramesonephric duct are appendix testis on the superior pole of testis and prostatic utricle inside the prostate gland.

iv. The remnant of Müllerian tubercle is colliculus seminalis inside the prostate gland.

Descent of Testis (Fig. 88.5)

The descent of testis from the posterior abdominal wall to the scrotum is a gradual process. The spermatogenesis needs lower temperature than that of the body. Hence,
the testis descends to the scrotum with the help of gubernaculum testis and processus vaginalis. The gubernaculum testis (mesenchymal band) extends from the lower pole of the testis and traverses the inguinal canal to reach the bottom of the genital or labioscrotal swellings (future scrotum). It pulls the testis downwards. The processus vaginalis is a peritoneal pouch, which precedes the testis and lies in front of gubernaculum. The testis invaginates into the processus vaginalis after reaching the scrotum and acquires a serous envelope (tunica vaginalis). At the end of descent, the gubernaculum testis is greatly shortened.

Fate of Gubernaculum Testis

The gubernaculum is reduced to the scrotal ligament, which connects the lower pole of testis to the scrotal wall.

Fate of Processus Vaginalis

The distal part of processus vaginalis forms the tunica vaginalis testis. The part of processus vaginalis between tunica vaginalis and peritoneal cavity is obliterated and reduced.
to a fibrous strand (which is one of the contents of spermatic cord in male).

**Chronology of Descent (Fig. 88.6)**
The testis descends in the iliac fossa at third month of intra-uterine life. It reaches the deep inguinal ring at seventh month, passes through the inguinal canal during the eighth month. It is in the scrotum at term or immediately after birth.

**Clinical insight ...**

**Anomalies of Descent of Testis**

i. Cryptorchidism or undescended testis may be unilateral or bilateral (Fig. 88.7). The testis may be arrested anywhere in the path of its descent. An undescended testis is incapable of spermatogenesis and is more liable to malignancy.

ii. Ectopic testis is a normally descended testis but in abnormal position. The ectopic testis may be found in the anterior abdominal wall, thigh, femoral canal, perineum or at the root of the penis. The ectopic testis is functionally normal but it is more liable to injury.

**Female Reproductive Organs (Fig. 88.8)**
The female reproductive organs consist of ovaries, fallopian tubes, uterus and vagina.

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**Embryologic insight ...**

**Development of Ovaries from Indifferent Gonad**
The genital ridge and the primordial germ cells (migrated from the endoderm of yolk sac) form the indifferent gonad (Fig. 88.2). The proliferating coelomic epithelium forms sex cords, which invade the mesenchyme of the genital ridge and surround each primordial germ cell to give rise to the primordial ovarian follicles. The surface epithelium of the ovary is called **Contd...**
Descent of Ovary (Fig. 88.5)
The ovary descends from the posterior abdominal wall to the true pelvis. The gubernaculum ovarii and processus vaginalis are formed. The gubernaculum ovarii becomes attached to the paramesonephric duct (at the future site of junction of uterine tube and uterus) and then passes through the inguinal canal to the genital or labioscrotal swelling, which will later on form the labium majus. Thus, it is clear that the attachment of gubernaculum to the paramesonephric duct prevents the descent of ovary outside the abdomen.

Fate of Gubernaculum Ovarii
It remains long and is changed into ligament of ovary and round ligament of uterus. If the gubernaculum ovarii fails to contact the paramesonephric duct the ovary may be pulled out of the abdomen, giving rise to ectopic ovary.

Fate of Processus Vaginalis
The processus vaginalis or canal of Nuck is very small. It normally obliterates completely.

Embryological Remnants in Female (Fig. 88.9)

i. The epoophoron and paroophoron are the remains of mesonephric tubules, which are located in the broad ligament.

ii. Gartner’s duct is the remnant of mesonephric duct. It runs parallel to but below the uterine tube in mesosalpinx and then passes downward by the side of uterus to the level of internal os, where it passes in the tissues of the cervix. The duct sometimes forms a cyst called Gartner’s cyst in the broad ligament.

Congenital Anomalies of Uterus (Figs 88.10A to D)

i. Uterus didelphys is complete duplication of uterus, cervix and vagina due to failure of fusion of the caudal parts of paramesonephric ducts.

ii. Uterus bicornis bicornis (Fig. 88.11) is characterized by double uterus and cervix but single vagina. This is due to incomplete fusion of the caudal parts of the paramesonephric ducts.

iii. Septate uterus shows an incomplete septum in the uterine cavity.

iv. Unicornuate uterus is due to unilateral suppression of paramesonephric duct.

v. In Müllerian agenesis syndrome or Rokitansky syndrome there is failure of development of Müllerian tubes or paramesonephric tubes. As a result the uterine tubes, uterus and vagina are absent. The female born with this syndrome will have primary amenorrhea.

Development of Vagina
The vaginal plate develops from sinuvaginal bulbs which are formed by endodermal proliferation of urogenital sinus between the blind lower end of uterovaginal canal and the urogenital sinus.

i. According to one view, the entire vagina develops from the sinuvaginal bulbs and hence is endodermal.

ii. According to another view, upper one fifth including fornices develops from mesoderm of uterovaginal canal while lower four fifth develops from endoderm of sinuvaginal bulbs.

Congenital Anomalies of Vagina
i. Duplicate vagina is associated with duplication of uterus and cervix.
Contd...

- Imperforate hymen causes hematocolpos (accumulation of menstrual blood in vagina) after the onset of puberty. This is due to failure of the central part of Müllerian eminence to disintegrate.
- Congenital rectovaginal or vesicovaginal fistula.

**Fate of Müllerian Eminence**

The central part of Müllerian eminence degenerates to form hymenal orifice and the peripheral part is retained as the hymen.

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**GROSS ANATOMY OF TESTIS, EPIDIDYMIS, VAS DEFERENS**

The testes are responsible for the production of sperms and the secretion of testosterone. The sperms are transported in sequence by vasa efferentia, epididymis, ductus deferens (vas deferens) and ejaculatory duct to the prostatic urethra.

The secretions of prostate seminal vesicles and bulbourethral glands provide nourishing liquid medium to the sperms. The testes, epididymes and the part of vasa deferentia are located outside the abdominal cavity (Fig. 88.12A) and part of the vasa deferentia, seminal vesicles, ejaculatory ducts and prostate are inside the pelvic cavity.

**Location and Parts of Testis**

The testis and epididymis are suspended in one half the scrotum by the spermatic cord. The left testis usually lies at a slightly lower level than the right because the left
Spermatic cord is longer than the right. The testis is oval-shaped structure of rubbery consistency and measures 5×3×2.5 cm in the adult. Each testis has superior and inferior poles, anterior and posterior borders and lateral and medial surfaces. The inferior pole of the testis is attached to the scrotal wall by scrotal ligament, which is the remnant of the gubernaculum testis.

**Epididymis**

The epididymis is a very long and highly coiled tube attached to the posterior margin of testis. It consists of the head, body and tail. The head of epididymis is applied to the superior pole of the testis and the body lies against the posterolateral surface hence the swellings of the epididymis are posterolateral to testis.

**Clinical insight ...**

**Anteversion and Inversion of Testis (Fig. 88.12B)**

Anteversion of testis means the epididymis is related to the anterior border of testis. In inversion of testis both epididymis and testis are reversed (upside down) so that the head of anteverted epididymis is towards the upper pole of testis and tail towards lower pole. These anomalies predispose to torsion of testis. In torsion, the testis is rotated around the spermatic cord within the scrotum leading to occlusion of testicular artery and necrosis of testis.

**Tunica Vaginalis Testis**

The tunica vaginalis is a serous sac. Both the testis and epididymis are covered by the two layers of the tunica vaginalis on all sides except at the back. The parietal layer of the tunica lines the innermost layer of scrotal wall and the visceral layer covers the front and sides of the testis and epididymis. The two layers enclose a potential space. On the lateral aspect the visceral layer dips in the space between the body of epididymis and the testis to form a sinus of epididymis, which is on lateral side (and thus helps in side determination of an isolated testis).

**Coverings of Testis**

There are three coverings for the testis, which collectively form its capsule. The tunica vaginalis is a serous sac for both testis and epididymis. The tunica albuginea is a thick layer of fibrous tissue, which is thickest along the posterior margin of the testis. The tunica vasculosa lies deeper to tunica albuginea. In addition to the above three immediate coverings of testis there are others forming the wall of the scrotum, which also cover the testis and epididymis.

**Testis and Epididymis on Section (Fig. 88.13)**

i. The tunica albuginea projects in the interior of the testis as a septum called mediastinum testis from the posterior margin of testis.

ii. The mediastium septum is traversed by blood and lymph vessels of testis and by the intercommunicating network of channels called rete testis.

iii. The fibrous septa project from the mediastinum testis in the interior to divide the testis into 200 to 300 lobules. Each lobule contains convoluted seminiferous tubules, which are the seats of sperm production. The seminiferous tubules join the rete testis and discharge the sperms into the spaces of the rete from where the sperms enter into the efferent ductules for onward transmission into the duct of epididymis. The head of
the epididymis consists of highly convoluted efferent ductules, which connect the duct of the epididymis and the testis. The highly coiled duct of epididymis is about 6 to 7 m long and forms the body and tail of epididymis, where it becomes continuous with the ductus deferens.

**Microscopic Structure of Seminiferous Tubule**

The spermatogonia rest on the basement membrane of the seminiferous tubules. In addition there are spermatocytes and spermatids also. The Sertoli cells or supporting cells are present in between the germ cells. The nuclei of these cells are of cartwheel shape hence the Sertoli cells lose the capacity for mitosis. These tall cells bear pits on their sides, where the germ cells come in close contact. The function of the Sertoli cells is to support and nourish the immature germ cells. They help in phagocytosis of residual bodies. They secrete estrogen and provide blood testis barrier.

**Arterial Supply (Fig. 88.14)**

The testicular artery is a branch of abdominal aorta. It enters the deep inguinal ring and travels in the spermatic cord to supply the testis and epididymis. The artery to vas deferens from the superior or inferior vesical artery and cremasteric artery from the inferior epigastric artery are additional sources of blood supply.

**Venous Drainage**

Many small testicular veins emerge from the testis to form a large venous network called pampiniform plexus, which forms the main bulk of the spermatic cord. At the deep inguinal ring the plexus is replaced by testicular vein.

### Clinical insight ...

**Varicocele**

The varicocele is a condition in which the pampiniform plexus becomes tortuous and dilated. On palpation the spermatic cord feels like a bag of worms. The rise in scrotal temperature due to varicocele may sometimes interfere with spermatogenesis.

**Causes of Frequency of Varicocele on Left Side**

1. The left testicular vein is longer than the right. The left vein opens into the left renal vein at right angle while the right vein opens into the inferior vena cava at an acute angle.
2. The left testicular vein ascends posterior to the descending colon, which when loaded may compress the vein.

**Lymphatic Drainage**

The testis and epididymis are drained by lymphatics to preaortic and para-aortic or lateral aortic lymph nodes on the posterior abdominal wall. At times enlargement of these lymph nodes may be the only sign of the carcinoma (seminoma arising from germ cells).

**Nerve Supply**

The testis and epididymis receive sympathetic efferent nerve supply through celiac and testicular plexuses from T10 to T12 segments of spinal cord. The afferent fibers travel in sympathetic nerves in the same plexuses to the lesser and least splanchnic nerves, which carry them to the same segments of spinal cord. The testicular pain is referred to the middle and lower abdominal wall.

**Testicular Thermoregulation**

The scrotal temperature is three degrees lower than the body temperature. The factors responsible for maintaining the temperature of scrotum are as follows.

1. The scrotal sweat glands are numerous and the subcutaneous fat is absent in scrotal skin.
2. The contraction of dartos muscle in cold conditions reduces the surface area of scrotal skin.
3. The countercurrent heat exchange mechanism is said to exist between the testicular artery and veins in pampiniform plexus in the spermatic cord. The artery is entwined in venous plexus so that heat is absorbed from the artery into the veins. In this way pre cooled blood reaches the testis.
Ductus Deferens or Vas Deferens

The ductus deferens is a thick-walled muscular tube, measuring 45 cm in length. The sperms are stored and transported to the prostatic urethra through it. The vas can be felt superomedial to the pubic tubercle and can be easily identified in the spermatic cord because it has the consistency of a plastic tube.

Course (Fig. 88.1)

i. The first part of vas deferens is in the scrotum, where it begins at the tail of epididymis. It is highly coiled. It ascends along the posteromedial aspect of testis to the superior pole of the testis.

ii. The second part is the component of spermatic cord. It extends from superior pole of testis to the deep inguinal ring. It passes through the superficial inguinal ring, inguinal canal and deep inguinal ring. It is covered with the three concentric layers of spermatic fasciae along with the rest of the contents of spermatic cord.

iii. The third part of the vas deferens (pelvic part) begins at the deep inguinal ring after it separates from the spermatic cord. It turns medially by hooking around the inferior epigastric artery and then turns backward to cross the external iliac vessels and come to lie in the lateral wall of true pelvis after crossing the pelvic brim. On its way to the base of the urinary bladder it crosses in succession, the superior vesical artery, obturator nerve and vessels, inferior vesical artery, and lastly the ureter. The vas then turns downwards and medially towards the base of the urinary bladder medial to the seminal vesicle, where it ends by joining the duct of seminal vesicle to form ejaculatory duct on each side. The terminal dilated part of the vas deferens that lies behind the urinary bladder is called the ampulla.

Spermatic Cord

The spermatic cord is 7.5 cm long and extends from the upper end of the posterior border of testis to the deep inguinal ring. It is composed of tubular sheaths enclosing the ductus deferens and the associated blood vessels and nerves.

Coverings of Spermatic Cord

The coverings of the spermatic cord are derived from the muscles and fascia of the anterior abdominal wall. The outer covering is the external spermatic fascia, which is continuous with external oblique aponeurosis at the superficial ring. The cremaster muscle and fascia from the internal oblique muscle form the intermediate covering. The inner covering is the internal spermatic fascia derived from the transversalis fascia at the deep ring.

Contents of Spermatic Cord (Fig. 88.15)

i. Vas deferens lies in the posterior part of the cord.

ii. Pampiniform venous plexus gives the bulk to the cord.

iii. Three arteries, namely, testicular, deferential and cremasteric

iv. The lymphatics of the testis and epididymis

v. The autonomic nerves and the genital branch of genitofemoral nerve

vi. Fibrous remnant of the embryonic processus vaginalis

Clinical insight ...

Conventional Vasectomy

This is a family planning operation in male. A small incision is placed in the upper part of the scrotum on both sides. The vas deferens is identified from its position and its feel in the spermatic cord, after cutting open the coverings. Each duct is cut and the cut ends are ligated. In this way there is a break in the path of the sperms. After the operation the normal ejaculate does not contain sperms.

No Scalpel Vasectomy (NSV)

No scalpel vasectomy is a no incision and no stitch vasectomy with minimal dissection. The procedure is performed under local anesthesia. The vas deferens is fixed at the median raphe of scrotum with special ring forceps (Fig. 88.16). A sharp and pointed instrument is used to puncture the skin directly overlying the vas. The puncture hole is enlarged to expose the vas. Next the vas is firmly grasped with the puncturing instrument and rotated clockwise. In this way the vas is delivered out of the puncture hole. Subsequently the procedure of placing ligatures at the ends of the extruded loop of the vas and excision of a segment between the ligatures is similar to conventional vasectomy.

Fig. 88.15: Transverse section of spermatic cord to show details of its contents
Prostate

The prostate is an accessory sex gland in the male. It is located deep in the pelvic cavity. The prostate is composed of glandular and fibromuscular tissue hence it is firm in consistency. The size and activity of prostate are under the influence of sex hormones. The prostate becomes functionally active from the age of puberty. Its secretion is added to seminal fluid in the prostatic urethra. The prostatic secretion is ruch in acid phosphatase.

Shape and Size

The shape of the prostate resembles an inverted cone with broad base upward and pointed apex downward. Its vertical diameter is 3 cm, anteroposterior diameter is 2 cm and the transverse diameter at the base is 4 cm (length is smaller than width).

Location (Fig. 88.17)

The prostate lies between the urinary bladder and urogenital diaphragm. It lies behind the lower margin of pubic symphysis and in front of rectal ampulla. It surrounds the initial 3 cm of the urethra.

Embryological Remnants inside Prostate

The prostatic utricle derived from the caudal end of the fused paramesonephric ducts and the colliculus seminalis derived from the Müllerian tubercle are the embryonic remnants inside the prostate.

Capsules (Fig. 87.11)

The prostate is covered with a true capsule and outer to it, there is a false capsule. The prostatic venous plexus is located between these two capsules.

i. The true capsule is the condensation of connective tissue stroma of the prostate. It is adherent to the prostate.

ii. The false capsule is derived from pelvic fascia. The false capsule is continuous with puboprostatic ligaments anteriorly, true ligaments of bladder posteriorly and rectovesical fascia posteriorly.

Relations (Fig. 87.8)

The prostate has five surfaces, superior (base), posterior, right and left inferolateral and anterior.

i. The superior surface is also called vesical surface since it is in contact with the neck of bladder. This surface is pierced by urethra nearer the anterior aspect.

ii. The posterior surface is separated from the ampulla of rectum by Denonvillier’s fascia or rectovesical fascia. The right and left ejaculatory ducts pierce this surface to enter the prostate to open in to the prostatic urethra.
iii. The anterior surface lies about 2 cm behind the pubic symphysis. It is related to the retropubic space, which contains retropubic pad of fat and vesical venous plexus. This surface is connected to the pubic bones by puboprostatic ligaments, which form the floor of the retropubic space.

iv. The right and left inferolateral surfaces are supported by anterior parts of levator ani muscles. The medial fibers of this muscle are called levator prostatae.

**Internal Features**

1. The prostatic urethra passes through the gland.
2. The right and left ejaculatory ducts pass through the prostate to open into the prostatic urethra.
3. The ducts of prostatic follicles open into the prostatic sinuses of prostatic urethra.
4. The prostatic utricle is a vestigial structure inside the prostate.

**Surgical Lobes (Figs 88.17 and 88.18)**

The prostate is incompletely divided into five lobes.

1. Anterior lobe or isthmus lies in front of urethra. This lobe is the connecting bridge between the anterior ends of the two lateral lobes. It is devoid of glandular tissue hence adenoma never occurs in this lobe.
2. Posterior lobe is situated behind the urethra and below the ejaculatory duct. It connects the posterior ends of the two lateral lobes. It contains glandular tissue and is the site of primary carcinoma. This lobe is palpable per rectum.
3. Median lobe lies between the urethra and the ejaculatory ducts. It is a wedge-shaped lobe in contact with trigone of bladder. The bulge produced by it on the lower end of trigone is called the uvula vesicae. It contains more glandular tissue than other lobes and is more susceptible to benign hypertrophy of prostate (BHP). The median lobe is not palpable per rectum.

**Prostatic Urethra**

The prostatic urethra is the proximal 3 cm of the male urethra lying inside the prostate gland. It pierces the base of the prostate and leaves it at the apex. It lies nearer the anterior surface. It is the most dilatable and widest part of male urethra.

**Features of Posterior Wall (Fig. 87.11)**

1. Urethral crest is a midline longitudinal ridge on the posterior wall of the prostatic urethra.
2. Colliculus seminalis is an elevation at the middle of urethral crest. It has three openings on it, a median for prostatic utricle and lateral for ejaculatory duct of each side.
3. Prostatic sinus is a groove on each side of the urethral crest. About 15 to 20 prostatic ducts open into the prostatic sinus to pour the secretion of prostate into the urethra.

**Structure**

The prostate consists of stroma and glandular tissue.

1. The fibromuscular stroma is composed of smooth muscle and fibrous tissue. The smooth muscle of the stroma is continuous above with the smooth muscle of bladder wall. A peculiar feature of the muscle in the prostate is the presence of striated muscle subjacent to the true capsule. This band of striated muscle is in continuity with the striated muscle of sphincter urethrae muscle surrounding the membranous urethra in the deep perineal pouch. The intraprostatic striated muscle is connected to the true capsule and stroma by collagen tissue. The function of the intraglandular smooth muscle is to compress the follicles to facilitate their drainage in prostatic urethra. The function of the striated muscle is probably to expand the prostatic urethra to accommodate seminal fluid (3–5 ml) prior to ejaculation.
2. The glandular tissue is arranged in three concentric zones. The peripheral zone consists of long branching glands, whose ducts curve to reach the posterior wall of the prostatic sinuses below the level of colliculus seminalis. The internal zone consists of submucosal glands, whose ducts open on the floor of prostatic sinuses at the level of colliculus seminalis. The submucosal glands

![Fig. 88.18: Cross section through prostate to show internal structures](image-url)
are prone to benign hypertrophy of prostate (BHP). The innermost zone consists of simple mucosal glands surrounding the upper part of the prostatic urethra.

**Arterial Supply**
The inferior vesical, middle rectal and internal pudendal arteries richly supply the prostate.

**Venous Drainage**
The prostatic venous plexus lying between the true and false capsules drains the gland. Its main tributary from the anterior aspect is the deep dorsal vein of penis. The prostatic plexus drains into vesical venous plexus through which it drains into internal iliac vein. The communications of the pelvic venous plexuses with the internal vertebral venous plexuses (Batson’s plexus) is responsible for deposits of malignant cells from the prostate into the vertebral column and skull.

**Lymphatic Drainage**
The lymph from prostate is drained into internal iliac, external iliac and sacral group of lymph nodes.

**Nerve Supply**
The parasympathetic supply is from the pelvic splanchnic nerves via the inferior hypogastric plexus. The sympathetic nerves originating in L1 segment of spinal cord and reaching the gland through the hypogastric plexuses supply the smooth muscle of the prostate. The sympathetic supply of prostate, seminal vesicles and vas deferens is responsible for ejaculation. The striated muscle inside the prostate is supplied by pudendal nerve.

**Age Changes in Prostate**

1. In the newborn and childhood the prostate has fibromuscular stroma and the rudiments of duct system.
2. At the age of puberty there is a spurt in the growth of prostate under the influence of testosterone. The prostatic follicles develop and proliferate and begin secretion of acid phosphatase and prostate specific antigen (PSA) in addition to other constituents like prostaglandins.
3. During the third decade glandular epithelium of the follicles grows by irregular multiplication of epithelial infoldings in the lumen of follicles.
4. After third decade amyloid concretions start forming in the follicles.
5. After 45 to 50 years the changes occur on one of the two lines. The prostate may show gradual benign hypertrophy or progressive atrophy.

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**Clinical insight ...**

1. The prostate is palpated per rectum, which is an easy method to detect prostatic size.
2. Benign hypertrophy of prostate (BHP) affects the middle lobe, which projects into the urinary bladder and obstructs the urinary outflow. As the patient strains to urinate, the enlarged median lobe blocks the internal urethral opening more. This leads to chronic obstruction to bladder outflow and effects of backpressure on the bladder, ureter and renal pelvis and calyces.
3. The carcinoma of prostate is the most common malignant tumor in men over 65 years. It may spread locally involving bladder neck, seminal vesicle, ureters and rectum. The spread by lymphatic route involves external and internal iliac nodes besides the sacral nodes. The spread by venous route deposits cancer cells in pelvic bones, lower lumbar vertebrae, head of femur, ribs and skull.
4. Rise in serum acid phosphatase and serum PSA (prostate specific antigen) are the biochemical parameters indicative of cancer.

**Surgical Approaches to Prostate (Fig. 88.19)**

Surgical removal of the prostate is called prostatectomy. There are four approaches to the prostate.

1. The retropubic approach is through the retropubic space or cave of Retzius. It is an extraperitoneal approach.
2. The suprapubic transvesical approach is through the urinary bladder. The prostate is enucleated by a finger inserted via the cavity of bladder into the urethra.
3. Perineal approach is an almost outdated technique, where the prostate is approached through the rectovesical fascia.
4. The transurethral approach is the most accepted approach nowadays. It is known as transurethral resection of prostate (TURP).
Seminal Vesicle and Ejaculatory Duct

The paired seminal vesicles are about 5 cm long lobulated structures, which lie in close contact with the base of the urinary bladder and in front of the rectum. Each is located lateral to the ampulla of vas deferens. The function of the seminal vesicle is to produce secretion rich in fructose, which is added to the seminal fluid. The seminal vesicle is a coiled tube held together by fibrous connective tissue. Its uncoiled length is 10 to 15 cm. It narrows to form a duct, which joins with the ductus deferens to form ejaculatory duct. The ejaculatory ducts pierce the posterior surface of prostate to open into the prostatic urethra. They pour the seminal fluid into the prostatic urethra.

Arterial Supply

The artery to vas deferens or deferential artery, either a branch of superior vesical artery or the inferior vesical artery supplies the vas deferens. The seminal vesicle, ejaculatory duct and ampulla of vas deferens receive branches from inferior vesical and middle rectal arteries.

Nerve Supply

The testicular plexus supplemented by hypogastric plexuses supplies the sympathetic efferent fibers to the smooth muscle in the wall of the ductus, seminal vesicle and ejaculatory duct. The fibers originate in L1 segment of the spinal cord. On sympathetic stimulation the contraction of the smooth muscle helps in pouring the contents and secretions of the above structures into the prostatic urethra as seminal fluid (ejaculation).

GROSS ANATOMY OF OVARIES, FALLOPIAN TUBES AND UTERUS

Ovaries

The main function of the ovaries is to produce mature oocytes by a process called oogenesis (Fig. 7.1) and also to produce female sex hormones during the reproductive life. The ovary liberates usually one mature oocyte at ovulation in each ovarian cycle into the peritoneal cavity from where it is picked up by the fimbriated end of the fallopian tube (Fig. 88.20).

Position of Ovaries

i. In nulliparous women (who have borne no children), the ovaries are located inside the true pelvis on the lateral pelvic wall in the ovarian fossa.
ii. In multiparous women (who have borne children) the location of the ovaries is not constant. The ovaries rise in the abdominal cavity along with expanding pregnant uterus and after parturition (childbirth) when the uterus returns to the pelvic cavity the ovaries do so but not in the same position. Frequently, the ovaries lie in the rectouterine pouch.

Shape and Appearance

The ovaries are almond shaped. In the living, the ovaries are grayish pink and present smooth appearance before regular ovulation begins. After the onset of puberty the surface of ovary is rough because of the scarring, which results from repeated ovulation and degeneration of successive corpora lutea.

Examination of Ovary

i. The normal ovaries are not palpable on vaginal or abdominal examination. Enlarged ovaries or the ovaries prolapsed in rectouterine pouch are palpable by vaginal examination.
ii. The ovaries are observed by means of a laparoscope inserted through the anterior abdominal wall. This method can also be used to remove the ova from Graafian follicles for in vitro fertilization.
iii. The ultrasound examination (per vaginum) is used to study the anatomy of intrapelvic reproductive organs in female.

Functional Importance

The ovaries liberate one ovum per ovarian cycle at ovulation (Fig. 7.2) in the peritoneal cavity. The maturation of
ovarian follicles, ovulation and development of corpus luteum are sequential events, which constitute the ovarian cycle. The maturation of Graafian follicle is under the influence of FSH of anterior pituitary. The granulosa cells of Graafian follicle secrete estrogen, which acts on endometrium. After ovulation the ruptured Graafian follicle becomes the corpus luteum, which is under the influence of luteinizing hormone of pituitary gland. The corpus luteum secretes progesterone and estrogen. The progesterone acts on the endometrium and prepares it for implantation. Thus the ovary releases the ovum and prepares the uterus through the actions of its hormones for implantation of fertilized ovum each month.

**Parts of Ovary**
The long axis of ovary is nearly vertical. The ovary presents following parts:

i. Lateral and medial surfaces.
ii. Upper and lower poles.
iii. Anterior and posterior borders.

The boundaries and relations of the ovarian fossa are also the relations of the ovary. The ovarian fossa (Fig. 88.21) is a shallow recess of the peritoneal cavity situated on the lateral wall of pelvis. The lateral surface of the ovary rests on the floor of the ovarian fossa, which is formed by the parietal peritoneum, obturator nerve and vessels, obturator fascia, obturator internus muscle from within outwards. The relationship with the obturator nerve explains why ovarian pathology gives rise to pain radiating down to the medial side of thigh to the knee. The external iliac vessels form the superior or anterior boundary of the fossa while the internal iliac vessels and the ureter form its posterior boundary. The medial surface of the ovary is in contact with ovarian fimbriae of the uterine tube.

**Peritoneal Relation**
The ovary is covered with germinal epithelium, which is the modified mesothelium. At the anterior or mesovarian border the germinal epithelium of ovary is continuous with mesothelium of the peritoneum of mesovarium.

**Ligaments of Ovary**

i. The mesovarium suspends the ovary from the back of broad ligament. It is a double fold of peritoneum attaching the posterior layer of broad ligament to the anterior border of ovary. It carries ovarian blood vessels from the broad ligament to the ovary.

ii. The infundibulopelvic ligament or suspensory ligament of ovary extends from the upper pole of ovary and adjoining infundibulum of uterine tube to the lateral wall of pelvis. It is a part of broad ligament lateral to the attachment of mesovarium. The ovarian vessels and accompanying nerve plexuses reach the broad ligament via suspensory ligament of ovary. The ovarian vein is in the form of pampiniform plexus in this ligament. Occasionally this plexus becomes varicose giving rise to varicocele (a condition usually more common in male). Ovarian torsion is due to very long mesovarium or suspensory ligament. The torsion compresses the ovarian blood vessels producing ischemia and abdominal pain.

iii. The ligament of ovary, a derivative of gubernaculum attaches the lower pole of ovary to the tubouterine junction.

**Arterial Supply**
Each ovarian artery arises from the abdominal aorta just below the renal artery. It crosses the pelvic brim to enter the infundibulopelvic ligament and to reach the ovary via the mesovarium.

**Venous Drainage**

i. The right ovarian vein drains into inferior vena cava.

ii. The left ovarian vein drains into left renal vein.

**Lymphatic Drainage**
The lymphatic vessels of ovary travel along the ovarian blood vessels and terminate into lateral aortic (paraaortic) group of lymph nodes.
Nerve Supply

The ovarian plexus of autonomic nerves arising from the celiac plexus supplies the ovary. The afferent fibres carrying pain sensation run in sympathetic pathways to spinal segments T10 to T12. The ovarian pain is referred to lower abdominal and pubic region. Cutting the suspensory ligament, which carries the ovarian plexus, may alleviate intractable ovarian pain.

Embryologic insight ...

Developmental Sources (Fig. 88.2)

i. Primordial germ cells from endoderm of yolk sac.
ii. Follicular cells from mesoderm of coelomic epithelium
   (For descent of ovary refer to Figure 88.5).

Clinical insight ...

Ovarian Disorders

i. The functional tumors arise from the cells of Graafian follicle or from the cells of corpus luteum.
ii. The teratoma of the ovary arises from undifferentiated cells persisting from embryonic life.
iii. The Krukenberg’s tumors are due to secondary deposits from other places in to the ovaries (in breast cancer the malignant cells reach ovaries by retrograde transcoelomic spread).
iv. There may be malignancy in ovary (primary ovarian cancer), which may result in massive enlargement of ovary (Fig. 88.22).
v. In ovarian endometriosis (Fig. 88.23) there are deposits of endometrial tissue on the surface of ovary forming chocolate cysts in the ovary.
vi. In ovarian dysgenesis the ovary is devoid of germinal cells. This is found in Turner’s syndrome (45 XO). The patients show characteristic physical appearance. They show short stature, webbed neck, cubitus valgus and amenorrhea (Fig. 7.29).
vii. Polycystic disease of ovary (PCDO) is the leading cause of female infertility. The main clinical features include obesity, irregular menstruation, acne, hirsutism, etc. There are anovulatory cycles due to hormonal imbalance. The ultrasound examination shows polycystic ovaries.
viii. The inflammation of ovary is called oophoritis.

Obturator Nerve and Ovarian Pathology

The obturator nerve is located in the lateral wall of ovarian fossa. The ovarian tumors are likely to compress the obturator nerve or oophoritis is likely to affect the obturator nerve through inflammation of parietal peritoneum covering the ovarian fossa. The irritation of obturator nerve gives rise to referred pain in medial side of thigh (from hip to knee).

Uterine Tube or Fallopian Tube

Each uterine tube extends from the tubouterine junction laterally in the free margin of the broad ligament. Its lateral (ovarian) end is fimbriated and bears 5 to 6 fimbriae. This end is very close to the ovary. The fallopian tube communicates the uterine cavity with the peritoneal cavity.

Length and Shape

The length of the fallopian tube is 10 cm. The shape of the tube is like that of a trumpet (salpinx).
Functions
The fallopian tube transports the ovum from the ovary to the uterine cavity. It plays a coordinating role in gamete transport for fertilization to take place in the ampulla.

Parts (Fig. 88.24)
The tube is divided into four parts, interstitial, isthmus, ampulla and infundibulum.

i. The interstitial or intramural part passes through the myometrium to open in the endometrial cavity. This segment is the shortest (1.25 cm) and narrowest.
ii. The isthmus lies immediately outside the uterus. Its length is 2.5 cm.
iii. The ampulla is lateral to the isthmus. It is the longest (5 cm) and widest part of the tube. It is the site of fertilization.
iv. The infundibulum (1.25 cm) is the most lateral part of the tube, which opens in the peritoneal cavity. The infundibulum is funnel-shaped and provided with finger like projections called fimbriae. The tubal ostium is guarded by these motile and prehensile fimbriae. Of the five to six fimbriae one is longer than the rest and is called ovarian fimbria since it is attached to the medial surface of the ovary.

Peritoneal Relations
The fallopian tube is located in the upper part of broad ligament. It is covered with peritoneum completely except a small area inferiorly, which is left bare by the reflection of the peritoneum to form two layers of mesosalpinx.

Relation to Ovary
The infundibulum of fallopian tube reaches the lower end of the ovary and then follows its anterior border to reach its upper pole. It arches over the upper pole and turns down to end in relation to the posterior free margin and medial surface. So the lateral end of the fallopian tube is related to all parts of the ovary except its lateral surface.

Blood Supply
The medial two-thirds of the fallopian tube is supplied by uterine artery while the lateral one-third is supplied by ovarian artery. The blood drains through corresponding veins.

Lymphatic Drainage
The lymph vessels travel along ovarian vessels to terminate in lateral aortic or para-aortic lymph nodes.

Nerve Supply
The fallopian tube is supplied through the ovarian and inferior hypogastric plexuses. Therefore, its parasympathetic supply is from vagus as well as pelvic splanchnic nerves. The sympathetic innervation is through spinal segments T10 to L2.

Radiological Examination
Hysterosalpingography is a radiological method to investigate the female genital passages. The radiopaque dye is injected in through the cannula in the uterine cavity under direct vision. About 15 ml of medium is injected to outline the uterus and tubes. If the tubes are patent there will be spillage of dye in the peritoneal cavity. The tubes are inspected by means of the ultrasound.

Clinical insight ...

i. Tubectomy is the operation of female sterilization as it prevents the meeting of sperm and ovum. In minilaparotomy a small supraububic incision is given to approach the fallopian tube. Then each tube is brought outside through the incision, ligated at two points and the segment of the tube between the ligatures is cut.

ii. In laparoscopic sterilization a small subumbilical incision is placed under local anesthesia. An operating laparoscope is introduced to visualize the pelvic viscera. The fallopian tubes are identified and clipped at both ends.

iii. The inflammation of the tube is called salpingitis, which is the commonest cause of tubal block leading to sterility due to failure of fertilization.

iv. The tubal block can be detected by a test called tubal insufflation. In this test carbon dioxide is introduced in the fallopian tube via the vaginal route. On auscultation of lower abdomen a bubbling sound is heard if the tube is patent.

Fig. 88.24: Parts of uterine tube and length of each part
Abdomen, Pelvis and Perineum

Uterus

The uterus is a hollow muscular organ situated between the urinary bladder in front and the rectum behind in the pelvic cavity. Its wall has three layers, the perimetrium, myometrium and endometrium from without inward. The endometrium (mucosa) shows cyclical changes in response to ovarian hormones from the age of puberty to the menopause. The implantation of zygote takes place in the uterine decidua (endometrium after conception is called decidua). All the layers of uterus increase in size considerably during pregnancy because the uterus houses not only the fetus but also the placenta and the amniotic sac.

Shape and Size

In the adult the uterus is pear-shaped (piriform) and measures 7.5 × 5 × 2.5 cm. The fundus and body together are 5 cm long and the cervix is 2.5 cm long.

Parts (Fig. 88.25).

The uterus consists of fundus, body and cervix.

i. The fundus is the rounded upper part above the level of the entrance of uterine tubes. The uterus gives attachment to two ligaments at the tubouterine junction or the lateral angle of uterus. The ligament of ovary is attached posteroinferior and round ligament of uterus anteroinferior to this junction.

ii. The body of uterus is between the fundus and the isthmus.

iii. The isthmus is the constricted part measuring about 0.5 cm between the body and the cervix.

iv. The cervix is cylindrical in shape. It extends from the isthmus and ends at external os, which opens in vagina by perforating its anterior wall. Thus, cervix is divisible into supravaginal and vaginal parts.

Uterine Cavity

The uterine cavity is divisible into the cavity of the body and that of cervix. The shape of the cavity of the body is like the inverted isosceles triangle while that of the cervix is spindle shaped. The cavity of cervix (cervical canal) communicates with that of body at internal os and with that of vagina by external os. Therefore, the cervical canal extends between internal and external os. The uterine cavity as measured by an instrument called uterine sound is 6 cm long from the external os to the wall of fundus. The ratio of length of cervix and of uterus varies with age. From birth till the age of puberty the ratio is 2:1 while after puberty it becomes 1:2.

Normal Position of Uterus (Fig. 88.26)

When the urinary bladder is empty the position of uterus is described as anteverted and anteflexed. The body of the uterus is tilted forward on the superior surface of urinary bladder, which provides support to the uterus.

Fig. 88.25: Uterus, uterine tube and ovary seen from posterior aspect

Fig. 88.26: Normal antverted and anteflexed position of uterus (Angle of Anteversion <abc = 90° and angle of anteflexion <bcd = 125 to 170°)
Definition of Anteversion
The term anteversion is defined as the angulation between the long axis of the cervix and the long axis of the vagina. The angle of version is 90°. Due to this angulation the uterus is bent forward. When the bladder is fully distended the uterus lies in line with the vagina then the position of uterus becomes retroverted. So, retroverted position can be normal in fully distended state of the bladder.

Definition of Anteflexion
The term anteflexion is defined as the angulation between the long axis of the body of uterus and long axis of the cervix. The angle of flexion is 120º to 170º. Due to this angulation the uterus is bent downward.

Clinical insight ...

Abnormal Positions of Uterus (Figs 88.27A and B)

i. In some women the uterus is permanently retroverted so that the body of uterus bends backwards in the rectouterine pouch. Retroversion predisposes to prolapse of uterus because of lack of support of urinary bladder in this position.

ii. Sometimes the axis of uterine body passes upwards or backwards as a result of which there is no angulation between the uterus and cervix. In such cases the uterus bends back on the cervix causing narrowing of the cervical canal. This is known as retroflexion, which may cause painful menstruation and reduce the chances of conception.

Peritoneal Relations (Fig. 80.5A)
The uterus is intraperitoneal but the level of reflection of peritoneum from its anterior and posterior aspects is different. The uterus is held from the lateral wall of pelvis by a flat sheet of peritoneum on either side called broad ligament.

i. The peritoneum covers the anterior surface of the body of uterus up to the level of isthmus from where it is reflected on the superior surface of bladder. This reflection gives rise to a shallow peritoneal pouch called uterovesical pouch of peritoneum. The anterior or vesical surface of uterus is thus related to urinary bladder.

ii. The peritoneum covers the entire posterior surface of the body and cervix of the uterus and then goes down to cover the posterior fornix of vagina. From this level, it is reflected on the anterior surface of rectum. This reflection forms a deep peritoneal pouch called rectouterine pouch of Douglas or cul-de-sac (CDS). The bottom of this pouch is 5.5 cm above the anal orifice. This is the lowest part of female peritoneal cavity. This pouch can be approached surgically through the posterior fornix of vagina for aspiration of accumulated fluid. The rectouterine pouch normally contains sigmoid colon and coils of intestine, which make contact with the posterior or intestinal surface of uterus.

Cervix (Cervix Uteri)
The cervix is shorter, narrower and more cylindrical than the body of uterus. It is the most fixed part of the uterus. The cervix is divisible in to the supravaginal cervix and vaginal cervix.

i. The anterior wall of the supravaginal cervix is not covered with peritoneum. It is directly related to the base of the bladder. Laterally at a distance of 2 cm this part of the cervix is related to the uterine artery crossing in front of the ureter. This relation is of surgical importance because during clamping the uterine artery in the operation of hysterectomy, the ureter is in danger of injury. The posterior wall of the supravaginal cervix is covered with peritoneum of rectouterine pouch, which separates it from the rectum.

ii. The vaginal part of the cervix lies in the interior of the upper part of the vagina and is incircled by vaginal fornices. Its rounded lower end bears an aperture called the external os. At the lower end of cervical canal the simple columnar epithelium changes to the stratified squamous nonkeratinized type covering the lips of the external os and the outer surface of the vaginal cervix. The shape of the external os is circular in nulliparous women but after childbirth the shape changes to a transverse slit. The external os possesses a shorter, thicker and more projecting anterior lip and a longer and thinner posterior lip.)
Cervical Canal (Fig. 88.25)
It is the cavity of cervix extending from the internal to the external os. Its lining epithelium is simple columnar but it does not show periodic changes during menstrual cycle. The cervical glands are branched tubular in type and secrete mucus with high content of fructose. The mucus collects as a plug in the cervical canal. The palmate folds arise from the longitudinal mucosal ridges of the anterior and posterior cervical walls and interdigitate. The palmate folds close the cervical canal.

Functional Isthmus
The upper third of cervix including the internal os is called the functional isthmus. It behaves more like the body of uterus in having same epithelium like the uterus and in its response to ovarian hormones. From second month of pregnancy it is taken up in the body of the uterus to form the lower uterine segment. An incision is placed in the lower segment in the operation of lower segment cesarean section (LSCS).

Per Speculum Examination of Cervix
Direct inspection by speculum examination exposes the interior of the vagina including the vaginal cervix. The digital palpation helps in assessing the shape and consistency of the cervix.

Ligaments Attached to Cervix (Fig. 88.28)
The cervix being the most fixed part of the uterus gives attachments to the ligaments. There are three ligaments, which form a triradiate ligament, consisting of, Mackenrodt’s ligament laterally, uterosacral ligament posteriorly and pubocervical ligament anteriorly.

Blood Supply of Uterus (Fig. 88.25)
The uterus receives blood from a pair of ovarian arteries supplemented by a pair of ovarian arteries. Each uterine artery is a branch of anterior division of internal iliac artery. The uterine arteries are highly tortuous in nonpregnant state. As the uterine artery ascends by the lateral margin of uterus it gives a series of arcuate arteries, which run transversely on the anterior and posterior surfaces of the body of uterus. The branches of the two sides anastomose in the midline. The radial branches of the arcuate arteries enter the inner longitudinal layer of the myometrium (stratum vasculare). The muscle bundles in this layer are arranged in the pattern of figure of eight and hence on their contraction the blood vessels are clamped. This is the reason why these muscle bundles are known as living ligatures of the uterus. This action is important in controlling uterine bleeding during parturition and menstruation. The uterine veins drain in to the internal iliac vein.

Lymphatic Drainage (Figs 88.29A and B)
i. The lymph vessels from the fundus pass along the ovarian vessels to drain in to the lateral aortic and preaortic lymph nodes. A few vessels from the lateral angle of uterus (tubouterine junction) reach the

![Fig. 88.28: Illustration of ligaments attached to cervix uteri.](image)
![Figs 88.29A and B: Lymphatic drainage of uterus, ovary, fallopian tube and cervix.](image)
superficial inguinal nodes along the round ligament of uterus.

ii. The lymph vessels from the body travel via the broad ligament to the external iliac lymph nodes.

iii. The cervix drains laterally into the external iliac and obturator lymph nodes. A few vessels terminate in paracervical nodes, which are located at the crossing of ureter and uterine artery. The enlarged paracervical node (due to cervical cancer) may block the ureter. Some lymph vessels travel in posterior direction to drain into sacral lymph nodes. A few lymph vessels pass along the uterine vessels to terminate into internal iliac nodes.

**Nerve Supply**

The autonomic nerve supply to the uterus is derived from uterovaginal plexuses, which lie in the broad ligaments. The efferent sympathetic fibres arise from T12 to L1 segment of spinal cord. The efferent parasympathetic fibers arise from S2 to S4 segments of spinal cord. The pain sensation from cervix and uterus during childbirth passes through parasympathetic pathways (pelvic splanchnic nerves) to the second to fourth sacral segments of spinal cord. The caudal analgesia is a method to give nerve block to achieve painless labor.

**Ligaments of Uterus**

The ligaments are divided into peritoneal and nonperitoneal. The broad ligament is the peritoneal ligament and round ligament is the nonperitoneal one. (These two ligaments may be regarded as false ligaments of uterus).

1. The broad ligament of uterus is a large peritoneal fold enclosing parametrium (connective tissue of pelvis fascia) and extending from the body of uterus to the lateral pelvic wall. It has two margins, free anterior margin and fixed posterior margin or base (Fig. 88.30). It has anteroinferior and posterosuperior layers forming corresponding surfaces. The broad ligament consists of four parts.
   i. The mesovarium is the part of the posterior layer attached to the anterior margin of ovary.
   ii. The suspensory ligament of ovary is the part lateral to the ovary.
   iii. The mesosalpinx is that part which lies between the uterine tube and the ovary.
   iv. The mesometrium is the remaining part.

A large number of structures are located inside the different parts of the broad ligament.

a. The mesosalpinx contains the uterine tube, round ligament of uterus, ligament of ovary, paroophoron and epiophoron.

b. The mesovarium transmits the ovarian blood vessels and nerve plexuses.

c. The contents of the suspensorial or infundibulo-pelvic ligament are the ovarian vessels, lymph vessels and nerve plexuses.

d. The contents of the mesometrium are the uterine vessels, uterovaginal nerve plexuses, lymphatic vessels and the duct of Gartner.

2. The round ligament of the uterus is the remnant of gubernaculum ovarii. It extends from tubouterine junction to the labium majus. It is about 10 to 12 cm long and passes through the broad ligament diagonally down and laterally to the pelvic floor. On its way to the deep inguinal ring it crosses the pelvic brim and hooks round the inferior epigastric artery. It is the content of female inguinal canal. After coming out of the superficial ring it splits into fibrous strands, which attach to the skin of labium majus. It is accompanied by lymphatics, which drain the lateral angles of fundus to the superficial inguinal lymph nodes.

**Supports of Uterus**

There are four factors that maintain the uterus in the anteverted and anteflexed position in the pelvic cavity.

1. Pelvic diaphragm is the most important support since it cradles the uterus from below. It is constantly subjected to strain due to rise in intra-abdominal pressure in such acts as coughing, sneezing and straining at stools. The vaginal delivery puts an extra strain on the pelvic diaphragm.
2. The true ligaments of the uterus are the condensation of the pelvic fascia. These ligaments pass from the cervix in three different directions and fix it to the pelvic walls. These ligaments form a hammock of condensed pelvic fascia and support the uterus against vertical descent. In the operation of hysterectomy it is not possible to free the cervix and vagina unless these three ligaments are cut.
   i. Mackenrodt’s ligament or transverse cervical ligament or cardinal ligament connects the lateral aspect of vagina and cervix to the lateral pelvic wall. It passes through the base of the broad ligament. The uterine artery may pass through a special tunnel in the ligament or it may pass superior to it.
   ii. The uterosacral ligament extends from the posterior aspect of cervix backward lateral to rectum to gain attachment to the sacrum.
   iii. The pubocervical ligament extends from the anterior aspect to the back of pubic symphysis.

3. The urogenital diaphragm and the perineal body provide additional support to the uterus by supporting the vagina.

**Radiological Examination**

i. The ultrasound examination of the pelvis reveals the anatomy of uterus and ovaries and other pelvic organs.

ii. The hysterosalpingography is another method of visualizing the genital tract.

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**Gravid Uterus**

The uterus shows immense growth during pregnancy to accommodate the growing fetus, placenta with umbilical cord, amniotic cavity filled with amniotic fluid and other fetal membranes (Fig. 88.31). The placenta is a composite organ of temporary life composed mainly of chorionic villi floating in an intervillous space filled with maternal blood. The placenta performs the functions of multiple organs of fetus. It has maternal surface and fetal surface. The maternal surface is rough due to presence of cotyledons (Fig. 88.32A). The fetal surface is covered with amnion and gives attachment to umbilical cord (Fig. 88.32B).

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**Fig. 88.31:** A full-term fetus in an immensely enlarged uterus (Note also placenta, umbilical cord and amniotic cavity)
i. If the supports of the uterus become weak due to any cause the uterus descends in the vagina. This is called prolapse of the uterus. The loss of tone of the muscles of pelvic diaphragm and perineal tears and repeated childbirths are the main causes of the prolapse. There are different degrees of uterine prolapse (Figs 88.33A to C). In the first degree prolapse the cervix descends in the vagina. In the second degree the cervix descends to the level of vulva. In the third degree the cervix protrudes outside the vaginal orifice. In procidentia the whole uterus protrudes outside the vaginal orifice.

ii. To diagnose the disorders of endometrium a procedure called dilatation and curettage (D and C) is very common in gynaecology. At first the size of the uterine cavity is measured with the help of an instrument called the uterine sound. The cervix is then gradually dilated and the endometrium is scraped with a curette. This is useful in detecting endometrial cancer and in assessing the hormonal status of the ovaries after histological examination of the curetting.

iii. The myoma or fibroid is a tumor of myometrium. It is more common in younger age group. If single, myomectomy alone is possible but if multiple, hysterectomy is required.

iv. Placental pathologies affect the uterus. The vesicular mole is the cystic degeneration and dilatation of the chorionic villi. Choriocarcinoma is the malignancy of the vesicular mole.

v. Among the intrauterine contraceptive devices (IUCD) copper-T is commonly used. The principle underlying occluding the uterine cavity is to prevent implantation of the blastocyst.

vi. The surgical removal of uterus is called hysterectomy. It is performed by vaginal or abdominal route.

vii. Hysterotomy is opening the uterus by incising its anterior wall. This is done in fetal surgery in which fetus is operated upon to rectify congenital defects before birth.

viii. In some women it is not possible to have normal vaginal delivery. The baby is born through an operation called the lower segment cesarian section (LSCS). The abdomen is opened either through a vertical infraumbilical midline incision or through a low transverse incision (modified Pfannenstiel).
PERINEUM IN MALE AND FEMALE

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PERINEUM

The perineum is the lowest region of the trunk in the erect position. It lies below the level of pelvic diaphragm. The perineum is traversed by the anal canal and urethra in male and by the anal canal, urethra and vagina in female. The male external genital organs are suspended from the perineum while the female external genitalia form the surface features of the perineum.

Bony Boundaries (Fig. 89.1)

Anteriorly, the perineum is bounded by the inferior margin of pubic symphysis and posteriorly by the coccyx. The lateral boundary on each side is formed by the ischiopubic ramus, ischial tuberosity and sacrotuberous ligament from before backward.

Subdivisions

The perineum is divided into anterior urogenital triangle and posterior anal triangle by an imaginary line in the coronal plane passing through the anterior ends of the ischial tuberosities. The anal triangle contains the anal canal in the midline and the ischiorectal fossa on either side of anal canal.

Fig. 89.1: Boundaries and subdivisions of perineum
The urogenital triangle differs in the two sexes as it gives passage to urethra in male and to urethra and vagina in female.

**Superficial Fascia**

The superficial fascia is subdivided into superficial fatty (of Camper) and deep membranous layer (of Colles). The attachments of the membranous layer are as follows. Laterally, it is attached to the ischial tuberosities and to the lateral margins of ischiopubic rami. Anteriorly, it crosses the front of the bodies of pubic bones up to the pubic tubercles, and then it becomes continuous with the membranous layer of superficial fascia of the anterior abdominal wall (Scarpa). In the male, this layer forms the fascial sheath and fundiform ligament of penis and continues as dartos muscle of scrotum. Posteriorly, the membranous layer fuses with the posterior margin of the perineal membrane (inferior fascia of the urogenital diaphragm).

**Fascial Boundaries of Urogenital Triangle**

The urogenital triangle consists of superficial and deep perineal pouches bounded by three fascial layers. In the erect position of the body, these three layers are placed one above the other.

i. The lowermost layer is the membranous layer of superficial fascia of the perineum.

ii. Superior to the membranous layer is the perineal membrane or inferior fascia of urogenital diaphragm.

iii. Above the perineal membrane lies the superior fascia of urogenital diaphragm.

These three layers of fasciae fuse posteriorly with each other.

**Perineal Pouches**

i. The superficial perineal pouch is enclosed by the membranous layer of superficial fascia and the perineal membrane. In the male, the rupture of the bulbar urethra at the point of passage through perineal membrane causes extravasation of urine into the anterior abdominal wall due to fascial continuity. This space is open anteriorly and is continuous with the anterior abdominal wall.

ii. The deep perineal pouch is enclosed by the inferior and superior fasciae of urogenital diaphragm. It is a completely closed space. Thus, the perineal pouches are located one above the other in the narrow space bounded by the ischiopubic rami and pubic arch in the erect position of body.

**Ischiorectal Fossa**

The ischiorectal fossa is renamed as the ischioanal space since it is located between the ischial tuberosity and the anal canal (not the rectum). The ischiorectal fossa is a fat-filled space on either side of the anal canal. The right and left fossae allow distension of anal canal during defecation.

**Boundaries (Fig. 89.2)**

The ischiorectal fossa is wedge-shaped space having a base, apex, anterior, posterior, lateral and medial walls.

i. The vertical lateral wall is partly muscular and partly bony. The obturator internus muscle and the fascia covering it form the upper larger part and the medial surface of the ischial tuberosity forms the lower smaller part of this wall.

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**Fig. 89.2: Boundaries and contents of ischiorectal fossa**

(Note that the inferior rectal nerve crosses the fossa from lateral to medial side)
ii. The sloping medial wall is formed by the perineal surface of the levator ani above and sphincter ani externus below.

iii. The meeting of the fascia lining the perineal aspect of levator ani and the fascia covering the obturator internus forms the apex, which is linear. Herniation of pelvic viscera into the ischiorectal fossa may occur if there is a gap at the apex of the fossa due to separation of levator ani from obturator fascia. The gap is called hiatus of Schwalbe.

iv. The perineal skin forms the base or floor of the fossa.

v. Posteriorly the fossa is bounded by the sacrotuberous ligament and the lower margin of gluteus maximus muscle.

vi. Anteriorly it is bounded by posterior margin of perineal pouches. Above the level of deep perineal pouch the fossa projects as anterior recess up to the level of pubic bone.

Fascial Relations
The ischiorectal fossa is a fascial space.

i. Obturator fascia lines its lateral wall.

ii. Anal fascia or inferior fascia of pelvic diaphragm lines its medial wall.

iii. Lunate fascia is the raised deep fascia on account of the projecting subcutaneous fat. Its summit is called tegmentum.

iv. Perianal fascia is an extension from the lower end of conjoint longitudinal tendon in anal wall.

The lunate and perianal fasciae divide the fossa into three compartments as follow:

i. Suprategmental space above tegmentum

ii. Ischioanal space proper

iii. Perianal space containing loculated fat.

Contents (Fig. 89.2)

i. The fossa is filled with a pad of fat, which is the fibrofatty tissue of the superficial fascia. Tension of the gluteus maximus muscles during standing compresses the fat around the anal canal contributing to anal continence.

ii. The inferior rectal nerve and vessels (branches of pudendal nerve and internal pudendal vessels in the pudendal canal) cross the fossa from lateral to medial side.

iii. The posterior scrotal nerves and vessels in male and posterior labial vessels and nerves in female from the perineal nerve and the internal pudendal vessels travel in the anterior part of the fossa.

iv. The perineal branch of the fourth sacral nerve travels in the posterior part of the fossa.

Pudendal or Alcock’s Canal
This is a fascial canal in the lateral wall of the ischiorectal fossa.

i. The canal is bounded by obturator fascia and lunate fascia.

ii. It extends from lesser sciatic notch to posterior boundary of perineal pouches.

iii. Its contents differ in its posterior and anterior parts. The posterior part gives passage to pudendal nerve and internal pudendal vessels. The pudendal nerve terminates into dorsal nerve of penis or clitoris and perineal nerve.

iv. The anterior part gives passage to internal pudendal vessels flanked above and below by dorsal nerve and perineal nerve respectively.

Clinical insight ...

i. Ischiorectal abscess is a common clinical condition because the fat in the fossa is poorly vascularized. The ischiorectal abscess is very painful because of the presence of the sensory nerves passing through the fossa. The abscess may burst on the skin forming a sinus. It may open on the skin and in the anal canal forming a fistula. The abscess on one side may spread to the other side behind the anal canal forming a horseshoe shaped abscess.

ii. While draining the ischiorectal abscess accidental injury to the inferior rectal nerve results in anal incontinence (due to loss of function of sphincter ani externus).

iii. The pudendal nerve block by perineal route is given in the pudendal canal. In this procedure, the anesthetic solution is injected in the canal about 2.5 cm from the surface along the medial surface of the ischial tuberosity.

iv. The pudendal nerve and its branches are entrapped in fibrosis of obturator internus muscle causing pudendal neuralgia. This entrapment is known as Alcock’s canal syndrome.

Anal Canal
The anal canal is the terminal part of the large intestine. It extends from the anorectal junction to the anal orifice. The anorectal junction lies in the pelvic cavity but the anal canal lies below the pelvic diaphragm in the anal triangle of the perineum. The anal canal is about 4 cm long and is directed backwards and downwards from the anorectal junction. It remains closed except during defecation. The muscular junction between the rectum and the anal canal is the anorectal ring, which is felt as a thickened ridge on digital examination.
Perineum in Male and Female

Chapter 89

Relations
i. Posteriorly, the anal canal is in contact with anoococcyeal ligament.
ii. Anteriorly, the perineal body separates the anal canal from the lower part of the vagina in the female and from the penile bulb and membranous urethra in the male.
iii. On each side, it is related to the ischiorectal fossa (Fig. 89.2).

Internal Appearance (Fig. 89.3)
The anal canal is divided into three parts. The upper part is 15 mm in length, the middle part (pecten) is 15 mm in length and the lower part is 8 to 10 mm in length.

Upper Fifteen millimeter
The mucous membrane of its part is lined by simple columnar epithelium. It is reddish in color and shows following features.
i. There are 6 to 10 longitudinal folds of mucous membrane called columns of Morgagni. Each column contains terminal radicles of superior rectal artery and vein. These terminal radicles are well developed in the left lateral, right posterior and right anterior positions hence, piles are more common at these three sites.
ii. Anal valves are transverse folds of mucous membrane uniting the lower ends of anal columns (They may show presence of small anal papillae, which are the remnants of anal membrane of embryonic life). The passage of hard stools is likely to injure the anal valves causing anal fissure.
iii. Anal sinus is the space above each anal valve. The anal glands open into the sinus. The opening of the gland is called anal crypt. The anal sinuses on the posterior wall are deepest and hence are prone to infection due to fecal matter getting trapped here. This favors abscess formation.
iv. Pectinate line is a transverse line, which runs all round the anal canal along the lower limit of the anal valves. It is the dividing line between the endodermally derived and ectodermally derived anal canal. The pectinate line is called the watershed line because it separates the two entirely different parts of the anal canal (in terms of development, nerve supply, blood supply and lymphatic drainage).

Pecten (Middle Fifteen Millimeter)
This part of the anal canal is lined by stratified squamous epithelium. The mucosa is less mobile here compared to the upper part. This region is referred to as a transitional zone. It is bluish in color because of the presence of rich venous plexus underneath it. The white line of Hilton denotes the lower limit of the pecten. It is whitish compared to the bluish color of the pecten. This line corresponds to the intersphincteric groove (vide infra) in the wall of the anal canal.

Lowest Eight to Ten Millimeter
It is the shortest part of the anal canal and is lined by true skin with sweat and sebaceous glands.

Anal Musculature (Fig. 89.4)
The musculature of the anal canal is divided into four groups (internal sphincter, external sphincter, anorectal ring and longitudinal muscle layer).
Internal Sphincter
The internal sphincter (sphincter ani internus) is the thickened circular smooth muscle surrounding the upper three-quarters of the anal canal. It extends from the anorectal junction to the intersphincteric groove. It is involuntary sphincter and hence receives autonomic nerves.

External Sphincter
The external sphincter (sphincter ani externus) is a voluntary muscle that surrounds the entire length of the anal canal. It is divisible into three parts, deep, superficial and subcutaneous.

i. The deep part is located outer to the internal sphincter. It has no bony attachment, but its few fibers are attached posteriorly to the anococcygeal raphe.

ii. The superficial part lies below the deep part and extends up to the intersphincteric groove, (which lies between the lower limit of internal sphincter and subcutaneous external sphincter). The superficial part is the only part of the external sphincter having bony attachment. It takes origin posteriorly from the last piece of coccyx and is inserted anteriorly into the perineal body on either side. It does not completely encircle the anal canal. It does not support the anal canal in the midline posterior (Fig. 89.4). It is postulated to be a predisposing factor for frequency of anal fissure on the posterior wall of anal canal (Fig. 89.10A).

iii. The subcutaneous part encircles the lowest part of anal canal below the intersphincteric groove. It has no bony attachments.

Nerve Supply
The inferior rectal nerve, a branch of pudendal nerve and the perineal branch of fourth sacral nerve supply the sphincter ani externus. This sphincter is the voluntary sphincter of anal canal.

Arterial Supply (Fig. 89.5)
The arterial supply of the anal canal is from two sources.

i. The superior rectal artery (continuation of inferior mesenteric artery) supplies blood to the mucosa of the anal canal above the level of pectinate line.

ii. The inferior rectal artery (a branch of internal pudendal artery) supplies the mucosa below the level of pectinate line.

Conjoint Longitudinal Muscle Layer
The longitudinal muscle of the anal canal (Fig. 89.2) separates the internal and external sphincters. It is the continuation of the longitudinal muscle layer of rectum with a small contribution from the puborectalis muscle (hence the name conjoint longitudinal muscle). This layer becomes progressively fibroelastic and breaks into a number of fibrous strands nearer the lower end of the anal canal. A large number of fibrous strands pass through the subcutaneous anal sphincter and attach to the dermis of the skin around the anus. These connections are responsible for puckering of the perianal skin. Some strands pass laterally between the subcutaneous and superficial parts of external sphincter to reach the ischiorectal fossa. Most medial strands pass medially through the intersphincteric groove to terminate into the anal mucosa at that level.

Development of Anal Canal
The anal canal develops from dual sources.

i. The part above the pectinate line is endodermal (postallantoic hindgut).

ii. The part below the pectinate line is ectodermal (proctodeum).

iii. The pectinate line is the line of demarcation between endodermal and ectodermal anal canal. It indicates the position of intervening anal or cloacal membrane, which ruptures by 7th or 8th week of intrauterine life.

iv. The congenital anomaly of anal canal called imperforate anus is due to the persistence of the embryonic anal (cloacal) membrane.
Internal Piles
The internal piles develop due to dilatation of the internal venous plexus at the pectinate line. The common causes of piles include constipation and portal hypertension. Since the pectinate line is the site of porto-systemic anastomosis, in portal hypertension this anastomosis dilates. The venous plexuses in right anterior, right posterior and left lateral positions are particularly large and hence are the frequent sites of primary internal piles. With reference to the clock, the primary internal piles are located at the 3 o’clock, 7 o’clock and 11 o’clock positions (Fig. 89.9A). The internal piles cause painless bleeding per rectum.

Nerve Supply of Anal Mucosa (Fig. 89.7)
- The anal canal above the pectinate line is insensitive to pain because the mucosa receives autonomic nerves.
- The mucosa below the pectinate line is supplied by the inferior rectal nerve, which carries somatic sensations hence the mucosa at this level, is pain sensitive. Any small injury causes intense pain.

Lymphatic Drainage (Fig. 89.8)
- The anal canal above the pectinate line drains into the internal iliac lymph nodes.
- The anal canal below the pectinate line drains into the superficial inguinal lymph nodes.

Clinical insight...

Internal Piles
The internal piles develop due to dilatation of the internal venous plexus at the pectinate line. The common causes of piles include constipation and portal hypertension. Since the pectinate line is the site of porto-systemic anastomosis, in portal hypertension this anastomosis dilates. The venous plexuses in right anterior, right posterior and left lateral positions are particularly large and hence are the frequent sites of primary internal piles. With reference to the clock, the primary internal piles are located at the 3 o’clock, 7 o’clock and 11 o’clock positions (Fig. 89.9A). The internal piles cause painless bleeding per rectum.

Contd...
External Piles
The dilatation of the internal venous plexus below the level of pectinate line gives rise to external piles. This part of the internal venous plexus is covered by sensitive mucosa and skin. While injecting the base of the pile with a sclerosing agent, the precaution to be observed is to inject above the pectinate line (where the mucosa is insensitive to pain) Figure 89.9B shows prolapse of piles in a patient.

Painful Conditions of Anal Canal
The painful conditions of anal canal include fissures, abscesses and fistulae. The susceptibility of anal canal to these conditions is due to exposure to trauma during passage of hard stools and exposure to infection.

i. Anal fissure is a tear in the mucosa at the anal valves with extension into the pecten (Fig. 89.10A). It is usually found on posterior wall in the midline.

ii. Infection of the anal sinus due to impaction of fecal particle may result is abscess in the wall of anal canal.

iii. When the anal abscess finds its way into the ischiorectal fossa and thence to the perianal skin, it is called anal fistula (an abnormal tract connecting the anal canal to the perianal skin).

Figure 89.10B shows external opening of fistula in ano by the side of the anal orifice. Presence of multiple external openings of the anal fistulae presents as watering-can perineum.

Urogenital Triangle
The urogenital triangle consists of superficial and deep perineal pouches, which differ in the male and female.

Superficial Perineal Pouch in Male
The boundaries of the superficial pouch are as follows. The membranous layer of the superficial fascia of perineum (Colles fascia) forms the inferior boundary and the inferior fascia of the urogenital diaphragm or the perineal membrane forms its superior boundary. The lateral limits are the conjoint ischiopubic rami. Posteriorly, the pouch is closed by the fusion of the superior and inferior walls. Anteriorly, the pouch is open, where it is continuous via the scrotum and penis with the anterior abdominal wall.

The bulbar part of the urethra passes through the bulb of penis in the superficial perineal pouch. If this part of the urethra ruptures (e.g. in straddle injuries) the urine leaks into superficial pouch distending the pouch as well as the external genitalia (Fig. 89.11). The urine may ascend in the anterior abdominal wall in the space between the membranous layer of superficial fascia (fascia Scarpa) and
Chapter 89

Fig. 89.10B: External opening of fistula in ano (arrow) by the side of the anal orifice

Fig. 89.11: Rupture of bulbar urethra in male causing accumulation of urine in superficial perineal pouch, external genitalia and anterior abdominal wall (leaking of urine is indicated by blue arrow)

Fig. 89.12: Superficial perineal pouch in male and female showing root of penis and clitoris respectively (attached to inferior surface of perineal membrane)

Fig. 89.13: Muscles of superficial perineal pouches in male and female

The superficial pouch in male contains the structures forming the root of penis, muscles, nerves and vessels.

1. The root of penis consists of three structures, the bulb of penis and two crura (Fig. 89.12). The bulb is attached to the inferior surface of perineal membrane and is traversed by the bulbar part of penile urethra. The bulb extends in the body of penis as corpus spongiosum. The crus is attached to the medial surface of conjoint ischio pubic ramus and adjoining perineal membrane. It continues in the body of penis as corpus cavernosus on each side. The eversion of the ischio pubic rami in male is due to attachments of crus and ischiocavernosus muscle.

2. There are three muscles on each side, namely, ischio cavernosus, bulbospongiosus and superficial transversus perinei as shown in Figure 89.13.
   i. The ischiocavernosus covers the crus of its side. It originates from the ischial ramus and is inserted in the crus at the point, where it continues as corpus cavernosus. This is the only perineal muscle, which is not attached to the perineal body.
   ii. The bulbospongiosus muscles cover the bulb of the penis. These muscles arise from the perineal body and fuse with each other at the median the aponeurosis of external oblique muscle. The extravasation of urine in these regions produces a circumscribed swelling of the perineum, scrotum and infraumbilical anterior abdominal wall. The urine cannot enter the thigh because of the fusion of membranous layer of superficial fascia of thigh and fascia lata at the Holden’s line (Fig. 93.2).

Contents

The superficial pouch in male contains the structures forming the root of penis, muscles, nerves and vessels.
raphe. Each inserts in the skin of the penis. So, this is the only muscle that has no bony attachments.

iii. The superficial transversus perinei muscle arises on each side from ischial tuberosity and inserts in the perineal body.

The three muscles of the superficial pouch are supplied by perineal branch of pudendal nerve.

iv. Posterior scrotal nerves and perineal branch of posterior cutaneous nerve of thigh are the cutaneous nerves that travel through the pouch.

v. Posterior scrotal vessels and transverse perineal branch of posterior scrotal vessels are seen in the space.

**Deep Perineal Pouch in Male**

The deep perineal pouch is a closed space bounded superiorly by the superior fascia of urogenital diaphragm and inferiorly by the inferior fascia of the urogenital diaphragm or perineal membrane. The conjoint ischiopubic rami limit the space laterally on each side. The fusion of the two fascial layers limits it posteriorly. The posterior margin is intimately fused with the perineal body. Anteriorly, the space is closed due to fusion of the superior and inferior fascial layers. The thickened anterior border of the perineal membrane forms transverse perineal ligament. There is gap between this ligament and the arcuate pubic ligament at the inferior margin of pubis.

**Contents**

i. Membranous part of urethra.

ii. Bulbourethral glands (Cowper’s glands) on either side of the urethra.

iii. Two striated muscles, sphincter urethrae surrounding the urethra and deep transversus perinei muscles.

iv. Dorsal nerve of penis courses forwards near the ischiopubic ramus on each side.

v. Internal pudendal artery, artery to the bulb, deep and dorsal artery of penis or clitoris course along the ischiopubic ramus.

**Muscles (Fig. 89.14)**

i. The sphincter urethrae muscle arises from the medial surface of inferior pubic ramus. The fibers of the two sides unite in front and behind the urethra. The posterior fibers attach to the perineal body. The perineal branch of pudendal nerve supplies the sphincter urethrae. It is a voluntary sphincter of urethra.

ii. The deep transversus perinei muscles are situated on each side but behind the sphincter urethrae. Each arises from the medial surface of ischial ramus and is inserted in the perineal body. Perineal branches of pudendal nerve supply the muscle.

**Urogenital Diaphragm (Fig. 89.15)**

The urogenital diaphragm is a muscular sheet (consisting of the two muscles of the deep perineal pouch) enclosed between the superior and inferior fasciae of urogenital diaphragm. Along the narrow anterior margin of the
diaphragm, the two fasciae fuse to form the transverse perineal ligament. At the midpoint of its posterior margin, the diaphragm gives attachment to the perineal body. This diaphragm lies below the anterior part of the pelvic diaphragm and it reinforces the pelvic diaphragm at the urogenital hiatus. The urogenital diaphragm is pierced by membranous urethra in male and urethra and vagina in female. It supports the prostate and neck of urinary bladder in male and the neck of urinary bladder and vagina in female. It provides voluntary control to urethra in both sexes.

Perineal Membrane in Male (Fig. 89.16)
The perineal membrane is the key structure in the urogenital triangle. It lies between the deep and superficial perineal pouches. In the anatomical position, the deep pouch is its superior relation while the superficial pouch forms its inferior relation. The perineal membrane is triangular in shape. Its base is directed posteriorly and gives attachment to the perineal body near its midpoint. All the three fascial layers bounding the perineal pouches fuse along the base of the perineal membrane. Its lateral margins are attached to the medial surfaces of ischiopubic rami. Its apex is directed anteriorly and is thickened to form transverse perineal ligament. Through the gap between this ligament and arcuate pubic ligament the deep dorsal vein of penis enters the pelvis. The structures that pierce the perineal membrane in the male are the urethra in the midline, ducts of the bulbourethral glands by the side of the urethra on each side and the artery to the bulb of the penis. At the base of the membrane two posterior scrotal nerves and vessels pierce on each side. The anterior part of the membrane, is pierced by dorsal nerve of penis in addition to deep and dorsal arteries of penis.

Perineal Body in Male
This is a mass of fibromuscular tissue lying between the bulb of penis in front and the anal canal behind. It provides attachment to a large number of muscles. The importance of perineal body in male is to support the prostate gland and anal canal.

Superficial Perineal Pouch in Female
The boundaries of the superficial pouch are the same as in the male.

Contents (Figs 89.12 and 89.13)

i. The urethra and vagina pass through the space.
ii. The crura of the clitoris are attached on each side to the ischiopubic rami. The bulb of vestibule is seen on each side of vagina attached to the lower aspect of the perineal membrane. The deep artery of the clitoris pierces at the central part of the lateral margin on each side to enter the crus of the clitoris. The dorsal arteries and nerves pierce at the apex to reach the dorsum of clitoris.
iii. The greater vestibular gland (Bartholin’s gland) is embedded in the bulb of the vestibule.
iv. There are three pairs of muscles in the superficial pouch in female. The ischiocavernosus covers the crus of clitoris. It is not attached to the perineal body. The bulbospongious covers the bulb of the vestibule on each side. The superficial transversus perinei is similar to that seen in the male.
v. Three blood vessels pass through the space, two posterior labial and the transverse perineal vessels.

vi. Three sensory pass through the space to reach the labium majus of its side. They are two posterior labial nerves and the perineal branch of the posterior cutaneous nerve of thigh.

Greater Vestibular (Bartholin’s) Gland
This gland is embedded in the erectile tissue of the bulb of the vestibule and is covered by the bulbospongious muscle. Its 25 mm long duct opens in the vagina below the hymen. It is a compound racemose gland, which secretes lubricating mucus. The gland becomes infected in gonorrhea (Bartholinitis). The bulbourethral glands in male are the homologue of Bartholin’s glands in female.

Deep Perineal Pouch in Female
The boundaries of the deep perineal pouch in the female are the same as in the male.

Contents (Fig. 89.14)
The urethra and the vagina pass through the deep space. The sphincter urethrae and the deep transversus perinei are the striated muscles, whose attachments and nerve supply are similar to corresponding muscles of male. The dorsal nerve of the clitoris enters the space from the ischiorectal fossa. The internal pudendal artery and its terminal branches (the dorsal and deep artery of clitoris) pass through the space.

Perineal Membrane in Female (Fig. 89.16)
In the female, the perineal membrane is very thin because it is pierced by the vagina apart from other structures like, urethra in the midline (urethra being in front of the vagina), arteries to the bulbs of the vestibule on each side of the vagina, the posterior labial vessels and nerves, the deep artery of clitoris and the dorsal arteries and nerve of the clitoris.

Perineal Body in Female
The perineal body or the central tendon of perineum is a mass of fibromuscular tissue, which lies between the anal canal and the lower part of the posterior wall of vagina. It is attached to the central point of the posterior margin of urogenital diaphragm. It gives attachment to the following muscles.

i. Right and left superficial transversus perinei
ii. Right and left bulbospongious
iii. Right and left deep transversus perinei
iv. Sphincter urethrae
v. Sphincter ani externus
vi. Right and left pubovaginalis part of levator ani.

Clinical insight ...

Importance of Perineal Body in Female
i. The perineal body is stretched during the second stage of labor at the time of childbirth. It is liable to tears, when the fetal head passes through the vaginal orifice. The tears of the perineal body may be accompanied by tear of the posterior wall of the vagina and of the anal sphincters. Rectal incontinence may result if the perineal tears are not repaired immediately. Weakened perineal body may predispose to prolapse of uterus.

Episiotomy (Fig. 89.17) is a simple surgical procedure performed in third stage of labor to prevent irregular and uncontrolled tears in the perineum during vaginal childbirth. A planned incision in the posterolateral direction in the perianal skin includes perineal muscles that are inserted into the perineal body and the posterior wall of vagina. This facilitates the easy passage of head through the enlarged vaginal orifice.

Vagina
The vagina is a fibromuscular tube connecting the cervical canal to the exterior at the vestibule. It is lined by stratified squamous nonkeratinized epithelium.

Functions
i. It is an excretory passage for menstrual flow, which consists of blood and pieces of endometrium.
ii. It is a female organ of sexual intercourse.
iii. It serves as a birth canal.

Location (Fig. 89.15)
The upper half of vagina lies in the pelvic cavity and the lower half in the perineum. The vagina passes through the pelvic diaphragm and the urogenital diaphragm.

Fig. 89.17: The site of episiotomy incision in a stretched perineal body to increase the size of vaginal orifice to facilitate passage of head through it
(Note that muscles inserted into the perineal body are cut)
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Length
The length of its posterior wall is 9 cm as against that of anterior wall, which is 7 to 7.5 cm.

Vaginal Fornices (Fig. 88.27)
The anterior and posterior walls of vagina are in apposition except at the upper end of vagina where the cervix projects into it. Here, the vagina is wide and forms anterior, posterior, right and left lateral fornices around the projecting cervix. The posterior fornix is the deepest and the pelvic organs can be felt through it. It provides surgical access to the rectouterine pouch of Douglas (cul-de-sac).

Relations
i. The upper part of the anterior wall is related to the base of the urinary bladder and terminal parts of ureters. The lower part of the anterior wall is intimately related to the urethra.
ii. The upper third of the posterior wall of vagina is covered with peritoneum of rectouterine pouch and related to the contents of the pouch. The middle third of the posterior wall is related to the ampulla of rectum. The lower third is related to the perineal body.
iii. The lateral wall on each side is related (from above downwards) to the crossing of ureter and uterine artery, transverse cervical ligament, medial fibers of levator ani (sphincter urethrae and bulbospongiosus), bulb of the vestibule and greater vestibular gland.

Blood Supply
The vagina receives blood from multiple branches of internal iliac artery (vaginal, uterine, middle rectal arteries) and inferior rectal branch of internal pudendal artery. The veins drain into the internal iliac veins.

Nerve Supply
The upper part of vagina receives autonomic nerve supply. Hence, it is pain insensitive. The lower part receives twigs from the inferior rectal and labial nerves (branches of pudendal nerve). It is pain sensitive.

Lymphatic Drainage (Fig. 88.30)
The upper third of vagina drains into external and internal iliac lymph nodes. The middle third drains into internal iliac nodes. The lower third drains into superficial inguinal nodes.

Supports of Vagina
The anterior vaginal wall is supported by the pubocervical ligaments, vesicovaginal fascia and posturethral ligament. The posterior vaginal wall is supported by uterosacral ligaments and rectovaginal fascia. The perineal body (pubovaginalis part of levator ani, sphincter urethrae and bulbospongiosus) provides the muscular support.

Per Vaginum Examination
Per vaginum (PV) examination provides a route for digital palpation of pelvic viscera.

i. The form and size of the body of the uterus are examined by bimanual palpation with two fingers of one hand in the vagina and on the other hand anterior abdominal wall above the pubic symphysis.
ii. The urinary bladder and urethra are felt through the anterior wall of vagina.
iii. The rectal ampulla is palpated through its posterior wall. The loops of intestine and sigmoid colon are felt in the pouch of Douglas.
iv. The ureter and pulsations of uterine artery can be felt through lateral fornices.
v. The size of the pelvis is often assessed by digital examination (internal pelvimetry).

Clinical insight ...

i. The cystocele is the prolapse of the anterior wall of vagina. During rise in the intra-abdominal pressure the anterior vaginal wall is pushed down by the urinary bladder. The rectocele is the prolapse of posterior vaginal wall by the pressure of rectum. These conditions are usually due to severe injury to perineal body as a result of repeated vaginal deliveries.
ii. For aspiration of pus or blood from the pouch of Douglas, a needle is introduced through the posterior wall of posterior fornix.

Female External Genitalia (Fig. 89.18)
The external genitalia in the female consist of the following structures.

i. The mons pubis is a fat filled, hair bearing skin superficial to the pubic bones.
ii. The pudendal cleft is the space between the two labia majora, which are fat filled and hair bearing folds of skin.
iii. The right and left labia majora join to form posterior commissure in front of the anus. The inner surfaces of the labia majora are hairless. The round ligaments of uterus are attached at their upper ends.
iv. The labia minora are a pair of smooth fat free and hairless skin. The anterior ends of labia minora split to form two folds. The posterior folds fuse and attach to the inferior surface of clitoris as the frenulum of clitoris. The anterior folds unite to form prepuce over the tip of the clitoris.
The vestibu... and greater vestibular glands.

vi. The clitoris resembles the penis but is not traversed by urethra. It lies in the anterior part of vestibule. The sensitive tip of the clitoris is called the glans. The vaginal orifice lies in the posterior part of vestibule. It is partly closed in virgin by hymen. The urethral orifice lies anterior to the vaginal orifice (about 2 cm posterior to the clitoris).

**Development of Male External Genitalia**

i. The scrotum develops from the fusion of genital (labioscrotal) swellings.

ii. The penis develops from the genital tubercle and genital or urethral folds. Its development is intimately related to the development of penile urethra. With the elongation of the genital tubercle, the urogenital membrane and the genital folds also elongate. The elongated genital tubercle forms the primitive phallus, which shows the cranial and caudal surfaces. The phallic part of urogenital sinus extends on the superior surface of the urogenital membrane (which lies in an ectodermal urethral groove on the caudal surface if phallus). The endoderm of the phallic part of definitive urogenital sinus proliferates to form the urethral plate. After the breakdown of the urogenital membrane at fifth to sixth weeks, the endoderm of the urethral plate and the surface ectoderm become continuous with each other at the edges of the disrupted membrane. With the canalization of urethral plate, the fusion of genital folds occurs and during this process, the endoderm fuses with endoderm, mesoderm with mesoderm and ectoderm with ectoderm. The site of fusion of genital folds is indicated by the penile raphe. In this way, the penile urethra is formed from the endoderm. However, the urethra in the glans develops from the ingrowth of surface ectoderm. Thus, the external urethral orifice is carried to the tip of the penis.

**Gross Anatomy of Female Urethra**

The female urethra is much shorter than the male urethra.

**Extent**

It extends from the bladder neck to the external urethral meatus in the vestibule of the vagina.

**Length**

The length of female urethra is about 4 cm.

**Relations**

The urethra is intimately related to the anterior wall of vagina. Its initial part lies behind the pubic symphysis and is fixed to the pubic rami by pubo-urethral ligaments. The paraurthral glands of Skene (homologous to prostate) and the urethral glands open into the urethra.

**Mucosal Lining**

The female urethra is lined by transitional epithelium in the uppermost part followed by pseudostratified or stratified...
Perineum in Male and Female

Chapter

Columnar epithelium. Nearer the external urethral meatus the epithelium is stratified squamous in type.

**Clinical insight ...**

### Urinary Stress Incontinence

It is an extremely common symptom, particularly in women, who have borne children and have suffered injury to perineal body during childbirth. This may result in increase in the angle between neck of bladder and urethra leading to herniation of urethral mucosa into the vagina (urethrocele). In this condition, a very small quantity of urine dribbles every time the intra-abdominal pressure rises during laughing, coughing or lifting heavy weight. Alternate contraction and relaxation of perineal muscles (Kegel’s exercises) strengthen the sphincter urethrae and pubococcygeus muscles. Sometimes surgical repair is necessary to relieve the symptoms.

**Embryologic insight ...**

### Development of Female Urethra (Fig. 89.20)

The female urethra is derived from endoderm of vesicourethral canal and mesoderm of the absorbed parts of the mesonephric ducts.

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### Development of Male Urethra (Fig. 89.20)

#### Prostatic Urethra

a. The prostatic urethra above the level of colliculus seminalis develops as follows.
   i. The posterior wall of prostatic urethra develops from the mesoderm of the absorbed part of mesonephric ducts.
   ii. The rest of the prostatic urethra develops from endoderm of vesicourethral canal.

b. The prostatic urethra below the level of colliculus seminalis develops from the endoderm of pelvic part of the definitive urogenital sinus.

### Membranous Urethra

It develops from the pelvic part of definitive urogenital sinus.

### Penile Urethra

The penile urethra (except the navicular fossa inside the glans) develops from canalization of the urethral plate derived from the endoderm of phallic part of the definitive urogenital sinus (Fig. 89.21).

### Congenital Anomalies

i. **Hypospadias** is the condition in which the urethral orifice lies on the undersurface of the penis (Fig. 89.22A). This defect is due to partial failure of the fusion of the genital or urethral folds. The location of the urethral meatus varies and accordingly hypospadias is of different types (Fig. 89.22B). In this defect, the tip of penis is curved inwards (ventrally), which is known as chordee (Fig. 89.22C).

ii. **Epispadias** means the urethral orifice opens on the dorsal surface of penis (Fig. 89.22D).

### Composition of Urethral Wall

The wall of the female urethra is composed of outer circularly arranged sphincter urethrae muscle and the inner longitudinally arranged smooth muscle.

### Sphincters of Female Urethra

i. The internal sphincter is composed of elastic and collagen fibers and a negligible amount of smooth muscle. It has been suggested that the passive elastic resistance offered by the elastic fibers is the major factor in the mechanism of internal sphincter in female

ii. The periurethral part of levator ani muscle provides additional occlusive force during raised intra-abdominal pressure.
iii. The sphincter urethrae muscle (voluntary sphincter) surrounds the female urethra in the deep perineal pouch.

Gross Anatomy of Male Urethra

The male urethra is a long fibromuscular tube functioning as a conduit for both urine and seminal fluid.

Extent

It begins in the neck of the urinary bladder and passes in succession through the prostate, pelvic diaphragm, perineal pouches and the penis to reach the external urethral meatus at the tip of the glans. The male urethra presents a double curve when the penis is in the flaccid state.

Length

The length of the male urethra is 18 to 20 cm.
either side of the crest is the prostatic sinus in which large number of prostatic ducts open. The widest part of urethral crest bears a rounded swelling called colliculus seminalis (verumontanum). At the summit of this eminence lies a blindly ending prostatic utricle (remnant of the fused paramesonephric ducts in male). The ejaculatory ducts open into the prostatic sinuses on either side of the prostatic utricle.

3. The membranous urethra begins at the apex of prostate and passes through the anterior part of levator ani to enter the deep perineal pouch, where it is surrounded by sphincter urethrae muscle. This is the short (1.5 cm), narrow and least dilatable part of male urethra. The mucous membrane of the membranous urethra is thrown into folds hence on cross section its lumen is stellate. The bulbourethral gland lies on either side of it. The membranous urethra pierces the perineal membrane about 2.5 cm posterior to the lower margin of pubic symphysis to enter the bulb of penis. The rigid perineal membrane fixes the urethra firmly to the bony pelvis. This makes the membranous urethra vulnerable to injury.

4. The penile part is the longest part of the male urethra being 15 cm in length. It traverses the bulb of penis in superficial perineal pouch, corpus spongiosum in penile body and the glans penis. The penile part has three subdivisions.
   i. The part inside the bulb of penis is called bulbar part or intrabulbar fossa. The floor and sides of its walls are greater in dimensions than its anterior

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**Parts (Fig. 89.23)**

The male urethra is divisible into four parts, pre-prostatic, prostatic, membranous and spongy or penile.

1. The pre-prostatic part extends from the bladder neck to the base of the prostate. It is just over 1 cm in length. The smooth muscle of its wall (part of sphincter vesicae) is richly innervated with sympathetic fibers. It contracts to prevent retrograde ejaculation of semen.

2. The prostatic part is the widest and most dilatable part of urethra. It is 2.5 cm long and its lumen is crescentic in shape. The features on its posterior wall are shown in Figure 87.9. A midline ridge like projection of mucosa is called the urethral crest. The linear depression on
wall hence it shows trapezoid shape on cross section. This part receives the ducts of the bulbo-urethral glands.

ii. The part inside the corpus spongiosum is called the spongy urethra. Its shape on cross section is a transverse slit.

iii. The part inside the glans penis is dilated and called navicular or terminal fossa. It opens to the exterior by external urethral meatus, which is the narrowest part of the urethra. The shape of the navicular fossa is a vertical slit. The urethral glands (glands of Littre) open into the entire length of spongy urethra in small out-pouchings of the mucosa called lacunae. The lacuna in the roof of the navicular fossa, which is called lacuna magna, is quite deep. The urethral glands are prone to gonococcal infection, which may cause scarring and strictures in the urethra.

**Mucosa of Male Urethra**

i. The prostatic urethra is lined by transitional epithelium above the level of colliculus seminalis, below which it is lined by patchy stratified columnar or pseudostratified columnar epithelium.

ii. The membranous urethra is lined by patchy stratified columnar or pseudostratified columnar epithelium.

iii. The spongy urethra is lined by stratified columnar epithelium.

iv. The navicular fossa is lined by stratified squamous epithelium.

**Urethral Sphincters**

i. The internal sphincter (vesical sphincter) controls the bladder neck and pre-prostatic part of urethra. It is composed of nonstriated muscle, collagen and elastic fibers. Its nerve supply is mainly sympathetic. On sympathetic stimulation, the smooth muscle in the male genital tracts and the internal sphincter contract simultaneously. This causes closure of the internal sphincter during ejaculation so that seminal fluid does not enter the urinary bladder.

(Although the significant role of internal sphincter in genital function is established. Postoperative urinary incontinence does not follow surgical excision of bladder neck or prostate. This observation is suggestive of the insignificant role of the internal urethral sphincter in continence of urine)

ii. The sphincter urethrae muscle around the membranous urethra in the deep perineal pouch forms the external sphincter. It is composed of three parts, smooth muscle fibers, sphincter urethrae muscle (with its circularly arranged striated muscle fibers forming the rhabdosphincter) and the pubourethralis part of levator ani. It is a voluntary sphincter after early infancy. This sphincter is supplied by somatic nerves (rhabdosphincter by pudendal nerve and pubourethralis by direct branches of fourth sacral nerve and also by branches of pudendal nerve). The sphincter urethrae is capable of sustained contraction and pubourethralis counters the periodic rise in intra-abdominal pressure (in coughing, lifting weight, etc).

**Arterial Supply**

The inferior vesical, middle rectal and penile branches of internal pudendal arteries supply the male urethra.

**Venous Drainage**

The proximal part of male urethra drains directly into prostatic venous plexuses. The remaining part of urethra drains into the prostatic plexuses indirectly through the deep dorsal vein of penis.

**Lymph Drainage**

The lymph vessels drain into internal and external lymph nodes. The distal part drains into superficial inguinal nodes.

**Clinical insight ...**

### Injuries to Male Urethra

i. Straddle injuries rupture the bulbar urethra. In such injuries the urine leaks into the superficial perineal pouch and may extravasate into the anterior abdominal wall after filling the superficial perineal pouch, scrotum and penis.

ii. In rupture of the membranous urethra, there is accumulation of urine in the deep perineal pouch.

iii. In the fracture of pelvic bones, the junctional area between prostatic and membranous urethra is ruptured. In such cases extravasation of urine occurs in extraperitoneal tissue of pelvis.

iv. Injury to the preprostatic urethra may cause damage to the vesical sphincter and its sympathetic nerve supply. This results in retrograde ejaculation and consequent sterility.

v. While passing a catheter in the male urethra (catheterization), following anatomical facts must be remembered. The external urethral meatus is the narrowest part of urethra hence maximum resistance is encountered to the passage of instrument at this site. The lacuna magna in the roof of navicular fossa, which is large enough to receive the tip of catheter, may be perforated. To avoid this, the catheter is kept as close to the floor of navicular fossa as possible. The double curve of the urethra is converted into a single continuous curve by elevating the penis during passage of the catheter. The membranous urethra is thin walled, narrow and most fixed. Any force applied during the passage of catheter through this part results in rupture of urethra.
Male External Genitalia
The external genital organs of male consist of the penis and scrotum. The penis is the male copulatory organ. It gives passage to the urine and semen. The scrotum houses both testes and epididymides.

Penis
The penis consists of two parts. The root or fixed part is located in the superficial perineal pouch. The free part or the body is elongated and enveloped in the skin. The penis is suspended from the perineal membrane and the ischiopubic rami.

Root (Figs 89.12 and 89.24A)
The root of the penis is formed by three masses of erectile tissues. The midline bulb of penis carries the bulbar urethra (the initial segment of penile urethra) and is pierced by right and left arteries to the bulb. On each side of the bulb, there is crus. Each crus is pierced by the deep artery of penis.

Body (Fig. 89.24A)
The body of penis is elongated and ends in glans penis. It consists of three elongated masses of erectile tissue, which are the continuation of the root of penis. The crura continue as the corpora cavernosa while the bulb continues as corpus spongiosum, which lies in a groove on the ventral surface of fused corpora cavernosa. The distal end of the corpus spongiosum is expanded to form the glans penis. The corpus spongiosum carries the penile urethra inside it. The external urethral meatus lies at the tip of the glans. The tapered ends of the corpora cavernosa are attached to the hollowed proximal surface of the glans. The slightly everted margin of glans is called the corona glandis and the narrowing of body proximal to corona glandis is called the neck of penis. The dorsal surface of the erect penis becomes the ventral surface in flaccid state. The ventral surface or the urethral surface of penis bears the penile raphe and faces dorsally in flaccid state. The erect penis is regarded as anatomical position of the penis.

Skin and Fasciae Covering Penis (Fig. 89.24B)
i. The skin covering the body of penis is loose, thin and hairless. At the neck of the penis, the skin is reflected upon itself to form prepuce or foreskin, which covers the glans. The prepuce is attached to the ventral surface of glans by a fold of skin called frenulum of the prepuce. Phimosis is the condition where the prepuce is too tight to retract over the glans penis. Accumulation of secretions (smegma) under the prepuce predisposes to infection and malignancy. It can also cause narrowing of external urethral meatus. Circumcision is the operation in which redundant part of prepuce is removed.
ii. The superficial fascia of penis contains no fat. The superficial dorsal vein lies in the midline.

iii. The fascia of penis or Buck’s fascia forms a common covering for the three erectile masses but it does not cover the glans. It is continuous with fascia of Scarpa of the anterior abdominal wall and dartos muscle of the scrotum. The suspensory ligament connects the pubic symphysis to the fascia of penis. Five structures lie deep to this fascia on the dorsal aspect of penis, single deep dorsal vein in the midline, flanked on either side by dorsal arteries and still laterally by dorsal nerves.

iv. Fibrous layer or tunica albuginea is a covering for each mass of erectile tissue (midline corpus spongiosum and bilateral corpora cavernosa).

**Arterial Supply**

Penis is a highly vascular organ. The corpora cavernosa receive deep artery of penis on each side while the corpus spongiosum receives a pair of artery to the bulb. In addition, the dorsal arteries lie along the dorsal surface and supply the superficial parts of the penis. Erection of penis is a vascular phenomenon. There is vasodilatation in the cavernous tissue as a result of parasympathetic stimulation (pelvic splanchnic nerves). The engorged corpora cavernosa and corpus spongiosum compress the veins thereby retarding the outflow of blood. Both arterial and venous factors are responsible for increasing and maintaining the internal pressure.

**Venous Drainage**

The veins of the penis do not correspond to the arteries. There are two veins, superficial dorsal vein and deep dorsal vein of penis.

i. The superficial dorsal vein drains the prepuce and the skin of the penis. It runs backwards in the superficial fascia of the dorsum and either ends in right or left superficial external pudendal vein or divides in two and each ends in the superficial external pudendal vein of its side.

ii. The deep dorsal vein drains blood from the glans penis and corpora cavernosa. It courses back in the midline between the right and left dorsal arteries of the penis lying deep to the fibrous sheath of the penis. At the root of the penis, it enters the space between the transverse perineal ligament and the arcuate pubic ligament to enter the pelvis. It divides in right and left branches, which empty into prostatic venous plexus. The deep dorsal vein communicates with internal pudendal veins before dividing into right and left branches.

**Lymphatic Drainage**

The skin of the penis including the prepuce drains into superficial inguinal lymph nodes and the glans penis drains into deep inguinal nodes (gland of Cloquet). The deeper tissues drain into internal iliac nodes.

**Nerve Supply**

The somatic and autonomic nerves supply the penis.

i. The somatic innervation is via the dorsal nerves of penis to the skin of the body, prepuce and glans.

ii. The pelvic splanchnic nerves supply parasympathetic innervation through cavernous nerves, which arise from prostatic nerve plexuses. The cavernous nerves supply vasodilator fibers to blood vessels in erectile masses.

iii. The sympathetic fibers from the L1 segment of spinal cord reach through the inferior hypogastric plexus. Their role is opposite to that of the parasympathetic.

**Scrotum**

The scrotum is a pendulous sac of skin, hung from the medial part of inguinal region of the lower abdominal wall and located between the thighs behind the flaccid penis. It houses testes and epididymes along with the lower parts of spermatic cords. A midline raphe is the indication of its internal division into two halves. The left half is at a slightly lower level compared to the right due to the greater length of the left spermatic cord.

**Layers of Scrotal Wall (Fig. 79.3)**

The layers of the scrotal wall are the skin, dartos muscle, external spermatic fascia, cremaster muscle, cremaster fascia and the internal spermatic fascia.

**Characteristics of Scrotal Skin**

The scrotal skin is thin, pigmented and rugose. It bears thinly scattered hairs and the dermis contains sebaceous and numerous sweat glands. Subcutaneous fat is absent. The dartos muscle is a thin layer of subcutaneous smooth muscle of scrotum. It extends in the scrotal septum, which contains all the layers of scrotal wall except the skin. The sympathetic nerves reach the dartos via genitofemoral nerve. The dartos contracts reflexly on exposure to cold. This makes the scrotal skin wrinkled and it is brought very close to the testes, thus helping in preservation of heat. In warm climate, the dartos relaxes and the scrotal skin becomes smooth and elongated, thus helping in dissipation of heat. The scrotal temperature is lower by about three degrees than that of the body temperature.
Blood Supply
The external pudendal branches of femoral artery, posterior scrotal branches from inferior rectal artery and the cremasteric branch from inferior epigastric artery supply the scrotal skin. The veins follow the arteries.

Lymphatic Drainage
The lymph drains from the scrotum to the superficial inguinal lymph nodes. Scrotal swellings due to carcinoma of scrotal skin or due to seminoma can be differentiated from the examination of the appropriate lymph nodes.

Nerve Supply
Four different nerves supply the scrotal skin.

i. Anterior one-third is supplied by the ilioinguinal nerve and genital branch of genitofemoral nerve (L1).

ii. Posterior two-thirds is supplied by posterior scrotal and perineal branch of posterior cutaneous nerve of thigh (S3).

It is important to note that two discontinuous dermatomes (L1 and S3) come in apposition at the junction of anterior third and posterior two-third of scrotum. The spinal anesthesia at S3 level may not be sufficient to anesthetize the entire scrotum.

Clinical insight ...

i. The most common cause of scrotal swelling is hydrocele (Fig. 89.25) in which there is collection of fluid in the tunica vaginalis testis. Elephantiasis is a common cause of huge swelling of the scrotum. The other causes of scrotal swelling are, inguinal hernia, varicocele, diseases of the tests and of epididymis.

ii. To drain the fluid from a hydrocele a needle is passed through successive layers of scrotum (skin, dartos, external spermatic fascia, cremaster fascia, internal spermatic fascia and parietal layer of tunica vaginalis). This procedure is called tapping the hydrocele.

iii. The eversion of the sac (tunica vaginalis) is another method of treating hydrocele (Fig. 89.26).

iv. The empty scrotum is a condition in which the testis fails to descend into the scrotum.

Pudendal Nerve
The pudendal nerve supplies the urogenital and anal triangles of the perineum and the external genitalia. It takes origin from the sacral plexus inside the pelvic cavity. Its root value is S2, S3, S4.

Course (Fig. 89.27)
This is divisible into three parts, namely, intrapelvic, gluteal, and perineal.

i. The intrapelvic part of pudendal nerve extends from its origin till it reaches the lower margin of the greater sciatic foramen below the piriformis muscle. It leaves the pelvis via this foramen to enter the gluteal region along with internal pudendal vessels and nerve to obturator internus muscle.

ii. The gluteal part of pudendal nerve is very short as it immediately leaves through the lesser sciatic foramen to enter the lateral wall of ischiorectal fossa. In the gluteal region, it is in contact with the apex of the sacrospinous ligament close to its attachment to the ischial spine. The pudendal nerve is medial to the
ii. The perineal part of the pudendal nerve begins at the posterior end of the pudendal or Alcock’s canal, which lies on the lateral wall of the ischiorectal fossa. In the posterior part of the canal, the pudendal nerve lies superior to the internal pudendal artery. It gives off the inferior rectal nerve here. In the anterior part of the canal, the pudendal nerve divides into its terminal branches, perineal nerve and dorsal nerve of penis or clitoris. The dorsal nerve, internal pudendal artery and the perineal nerve lie from above downward in the anterior part of the canal.

iii. The dorsal nerve of clitoris or penis is one of the terminal branches of the pudendal nerve (dorsal nerve of clitoris being much smaller than its counterpart in male). The dorsal nerve enters the deep perineal pouch from its posterior margin. It travels forwards on the superior surface of the perineal membrane in contact with the medial surface of ischiopubic ramus. Near the anterior end of the deep space the dorsal nerve pierces the perineal membrane and enters the gap between the transverse perineal ligament and the arcuate pubic ligament. The dorsal nerve and accompanying artery enter the dorsal surface of the clitoris or the penis.

Branches

i. Inferior rectal or hemorrhoidal nerve crosses the ischiorectal fossa from lateral to medial side. Since it is a mixed nerve, it supplies the sphincter ani externus and provides sensory branches to lower one-third of anal canal, perianal skin and lower 2 cm of vaginal mucosa.

ii. The perineal nerve is the larger terminal branch of the pudendal nerve. In the anterior part of the pudendal canal, it divides into the posterior scrotal or labial and muscular branches. The posterior scrotal or labial branches enter and course through the superficial perineal pouch to supply the posterior two-thirds of the scrotal or labial skin. The muscular branches supply all the five muscles of the urogenital triangle (superficial transverse, bulbospongiosus, ischiocavernosus, deep transverse and sphincter urethrae). The branch to bulbospongiosus supplies the urethra and corpus spongiosum also. The perineal nerve sends twigs to anterior part of levator ani muscle. These twigs enter the muscle from below.

iii. The dorsal nerve of clitoris or penis is one of the terminal branches of the pudendal nerve (dorsal nerve of clitoris being much smaller than its counterpart in male). The dorsal nerve enters the deep perineal pouch from its posterior margin. It travels forwards on the superior surface of the perineal membrane in contact with the medial surface of ischiopubic ramus. Near the anterior end of the deep space the dorsal nerve pierces the perineal membrane and enters the gap between the transverse perineal ligament and the arcuate pubic ligament. The dorsal nerve and accompanying artery enter the dorsal surface of the clitoris or the penis.
In the male, the dorsal nerves of penis is located deep to penile fascia lateral to the dorsal artery of its side. The dorsal nerves supply the penile skin, glans penis and prepuce.

To sum up the functions of the pudendal nerve, through nerve supply of sphincter urethrae it controls micturition, through nerve supply of external anal sphincter it controls defecation and through sensory nerve supply of penis or clitoris it performs sexual functions.

Internal Pudendal Artery

The internal pudendal artery (Fig. 89.28) is larger in male compared to the female. However, the course and distribution are similar in the two sexes.

Origin

The internal pudendal artery takes origin from the anterior division of internal iliac artery inside the pelvic cavity.

Course

It descends in lateral direction towards the inferior margin of greater sciatic foramen, where it leaves the pelvis along with pudendal nerve and nerve to obturator internus. The three structures enter the gluteal region for a short course. The artery turns around the dorsal aspect of the ischial spine to enter the ischiorectal fossa via lesser sciatic foramen. Then the internal pudendal artery traverses the pudendal canal by lying below the pudendal nerve at first and then between the latter’s two terminal branches. It enters the deep perineal pouch and runs along the ischiopubic ramus forwards to terminate behind the inferior pubic ligament by dividing into dorsal artery of penis or clitoris and deep artery of penis or clitoris.

Internal Pudendal Vein

The veins draining penis and scrotum in male and the external genitalia in female join to form internal pudendal vein or veins (which accompany the internal pudendal artery). Inside the pelvis the internal pudendal vein communicates with prostatic venous plexus in male and vesical venous plexus in female. It drains into internal iliac vein.
CASE 1
A 65-year-old man with a history of chronic cough noticed a gradually increasing swelling in the left groin. After physical examination the surgeon noted a lemon sized swelling above the pubic tubercle. The swelling increased in size on coughing. After manually reducing the swelling the surgeon occluded the deep inguinal ring with the thumb and then asked the patient to cough. The swelling appeared medial to the thumb.

Questions and Solutions
1. Which findings in the physical examination are confirmatory of inguinal hernia?
   The swelling is above and medial to the pubic tubercle and its size increased on coughing.
2. Name the test the surgeon performed to confirm the diagnosis of the type of hernia.
   Ring occlusion test
3. Give the type of inguinal hernia in this case.
   Direct inguinal hernia
4. Give the surface marking of deep inguinal ring.
   It is marked by a point located 1.25 cm above the midthigh point.
5. How does the hernia in the above case enter the inguinal canal?
   Posterior wall of inguinal canal (formed by Hesselbach’s triangle) is the entry point of the hernia.
6. Write a note on the conjoint tendon.
   The fusion of the aponeuroses of internal oblique and transversus abdominis muscles behind the medial end of inguinal ligament forms the conjoint tendon. The conjoint tendon is attached to the pubic crest and pecten pubis. It forms the medial half of the posterior wall of the inguinal canal. It strengthens the posterior wall opposite the deficiency (superficial ring) in the anterior wall. The conjoint tendon may weaken in old age due to decreased tone of the muscles of the anterior abdominal wall and if there is injury to iliohypogastric and ilioinguinal nerves. The weakened conjoint tendon predisposes to direct inguinal hernia.
7. Name the artery in lateral relation to the neck of hernia in the patient. What is it a branch of?
   Inferior epigastric artery is related laterally to the neck of direct inguinal hernia. It is a branch of external iliac artery.
8. Give the boundaries and contents of inguinal canal?
   Refer to chapter 79.

CASE 2
A 60-year-old man (with a history of chronic duodenal ulcer) was admitted to the hospital in an unconscious state. His pulse was weak and blood pressure was very low. Ultrasound scan revealed fluid in the peritoneal cavity. This case was diagnosed as perforation of the first part of duodenum.

Questions and Solutions
1. Which artery is eroded in the perforation of peptic ulcer on the posterior wall of the first part of duodenum? What is it a branch of?
   The gastroduodenal artery is eroded in perforation of the first part of duodenum because it is posteriorly related to this part. It is known as artery of duodenal hemorrhage. It is a branch of common hepatic artery.
2. **What is the length of first part of duodenum?**
5 cm.

3. **Enumerate the special features of the first part of duodenum.**
For special features of the first part of duodenum refer to chapter 81.

4. **Describe the internal features of the second part of the duodenum.**
There are circular folds of mucous membrane and two apertures lying on two raised papillae. The major duodenal papilla located at a distance of 8 to 10 cm from the pylorus. It is present at the proximal end of a longitudinal fold on the posteromedial wall. On its summit opens the hepatopancreatic ampulla pouring pancreatic juice and bile in this part. The major duodenal papilla is located about 2 cm proximal to the major duodenal papilla. On its summit opens the accessory pancreatic duct.

5. **Mention the development of the duodenum.**
   i. The first part of the duodenum develops entirely from the endoderm of the foregut.
   ii. The second part has dual development. The part above the major duodenal papilla develops from foregut and below that from midgut.
   iii. The third and fourth parts develop from the midgut.

6. **What is the effect of annular pancreas on the duodenum?**
The annular pancreas is the congenital anomaly of pancreas in which the pancreatic tissue surrounds the second part of duodenum like a ring. The pancreatic ring tends to compress the second part causing duodenal obstruction in newborn.

CASE 3
A 70-year-old man with complaints of progressive jaundice, frequent bowel movements with pale greasy stools, back pain and weight loss was diagnosed as having carcinoma of the head of pancreas after ultrasound examination and other appropriate investigations.

Questions and Solutions

1. **What is the anatomical and physiological basis of jaundice in cancer of pancreatic head?**
The common bile duct is embedded in the posterior surface of the head of the pancreas before joining the pancreatic duct. Therefore, in cancer of pancreatic head the CBD is blocked by cancer infiltration. The bile with contained bilirubin accumulates in the biliary tree leading to stasis in the biliary canaliculi. The bile escapes either through the lymph vessels of liver or through ruptured bile canaliculi into blood circulation. The type of jaundice in this case is obstructive or surgical jaundice.

2. **Which cells secrete bile?**
The hepatocytes secrete bile.

3. **Draw a diagram of the extrahepatic biliary apparatus.**
Refer to Figure 82.12

4. **Name the boundaries and contents of Calot’s triangle.**
The Calot’s (cystohepatic) triangle is bounded superiorly by inferior surface of right lobe of liver close to porta hepatitis, inferiorly by cystic duct and medially by common hepatic duct. It contains lymph node of Lund and right hepatic artery and cystic artery.

5. **Draw a diagram to show the arterial supply of common bile duct.**
Refer to Figure 82.14.

6. **Describe the development of the common bile duct and the main pancreatic duct.**
i. The common bile duct develops from the proximal part of hepatic bud, which takes origin from endoderm of foregut.
ii. The main pancreatic duct develops from ducts of both ventral and dorsal pancreatic buds. The smaller duodenal side of the main pancreatic duct develops from the duct of ventral pancreatic bud and the remaining larger part from the duct of dorsal pancreatic bud.

7. **Give the vascular relations and development of the uncinate process of pancreas.**
The uncinate process is related anteriorly to superior mesenteric vessels and posteriorly to abdominal aorta (it is held inside a vascular nutcracker). It develops from ventral pancreatic bud.

CASE 4
A 17-year-old boy was brought to the hospital with complaints of acute pain around the umbilicus, fever and vomiting. On examination, the surgeon found the
area of maximum tenderness at the McBurney’s point. The psoas test was positive.

Questions and Solutions

1. Name the clinical condition.
   Acute appendicitis

2. Give the surface marking of McBurney’s point. What is the importance of this point?
   McBurney’s point is located at the junction of lateral one-third and medial two-thirds of a line joining anterior superior iliac spine and pubic tubercle on the right side. It indicates the base of the appendix and is used for placing incision for appendicectomy.

3. Name the different positions of the affected organ mentioning the most common position.
   For different positions of appendix refer to Figure 81.32. The most common position of appendix is retrocecal.

4. Describe the arterial supply of the affected organ?
   The appendix receives arterial supply from a single appendicular artery, which is a branch of ileocolic artery. The appendicular artery travels in the mesoappendix from its base to the apex, where the mesoappendix is very short. As a result, the artery comes in direct contact with appendix at the tip. In acute appendicitis, the artery is at risk of thrombosis in this location. As a result, tip undergoes necrosis and gangrene and finally may perforate.

5. Which organ is called the abdominal tonsil and why?
   The vermiform appendix is called the abdominal tonsil because its submucosa contains the lymphatic aggregations, which offer immunological defense against microbes in digestive tract.

6. What is the anatomical basis of psoas test?
   The retrocecal appendix is in direct contact with the psoas major muscle. In inflammation of appendix the muscle goes in spasm. So, when the right thigh is extended there is pain due to stretch on the psoas major (which is the flexor of the thigh at the hip joint). A positive psoas test suggests inflammation of retrocecal appendix.

CASE 5

A middle aged man habituated to alcohol consumption was rushed to hospital because he had severe bout of blood vomiting (hematemesis). Physical examination revealed caput medusae and splenomegaly. The history of chronic alcoholism, symptoms and signs are indicative of obstruction to blood flow in a major blood vessel in the abdominal cavity.

1. Name the blood vessel that is involved.
   Portal vein

2. Describe formation, course and termination of this blood vessel.
   i. The portal vein is formed posterior to the neck of pancreas by the union of superior mesenteric and splenic veins at the level of L2 vertebra.
   ii. The portal vein terminates into right and left branches at the right end of porta hepatis.
   iii. The extrahepatic part, about 8 to 10 cm long, is divided into three parts, infraduodenal, retroduodenal and supraduodenal. The infraduodenal part lies below the first part of the duodenum. It is related anteriorly to the neck of pancreas, posteriorly to the inferior vena cava and on its right to common bile duct.
   The retroduodenal part lies posterior to the first part of duodenum. It is related anteriorly to the first part of duodenum, with common bile duct and gastroduodenal artery separating the two. Posteriorly it is in relation to inferior vena cava.
   The supraduodenal part is located in the free margin of lesser omentum. The common bile duct and hepatic artery proper lie anterior to it in the omentum, the artery being medial to the duct. Posteriorly the epiploic foramen intervenes between the portal vein and the inferior vena cava.
   The portal vein terminates in the liver by dividing into right and left branches.

3. Give the anatomical basis of hematemesis and caput medusae.
   i. Hematemesis is due to rupture of esophageal varices in the submucosa of lower end of esophagus, which is one of the sites of portosystemic anastomoses. At this site, esophageal branches of left gastric veins (portal vein tributary) anastomose with esophageal branches of azygos system (systemic veins). In portal hypertension on account
of cirrhosis there is obstruction to portal blood flow, as a result of which portal blood is not drained into IVC. Therefore, portal blood attempts to reach systemic venous circulation via the portosystemic anastomoses. The dilated submucous veins at lower end of esophagus are prone to rupture by slightest mechanical trauma (ingested food) causing hematemesis.

ii. The caput Medusae means an appearance resembling the head of Medusa, a mythological Greek Goddess, whose hair are like snakes radiating from her head. This appearance is seen around umbilicus in portal obstruction. The paraumbilical veins (portal tributary) anastomose with the superficial tributaries of superior epigastric and inferior epigastric veins (systemic veins). These veins enlarge and dilate and form a pattern of radiating veins around the umbilicus (caput Medusae).

4. Add a note on the development of the affected blood vessel.

The trunk of the portal vein develops from a small segment of left vitelline vein proximal to dorsal anastomosis, dorsal anastomosis and right vitelline vein proximal to dorsal anastomosis (Fig. 83.6).

CASE 6
An overweight 40-year-old woman (mother of four children) was brought to the casualty with complaint of spasmodic colicky pain in the right upper quadrant of abdomen, nausea, vomiting and fever. She complained that the pain radiated to the lower angle of scapula. She was very much uncomfortable, when asked to take deep inspiration. While palpating right upper quadrant she felt sharp pain at the tip of ninth costal cartilage.

Questions and Solutions

1. Identify the organ that is inflamed mentioning the common reason for this.
   Gallbladder is inflamed. The common cause for cholecystitis is gall stones.

2. Give the location of the organ.
   The gallbladder is located in the fossa to the right of quadrate lobe on the inferior surface of right lobe of liver.

3. Explain the radiation of pain to the inferior angle of right scapula.
   The sympathetic nerve supply of gallbladder is from T7 to T9 segments. When these fibers are stimulated in cholecystitis the pain is radiated to inferior angle of scapula where the skin is supplied by seventh intercostal nerve.

4. Name the different parts of the organ.
   Fundus, body and neck.

5. Name its inferior relations from before backwards.
   Transverse colon, superior duodenal flexure and first part of duodenum are its inferior relations from before backwards.

6. What is the function of this organ?
   The gallbladder stores and concentrates the bile.

7. Describe Hartman’s pouch and Phrygian cap.
   Hartman’s pouch or infundibulum is a projection from the right side of the neck of gallbladder in the downward direction. Impaction of gallstone in this pouch may cause adhesion with first part of duodenum or with bile duct and injury. Phrygian cap is a congenitally present peculiar shape of the gallbladder. The fundus folds on itself to form a cap like structure because of a constriction.

CASE 7
An elderly woman gave a history of passing blood-stained stools for three months. After the proctoscopic examination, diagnosis of internal hemorrhoids or piles was confirmed.

Questions and Solutions

1. Name the venous plexus, which is enlarged in internal hemorrhoids.
   Internal rectal venous plexus.

2. Describe the internal features of the anal canal.
   The anal canal is subdivided into three parts by pectinate line and Hilton’s line into upper 15 mm, middle 15 mm or pecten and lower 8 mm.
i. The upper 15 mm is lined by columnar epithelium, which is raised into 6 to 10 longitudinal folds of Morgagni. Each column contains radicles of superior rectal vessels. The venous radicles in left lateral (3 o clock), right anterior 11 o clock) and right posterior (7 o clock) become enlarged in portal hypertension causing primary internal piles. The anal valves are the crescentic mucous folds connecting the lower ends of the anal columns. The position of the valves corresponds to the wavy pectinate line. If the anal valve is torn it results in a painful condition called the anal fissure. The anal sinuses are the recesses above the valves and between the columns. The sinuses are deeper in the posterior wall of anal canal. The floor of the sinuses receives the ducts of anal glands.

ii. The intermediate area (pecten) is lined by non-keratinized stratified squamous epithelium.

iii. The lower area is also known as anal verge and is lined by true skin.

PECTINATE LINE divides the anal canal into two areas, which are different in development, arterial supply, venous drainage, lymphatic drainage and nerve supply. Hilton’s line is somewhat white in color. It corresponds to intersphincteric groove in the wall of the anal canal.

3. What is the development of anal canal? Mention one congenital anomaly.

The anal canal above the pectinate line develops from endoderm of hindgut and that below the pectinate line from the ectoderm of proctodeum. Imperforate anus is the congenital anomaly in which there is failure of rupture of embryonic anal membrane.

4. Name the subdivisions of external anal sphincter and give their nerve supply.

The external anal sphincter is subdivided into three parts, deep, superficial and subcutaneous. The inferior rectal nerve supplies the external sphincter.

Questions and Solutions

1. What is the reason for narrowing of the pyloric orifice in this condition?

The circular muscle layer at the pylorus is hypertrophied.

2. Give the surface marking of the pyloric orifice.

The midpoint of the pyloric orifice (which is 2 cm wide) lies at a point drawn 1.2 cm to the right of the midline on the transpyloric plane.

3. Which blood vessel helps in the identification of the pylorus during surgery?

Prepyloric vein of Mayo passes in front of the pylorus lying in a groove demarcating pyloric canal and pylorus

4. Enumerate the layers of the pylorus (from without inwards) that are cut during Ramstedt’s operation.

The order of layers cut is visceral peritoneum, longitudinal muscle layer and circular muscle layer.

5. Describe the blood supply and lymphatic drainage of stomach.

Refer to chapter 81.

CASE 9

A 62-year-old man came to the surgeon with complaints of passing blood stained stools and altered bowel habits for the last two months. His other complaints were pain radiating down the back of both thighs and weakness of hamstring muscles. On per rectum examination a growth was palpable on the posterior rectal wall.

Questions and Solutions

1. What is the extent of the rectum?

The rectum extends from rectosigmoid junction (third sacral vertebra) to anorectal junction (just below the tip of coccyx).

2. Mention the characteristic features of rectosigmoid junction.

The rectosigmoid junction is characterized externally by absence of the distinguishing features of large intestine and end of pelvic mesocolon. Internally the junction presents an acute angulation, which lies at a distance of 15 to 17 cm from the anal orifice.
3. **What is ampulla of rectum?**

Ampulla is the part of cavity of the rectum below the level of middle valve.

4. **Name the posterior relations of the rectum.**

Refer to chapter 87 for rectum.

5. **Which nerves are invaded by the growth?**

Sciatic nerves of both sides are involved as the sacral plexus is invaded by the growth (sacral plexus is in posterior relation of the rectum).

6. **Describe with the help of diagram the lymphatic drainage of rectum.**

Refer to chapter 87 for rectum.

7. **Describe the peritoneal relations of the rectum in male and female.**

The peritoneum reflects from the junction of middle and lower third of rectum on to the urinary bladder in male to form rectovesical pouch. In the female the peritoneum reflects from the same level on to the posterior fornix of vagina to form rectouterine pouch of Douglas.

8. **Write briefly on the development of rectum.**

The rectum develops from hindgut (above the level of middle valve from endoderm of preallantoic hindgut and below that from dorsal part of postallantoic hindgut).

CASE 10

A 28-year-old woman from poor socioeconomic background had a 2 months history of chronic cough, low grade fever, weight loss and low back ache. She went to the doctor when she detected a swelling in the right groin. Physical examination revealed a firm and mildly tender lump below the inguinal ligament in the femoral triangle. On radiological examination, a tubercular lesion was noted in the first and second lumbar vertebrae. It was suspected that pus from the infected vertebrae tracked down along a muscle of posterior abdominal wall and appeared as an abscess in the femoral triangle.

**Questions and Solutions**

1. **Name the muscle involved.**

Psoas major

2. **Describe origin, course and insertion of the above muscle.**

The psoas major takes origin from the lumbar vertebrae and intervening discs.

   i. Anterior surfaces of the transverse processes of all lumbar vertebrae.

   ii. Anterior surfaces of bodies of T12 to L5 vertebrae and intervertebral discs between them.

   iii. Tendinous arches between sides of adjacent upper four lumbar vertebrae.

   The psoas major muscle is divisible into three parts, abdominal, pelvic and femoral. The abdominal part passes downwards in paravertebral position on the posterior abdominal wall. It crosses the pelvic brim at the ala of the sacrum to enter the pelvis. The pelvic part passes downwards and laterally adjacent to iliacus muscle. The tendons of both muscles enter the thigh in femoral triangle behind inguinal ligament. The iliopsoas is inserted into lesser trochanter of femur.

3. **What is the importance of the fascia covering the above muscle?**

The psoas major is covered with psoas fascia, which forms a psoas sheath. The sheath is open superiorly. Hence the pus from lumbar vertebra enters the psoas sheath and travels down to its lower end and appears as psoas abscess in femoral triangle.

4. **Give the action of this muscle on hip joint and lumbar spine.**

The psoas major flexes the thigh at hip joint and brings about flexion of lumbar part of vertebral column along with rectus abdominis (as in sitting up from supine position).

5. **What is the nerve supply of this muscle?**

Direct branches of ventral rami of L1, L2 and L3 spinal nerves supply the psoas major muscle.

6. **How do the branches of lumbar plexus emerge from this muscle?**

Six branches of lumbar plexus emerge from the muscle as follows. The iliohypogastric, ilioinguinal, lateral cutaneous nerve of thigh and femoral nerve merge from the lateral margin from above downwards. The genitofemoral nerve emerges from its anterior surface and the obturator nerve emerges from its medial surface.
CASE 11

A 52-year-old obese woman presented to her physician with the complaint of increasing low back pain of one week duration. On examination of her anterior abdominal wall a tender pulsatile mass was felt just around the umbilicus. The arterial pulses in the lower limbs appeared diminished. Radiological studies confirmed aneurysm of infrarenal abdominal aorta and narrowing of common iliac arteries.

Questions and Solutions

1. **What is the meaning of the term aneurysm?**
   - Localized dilatation of the wall of the artery is called aneurysm.

2. **Which peripheral pulses are examined in lower limb?**
   - Femoral, popliteal, posterior tibial and dorsalis pedis

3. **What is the vertebral extent of abdominal aorta?**
   - From T12 to L4

4. **In which space will the blood of a leaking aortic aneurysm accumulate?**
   - Retroperitoneal space

5. **Name all the unpaired branches of abdominal aorta.**
   - Celiac trunk, superior mesenteric artery, inferior mesenteric artery and median sacral artery

6. **Why do most abdominal aortic aneurysms occur in infrarenal segment?**
   - Vasa vasora in tunica adventitia do not penetrate the tunica media. This means that media and intima are dependent on diffusion of oxygen and nutrients from luminal blood. If the diffusion is diminished due to atherosclerosis the tunica media weakens due to ischemia. This predisposes to dilatation of the vessel.

CASE 12

A 12-year-old boy presented with acute abdominal symptoms and frank bleeding per rectum. Plain radiograph and CT scan showed nothing abnormal in the abdomen and pelvis. Technetium scan showed a hot spot proximal to ileocecal junction.

Questions and Solutions

1. **Name the structure arising from ileum proximal to ileocecal junction and visualized by technetium scan.**
   - Meckel’s diverticulum

2. **Give its length and location**
   - It is usually two inches long (5 cm) and is attached to antimesenteric border of ileum two feet (60 cm) proximal to ileocecal junction.

3. **What is the embryological significance of this structure?**
   - Meckel’s diverticulum or ileal diverticulum is the persistent proximal part of vitellointestinal duct.

4. **What is its histological structure?**
   - It has the same layers like the ileum.

5. **Name the ectopic heterotopic tissue usually found inside it.**
   - Acid secreting oxyntic cells of gastric mucosa or pancreatic cells are seen in the mucosa of the diverticulum. This may produce peptic ulceration and perforation. Ulceration of diverticulum may cause frank bleeding per rectum.

6. **What is Littre’s hernia?**
   - When Meckel’s diverticulum is found in inguinal hernia, or femoral hernia or umbilical hernia it is known as Littre’s hernia. Littre’s hernia in inguinal canal is more common compared to other sites.

CASE 13

A 15-year-old boy (riding a bicycle) was hit in the perineum in an accident. He did not pass urine after the trauma. After a gap of ten hours the boy developed a swelling of the scrotum, penis and lower part of the anterior abdominal wall. The rupture of urethra was diagnosed.

Questions and Solutions

1. **What is the length and extent of male urethra?**
   - The length is 18 to 20 cm. The male urethra extends from neck of the urinary bladder to the external urethral meatus at the tip of penis.
2. Enumerate the parts of male urethra and the region of their location.

The parts of the male urethra are preprostatic, prostatic, membranous and spongy (bulbar and penile parts constitute the spongy part).

The preprostatic urethra and prostatic urethra are located in the pelvis above the pelvic diaphragm.

The membranous urethra is located in the deep perineal pouch.

The spongy urethra is subdivided into bulbar urethra (located in the bulb of penis in the superficial perineal pouch) and the penile urethra (located in the corpus spongiosum of penis).

3. Which part of urethra ruptures in straddle injuries?

The bulbar part is most susceptible to rupture in straddle injuries.

4. What is the explanation for circumscribed swelling in this patient?

The extravasation of urine in the perineum, scrotum and infraumbilical anterior abdominal wall produces a circumscribed swelling. If the bulbar urethra ruptures the urine first leaks into the superficial perineal pouch distending the pouch as well as the external genitalia. Then the urine ascends in the anterior abdominal wall in the space between the membranous layer of superficial fascia (fascia Scarpa) and the aponeurosis of external oblique muscle.

5. What prevents the urine from entering the thigh from the anterior abdominal wall?

The superficial fascia of thigh consists of superficial fatty layer and deep membranous layer. These two layers are continuous in front of the inguinal ligament with corresponding layers of anterior abdominal wall. The membranous layer is fused with the deep fascia of thigh along a horizontal line starting from the pubic tubercle and passing for about 8 cm laterally. This line is referred to as Holden’s line. This line of fascial fusion seals the space between the membranous layer of superficial fascia and the external oblique aponeuroses in the infraumbilical abdominal wall. This explains why the extravasated urine deep to the membranous layer of superficial fascia in the anterior abdominal wall does not descend into the thigh below this line.

6. Name the anomaly in which the external urethral meatus opens on the ventral surface of penis.

Hypospadias

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**CASE 14**

A postmenopausal woman came to the hospital with complaint of a sensation of something coming down the vagina, dribbling of urine while bending down and frequency of micturition. Per vaginum examination revealed the descent of cervix into the vagina (uterine prolapse).

**Questions and Solutions**

1. What is the normal position of the uterus?

   Anteversion and anteflexion

2. Describe the true ligaments of the uterus with the help of a diagram.

   The true ligaments of the uterus are the condensation of the pelvic fascia. These ligaments pass from the cervix in three different directions and fix it to the pelvic walls. They form a hammock of condensed pelvic fascia and support the uterus against vertical descent.

   i. The transverse cervical ligament (Mackenrodt’s ligament) or cardinal ligament) connects the lateral aspect of vagina and cervix to the lateral pelvic wall. It passes through the base of the broad ligament. The uterine artery may pass through a special tunnel in the ligament or it may pass superior to it.

   ii. The uterosacral ligament extends from the posterior aspect of cervix backward lateral to rectum to gain attachment to the sacrum.

   iii. The pubocervical ligament extends from the anterior aspect to the back of pubic symphysis.

   In the operation of hysterectomy these three ligaments are cut to free the cervix and vagina.

3. Describe the broad ligament of uterus.

   The broad ligament of the uterus is a peritoneal fold that passes from the uterus to the sidewall of pelvis on each side. This peritoneal fold faces anteroinferiorly and posterosuperiorly because the anteverted position of the uterus. It has free upper margin, which contains fallopian tube. The ligament of ovary lies in it posterior to the tube and round ligament of uterus is contained anterior to the tube. The other contents are vestigial remnants-paroophoron, epoophoron and Gartner’s duct. These embryonic vestiges may undergo cystic changes and enlarge to form cysts of broad ligament. The broad ligament also contains, connective tissue called parametrium supporting the uterine and ovarian blood vessels, nerves and lymphatics.
4. **What is the embryological importance of gubernaculum ovarii and what are its derivatives?**

The gubernaculum ovarii is a fibromuscular strand attached to the lower pole of developing ovary in the embryo. It plays a role in the descent of ovary from the posterior abdominal wall to the pelvic cavity. Its derivatives are ligament of ovary and round ligament of uterus.

5. **What is arterial supply of uterus and vagina?**

The uterine artery, a branch of anterior division of internal iliac artery and the ovarian artery, a branch of abdominal aorta supply the uterus.

The vagina receives blood from multiple branches of internal iliac artery (which are a direct vaginal branch, uterine artery and middle rectal artery) and also from artery to bulb of vestibule (from internal pudendal branch of internal iliac artery).

6. **Which part of levator ani surrounds the vagina and the urethra?**

The pubovaginalis surrounds the vagina and pubourethralis surrounds the urethra. Both are parts of pubococcygeus subdivision of levator ani.

7. **Give the length of uterine cavity. How is it measured?**

The length of the uterine cavity, (cavity of body plus cervical canal) from the wall of fundus to the external os is 6 cm. It is measured by an instrument called uterine sound.

8. **What is the development of uterus and name a few of its congenital anomalies.**

The uterus develops from uterovaginal canal, which is formed by fusion of caudal vertical parts of paramesonephric or Mullerian ducts.

The congenital anomalies of uterus are listed below.

i. Mullerian agenesis (Rokitansky syndrome) results in agensis of fallopian tube, uterus and vagina.

ii. Uterus didelphys consists of complete duplication of uterus, cervix and vagina. This is due to failure of fusion of right and left paramesonephric ducts.

iii. Uterus bicornis bicollis is characterized by double uterus and cervix but single vagina. This results due to failure of fusion of caudal ends of paramesonephric ducts.

iv. Unicorneate uterus results due to unilateral suppression of paramesonephric duct.

v. Septate uterus shows incomplete septum inside the uterine cavity.

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**CASE 15**

A 45-year-old woman was admitted to the hospital with complaints of dull and intermittent pain in both flanks and passage of blood clots in urine. On examination there was fullness in both flanks and kidneys were enlarged, which was confirmed on ultrasound examination. Intravenous pyelography confirmed the diagnosis of bilateral polycystic kidney.

**Questions and Solutions**

1. **Name the developmental sources of permanent kidney.**

The nephrons (secretory part of kidney) develop from metanephric blastema and the collecting part of the kidney develops from ureteric diverticulum of mesonephric duct.

2. **Give the embryological explanation of multiple cyst formation in polycystic kidney?**

There is failure of the process of luminal continuity between the developing nephrons and the collecting tubules during nephrogenesis. So, the urine that is secreted by the nephrons accumulates in them for want of outlet. Thus, the nephrons undergo cystic enlargement.

3. **What is the embryological explanation of pelvic kidney?**

A kidney located in pelvis (instead of lumbar region) is known as pelvic kidney. It may be unilateral or bilateral. This occurs due to arrest of the process of ascent of embryonic kidney, which begins development in sacral region. The ascent of the low placed embryonic kidney is achieved by differential growth of the body wall.

4. **What is the position of the suprarenal gland if the kidney is arrested in its ascent?**

The suprarenal gland develops in its normal position irrespective of the position of kidney.

5. **What is horseshoe kidney?**

A horseshoe kidney is the one that resembles a horseshoe in shape. In this case the lower poles of the two kidneys are connected by an isthmus, which usually lies anterior to aorta and IVC.

6. **Name the blood vessel, which prevents the ascent of the horseshoe kidney?**

The inferior mesenteric artery (lowest midline ventral branch of abdominal aorta) prevents the ascent of horseshoe kidney.
7. Describe the juxtaglomerular apparatus.

The juxtaglomerular apparatus is located near the glomerulus and consists of three parts, macula densa, juxta- medullary cells and mesangial cells of glomerulus. The macula densa and juxtaglomerular cells are the modified cells of closely related DCT and afferent arteriole. The modified DCT cells that acquire secretory granules are called macula densa. The adjacent smooth muscle cells of afferent arteriole become epitheloid and are called juxtaglomerular cells. The cells of macula densa are sensitive to sodium level in the fluid in DCT. Low sodium level activates the macula densa to secrete some substances which activate juxtaglomerular cells to secrete renin. The renin helps in regulation of blood pressure.

6. Name the surgical procedure that prevents fertilization in female.

Tubectomy prevents fertilization.

CASE 16

A 26-year-old woman with acute pain in the lower abdomen was rushed to the hospital in a state of shock. A history of two missed periods suggested early pregnancy. The abdominal wall showed tenderness and guarding. Ultrasound revealed empty and enlarged uterus and fluid in the pouch of Douglas.

Questions and Solutions

1. Name the structure that is ruptured in the above case giving the cause of the rupture.

The fallopian tube is ruptured due to tubal pregnancy.

2. What is the normal site of fertilization?

Normal site of fertilization is ampulla of fallopian tube.

3. Give the normal length and name the parts of the affected structure.

Normal length of fallopian tube is 10 cm. Its parts from ovarian end are, infundibulum, ampulla, isthmus and intramural.

4. What is the reason of tenderness and muscle guarding in the abdominal wall?

Due to rupture of fallopian tube there is hemorrhage in the peritoneal cavity including in the pouch of Douglas. There is irritation of parietal peritoneum, which results in tenderness and muscle guarding.

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CASE 17

A 75-year-old man had a one-year history of difficulty and frequency in micturition. Per rectum examination confirmed the enlargement of prostate. Investigations ruled our cancer of prostate.

Questions and Solutions

1. What is the probable diagnosis?

Benign hypertrophy of prostate (BPH)

2. Describe the age changes in the affected organ.

In childhood the prostate is small and is composed of fibromuscular stroma and rudiments of ducts. At puberty there is sudden increase in size under the influence of testosterone. There is proliferation of prostatic follicles, which begin to secrete acid phosphatase, prostate specific antigen and prostaglandins. During third decade of life there is irregular epithelial infoldings in the lumen of follicles. During fourth decade formation of amyloid concretions in the follicles begins. After 50 years the prostate may show gradual benign hypertrophy or progressive atrophy.

3. What is uvula vesicae?

The bulge produced by the median lobe of prostate on the apex of trigone of urinary bladder is called uvula vesicae.

4. Describe the capsules and relations of the affected organ.

Refer to chapter 88.

5. Name the embryological remnants inside this organ.

The embryological remnants inside the prostate are found in the prostatic urethra. An elevation in the middle part of the urethral crest on the posterior wall of prostatic urethra is known as colliculus seminalis (verumontanum). This is a remnant of Mullerian or sinus tubercle. The prostatic utricle (uterus masculinus) opens on this elevation in the midline. It is a remnant of paramesonephric ducts.
6. By which route the cancer cells from this organ spread to the vertebral column?

The communications of the pelvic venous plexuses with the internal vertebral venous plexuses (Batson’s vertebral venous plexus) is responsible for deposits of malignant cells from the prostate into the vertebral column.

CASE 18

A 30-year-old man was brought to the casualty with a bleeding stab wound in left loin. There was marked swelling in the left renal angle. Plain X-ray of abdomen revealed fracture of left 11th and 12th ribs. Urine specimen showed frank blood.

Questions and Solutions

1. Which organ (give its side) is injured?
   Left kidney

2. Give the relations of anterior surface of this organ.
   Refer to Figure 85.8.

3. Describe the coverings of this organ.
   Coverings of kidney from inner to outer side are true capsule, perinephric fat, fascial capsule and paranephric fat. The fascial capsule (fascia of Gerota) provides a common covering for the kidney and the suprarenal gland. It anterior layer is called fascia of Toldt and posterior layer is called fascia of Zuckerkandl. On horizontal tracing the anterior and posterior layers fuse along the lateral margin of kidney. Medially the anterior layer passes in front of the renal vessels to become continuous with the corresponding layer of the opposite side in front of the aorta and IVC. The posterior layer blends with psoas fascia and is attached to the bodies of lumbar vertebrae. On vertical tracing, superiorly the two layers fuse above the suprarenal gland, where they are continuous with diaphragmatic fascia. Anterior and posterior layers are joined to each other by a septum, which separates kidney and suprarenal gland. Inferiorly fascial capsule is open since its two layers continue downward along the ureter to merge with fascia iliaca. In nephroptosis (dropped kidney) kidney is displaced downwards from its normal position due to the opening in the fascial capsule. The renal vessels alone form the support to the kidney. This may give rise to kinking of ureter and consequent urinary obstruction. Another importance of the lower opening of the fascial capsule is that perinephric abscess may track down along the ureter into the pelvic cavity.

4. What is renal angle?

It is the angle between the lower margin of twelfth rib and lateral margin of erector spinae muscle. At this angle the kidney lies close to the surface. The renal pain is felt at the renal angle as dull ache. The lower margin of pleura crosses the renal angle. Therefore upper end of skin incision for approaching kidney by lumbar route must begin below the renal angle.

5. Name the anatomical structures that are encountered in succession in surgical approach to this organ by lumbar route.
   i. The skin
   ii. The superficial fascia
   iii. The deep fascia
   iv. Posterior layer of lumbar fascia from which originate the latissimus dorsi and serratus posterior inferior muscles
   v. Separate the plane between the latissimus dorsi and external oblique aponeurosis forcibly.
   vi. Middle layer of lumbar fascia
   vii. Quadratus lumborum muscle
   viii. Anterior layer of lumbar fascia with subcostal nerve and vessels, iliohypogastric nerve an ilioin guinal nerve.
   ix. Paranephric fat
   x. Fascia of Zuckerkandl
   xi. Perinephric fat

CASE 19

A 2-month-old male child was brought to the hospital because the mother noticed that the left scrotum of the boy was empty. On examination it was noticed that the right testis was in the scrotum. A swelling of 1.5 cm diameter was noted in the left inguinal region. On ultrasound examination it was confirmed that the left testis was in inguinal canal.

Questions and Solutions

1. Mention two common conditions resulting in empty scrotum in newborn.

   Undescended testis (Cryptorchidism) and ectopic testis are the common causes of empty scrotum in newborn.

2. Describe the process of descent of testis including the chronology.

   Refer to chapter 88.
3. What is the cause of empty scrotum in above case?
Cryptorchidism or undescended testis is the cause.

4. Give the fate of the structures responsible for descent of testis.
   i. The processus vaginalis, which is a peritoneal pouch preceding the testis forms the tunica vaginalis testis at its distal end. The remaining part of processus vaginalis is obliterated and reduced to a fibrous remnant in the spermatic cord.
   ii. The gubernaculum testis is shortened and becomes the scrotal ligament, which attaches the lower pole of the testis to the scrotal wall.

5. Differentiate between the lymphatic drainage of testis and scrotum.
The lymphatics of the testis drain into the lateral aortic nodes or para-aortic nodes and those of scrotum into the superficial inguinal nodes.

6. What is anteversion and inversion of testis?
Refer to chapter 88 (Fig. 88. 12B).

CASE 20
A 32-year-old man presented with the complaint of dragging feeling in the left side of scrotum. On examination of scrotum, the surgeon could feel the normal testis. Palpation of the spermatic cord gave “bag of worms” feeling to the examining fingers.

Questions and Solutions

1. Name the blood vessels, which when dilated give the feeling of bag of worms on palpation.
The dilated pampiniform plexus gives “bag of worms” feeling.

2. What is this condition called and on which side it is more common?
This condition is called varicocele and it is more common on left side.

3. What is the extent and length of the spermatic cord?
The spermatic cord extends from the superior pole of the testis to the deep inguinal ring. Its length is about 7.5 cm.

4. Give the extent and length of the vas deferens.
The vas deferens extends from the tail of epididymis to the ejaculatory duct. Its length is 45 cm.

5. Give the constituents of spermatic cord.
For constituents of the spermatic cord refer chapter 88.

6. How are the coverings of the spermatic cord derived?
The spermatic cord has three concentric coverings. The external spermatic fascia is derived from external oblique aponeurosis. The cremaster muscle and fascia are derived from internal oblique muscle and internal spermatic fascia is derived from fascia transversalis.

7. At what point does the pampiniform plexus become the testicular vein?
The pampiniform plexus becomes the testicular vein at the deep inguinal ring.

8. Where does the left testicular vein drain?
The left testicular vein drains into left renal vein.
1. Which dermatome overlies the pubic symphysis?
   a. T11
   b. T12
   c. L1
   d. L2.

2. Surgeon’s guide to the base of vermiform appendix during appendicectomy is:
   a. Mesoappendix
   b. Anterior tenia coli of cecum
   c. Terminal ileum
   d. McBurney’s point

3. Which of the following is the bilateral tributary of inferior vena cava?
   a. Hepatic
   b. Ovarian
   c. Suprarenal
   d. Renal

4. Which of the following nerves is called nervus furcalis?
   a. L3
   b. L4
   c. L5
   d. S1

5. Which of the following organs develops from a different germ layer than the rest?
   a. Liver
   b. Pancreas
   c. Spleen
   d. Stomach

6. A baby was born with a transparent swelling at the umbilicus. The umbilical cord was attached to the swelling. This anomaly is called:
   a. Gastrochisis
   b. Spigelian hernia
   c. Littre’s hernia
   d. Omphalocele

7. The anterior abdominal muscles actively contract in
   a. Normal expiration
   b. Forced expiration
   c. Forced inspiration
   d. Normal inspiration

8. The inferior margin of the aponeurotic posterior wall of rectus sheath is called:
   a. Falx inguinalis
   b. Linea alba
   c. Arcuate line
   d. Linea semilunaris

9. In the suprapubic incision for Caesarian section all the following are cut except:
   a. Anterior wall of rectus sheath
   b. Posterior wall of rectus sheath
   c. Transversalis fascia
   d. Rectus abdominis muscle

10. Which nerve is injured in a man who developed meralgia parasthetica after an operation on inguinal hernia?
    a. Genitofemoral
    b. Lateral cutaneous nerve of thigh
    c. Iliohypogastric
    d. Ilioinguinal

11. The vermiform appendix is characterized by:
    a. Mesentery
    b. Sacculations
    c. Taenia coli
    d. Appendices epiploicae

12. What is true about rectus abdominis muscle?
    a. Tendinous insertion
    b. Fleshy origin
    c. Attached posteriorly to rectus sheath
    d. Flexor of vertebral column

13. Which of the following pelvic organs is not related to obturator internus muscle?
    a. Rectum
    b. Pelvic appendix
    c. Ovary
    d. Urinary bladder

14. Which of the following vessels is not a content of spermatic cord?
    a. Testicular artery
    b. Testicular vein
    c. Artery to vas deferens
    d. Cremasteric artery
15. The rectum begins in front of the following vertebra
   a. S2  
   b. S3  
   c. S4  
   d. S5  

16. Which of the following is called external spermatic artery?
   a. Testicular  
   b. Deferential  
   c. Accessory obturator  
   d. Cremasteric  

17. Which of the following nerves is not related to obturator internus muscle below the level of arcus tendinous?
   a. Pudendal nerve  
   b. Dorsal nerve  
   c. Perineal nerve  
   d. Obturator nerve  

18. The transpyloric plane corresponds to the following except:
   a. Lower part of the hilum of right kidney  
   b. Origin of inferior mesenteric artery  
   c. Lower end of spinal cord  
   d. Fundus of gallbladder  

19. The center of the portal lobule is indicated by following structure
   a. Central vein  
   b. Space of Disse  
   c. Portal acinus  
   d. Portal triad  

20. Sphincter of Oddi consists of following number of smaller sphincters
   a. 2  
   b. 3  
   c. 5  
   d. 6  

21. The ascent of horseshoe kidney is arrested by
   a. Celiac ganglia  
   b. Median sacral artery  
   c. Inferior mesenteric artery  
   d. Cisterna chyli  

22. Which of the following subphrenic spaces is called Morison’s hepatorenal pouch?
   a. Right anterior intraperitoneal  
   b. Right posterior intraperitoneal  

23. Physiological umbilical herniation of midgut loop begins normally at following week
   a. Fifth  
   b. Ninth  
   c. Tenth  
   d. Twelfth  

24. Couinaud’s hepatic segment IV corresponds to
   a. Left lobe to the left of falciform ligament  
   b. Fossa for gallbladder  
   c. Caudate lobe  
   d. Quadrante lobe  

25. In congenital megacolon there is no development of
   a. Sympathetic ganglia in narrowed segment  
   b. Parasympathetic ganglia in narrowed segment  
   c. Sympathetic ganglia in dilated segment  
   d. Parasympathetic ganglia in dilated segment  

26. The lymphatics of cervix uteri drain into the following lymph node.
   a. Superficial inguinal  
   b. Deep inguinal  
   c. Internal iliac  
   d. Preaortic  

27. Which of the following organs is present in Mullerian agenesis syndrome?
   a. Uterus  
   b. Uterine tube  
   c. Ovary  
   d. Vagina  

28. Which of the following develops from septum transversum?
   a. Lesser omentum  
   b. Greater omentum  
   c. Phrenicocolic ligament  
   d. Suspensory ligament of Treitz  

29. Which is the longest part of fallopian tube?
   a. Intramural  
   b. Isthmus  
   c. Ampulla  
   d. Infundibulum  

30. What is true about the suprarenal medulla?
   a. Develops from mesoderm  
   b. Essential for life  

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Clinicoanatomical Problems and Solutions 811

Chapter 15.
31. The external trigone of urinary bladder is related posteriorly to:
   a. Prostate
   b. Seminal vesicle
   c. Urethra
   d. Rectum

32. The inferior vena cava begins at the level of:
   a. Sacral promontory
   b. L5
   c. L4
   d. L3

33. The membranous layer of superficial fascia of perineum is called:
   a. Fascia lunata
   b. Colles fascia
   c. Scarpas fascia
   d. Camper's fascia

34. The pacemaker for ureteric peristalsis is located in:
   a. Minor calyces
   b. Major calyces
   c. Pelvis
   d. Pelviureteric junction

35. A young woman presented in a gynecology outpatient department with a cystic swelling on one side of the vestibule. Which structure is affected?
   a. Perineal body
   b. Bartholin's gland
   c. Urethral meatus
   d. Bulb of the vestibule

36. Which of the following joints is not of secondary cartilaginous type?
   a. Lumbosacral
   b. Pubic symphysis
   c. Sacroccygeal
   d. Sacroiliac

37. Which of the following is not a retroperitoneal structure?
   a. Pancreas
   b. Celiac trunk
   c. Appendix
   d. Cisterna chyli

38. Which of the following pairs is correctly associated?
   a. Bulbourethral gland—Deep perineal pouch
   b. Sphincter urethrae—Superficial perineal pouch
   c. Greater vestibular glands—Deep perineal pouch
   d. Bulbs of the vestibule—Deep perineal pouch

39. What is not true about trigone of urinary bladder?
   a. Endodermal origin
   b. Lacks submucosa
   c. Highly sensitive
   d. Transitional epithelium

40. The germinal epithelium of ovary
   a. Produces new germ cells
   b. Produces ovarian stroma
   c. Is continuous with peritoneum
   d. Develops from endoderm

41. An old woman with cancer of ovary had difficulty in adduction of hip joint and sensory loss on the medial side of thigh. Which of the following nerves is infiltrated with cancer?
   a. Sciatic nerve
   b. Femoral nerve
   c. Lumbosacral trunk
   d. Obturator nerve

42. The pelvic splanchnic nerves carry the following fibers:
   a. Preganglionic sympathetic
   b. Postganglionic sympathetic
   c. Preganglionic parasympathetic
   d. Postganglionic parasympathetic

43. The ureter is related to the following bony parts except:
   a. Anterior superior iliac spine
   b. Ischial spine
   c. Sacroiliac joint
   d. Tips of lumbar transverse processes

44. Which of the following is known as coccygeus?
   a. Puborectalis
   b. Ischiococcygeus
   c. Pubococcygeus
   d. Iliococcygeus

45. The urogenital diaphragm is composed of all the following except:
   a. Superior fascia of urogenital diaphragm
   b. Perineal membrane
   c. Muscles of deep perineal pouch
d. Colles’ fascia

46. The hypospadias occurs due to:
   a. Undescended testis
   b. Ectopic testis
   c. Nonfusion of genital folds
   d. Incomplete fusion of genital folds

47. What is not true regarding anal canal?
   a. Pierces urogenital diaphragm
   b. Develops from endoderm and ectoderm
   c. Pecten is of bluish color
   d. Pectinate line is a watershed line

48. Female urethra developmentally corresponds to following part of male urethra:
   a. Membranous urethra
   b. Lower part of prostatic urethra
   c. Bulbar urethra
   d. Upper part of prostatic urethra

49. Juxtaglomerular cells are modified cells of following structure:
   a. Distal tubule
   b. Afferent arteriole
   c. Efferent arteriole
   d. Proximal tubule

50. Which discontinuous dermatomes meet at junction of anterior one third and posterior two third of scrotum?
   a. L1 and S3
   b. L2 and S3
   c. L1 and S4
   d. L2 and S4

KEY TO MCQs
1-c, 2-b, 3-d, 4-b, 5-c, 6-d, 7-b, 8-c, 9-b, 10-b, 11-a, 12-d, 13-a, 14-d, 15-b, 16-d, 17-d, 18-b, 19-d, 20-b, 21-c, 22-b, 23-b, 24-a, 25-b, 26-c, 27-c, 28-a, 29-c, 30-d, 31-d, 32-b, 33-b, 34-a, 35-b, 36-d, 37-c, 38-a, 39-a, 40-c, 41-d, 42-c, 43-a, 44-d, 45-d, 46-d, 47-a, 48-d, 49-b, 50-a.
LOWER LIMB
LOWER LIMB

The skeleton of lower limb is subdivided into hip bone and the bones of free lower limb (Fig. 91.1). The right and left hip bones together with sacrum and coccyx form the skeleton of pelvis (bony pelvis). While in standing position, the weight of the body is transmitted from the vertebral column bilaterally to the hip bones, hip joints, femurs, knee joints, tibias, ankle joints and the bones of the feet in succession.

Hip Bone or Innominate Bone

The hip bone is an irregular bone made up of three components, the ilium, pubis and ischium, which are united to each other at the acetabulum.

Articulations of Hip Bone

i. Pubic symphysis between the pubic bones.
ii. Sacroiliac joint between the sacrum and ilium.
iii. Hip joint between the acetabulum and the head of femur.

Anatomical Position

To hold the hip bone in anatomical position, one has to see that the pubic tubercle and anterior superior iliac spine lie in the same coronal plane. In this position, the pelvic surface of the body of pubis faces posterosuperiorly and the medial surface of the body of pubis lies in the midline.

Acetabulum

It is a cup-shaped cavity facing laterally and directed towards the lower limb. The ilium (two-fifth), ischium (two fifth) and pubis (one-fifth) take part in its formation. It presents a horse shoe shaped articular surface and a nonarticular acetabular fossa (where a pad of fat is located). At birth, the acetabulum presents Y-shaped cartilage (demarcating the three components of hip bone). By the age of puberty, two secondary centers appear in this cartilage to complete the ossification of acetabulum by seventeen years. From this, it is understood that if the acetabulum is fractured before the age of 17 it breaks into three pieces.

Obturator Foramen

It is a gap in the lower part of the hip bone. It is located between pubis and ischium. The obturator membrane fills the gap in the living. The membrane also bridges the obturator groove to convert it into obturator canal for the passage of obturator nerve and vessels.

Ilium

The ilium consists of upper end (iliac crest), lower end, three margins (anterior, posterior and medial) and three surfaces (iliac fossa, gluteal surface and sacropelvic surface).

Iliac Crest

i. It is the curved upper end of ilium extending from the anterior superior iliac spine (ASIS) to the posterior
superior iliac spine (PSIS). It is subcutaneous in its entire extent.
ii. The tubercle of the iliac crest lies about five centimeter behind the anterior end of the iliac crest on its outer lip. The transtubercular plane passes through the upper margin of L5 vertebra.

iii. The suprasicrinal plane passes through the highest points of iliac creasts (between the spines of third and fourth lumbar vertebrae). This plane is used to determine the site of lumbar puncture.

Subdivisions of Iliac Crest
The iliac crest is divisible into ventral segment (anterior two-third) and dorsal segment (posterior one-third). The ventral segment is further divided into inner lip, intermediate area and outer lip. The dorsal segment is divisible into outer slope and inner slope.

Attachments to Ventral Segment (Fig. 91.2A)
- i. The outer lip of ventral segment gives origin to tensor fasciae latae in front of the iliac tubercle, gives insertion to external oblique abdominis in its anterior two-third and origin to latissimus dorsi in its posterior one-third (part of the iliac crest between the external oblique and latissimus dorsi forms the base of lumbar triangle).
- ii. The intermediate area gives origin to internal oblique abdominis.
- iii. The inner lip gives origin to transversus abdominis in anterior two-third and to quadratus lumborum in posterior one-third (Fig. 91.2B).

Structures Attached to Dorsal Segment
- i. The outer slope gives origin to gluteus maximus.
- ii. The inner slope gives origin to erector spinae.

Anterior Border
- i. The anterior superior iliac spine gives origin to sartorius and attachment to inguinal ligament.
- ii. The anterior inferior iliac spine gives origin to straight head of rectus femoris and attachment to iliofemoral ligament.

Posterior Border
The posterior superior iliac spine lies subjacent to the skin dimple called dimple of Venus (well marked in female) in the upper part of the gluteal region. It corresponds to the spine of second sacral vertebra (level with lower end of subarchnoid space). This site is used to draw bone marrow from the iliac crest for studying the cells of bone marrow.

Greater Sciatic Notch
The greater sciatic notch with the help of sacrotuberosus and sacrospinous ligaments forms the greater sciatic foramen, which gives passage to the piriformis muscle with following intrapelvic nerves and vessels.
i. The superior gluteal nerve and vessels pass above the piriformis.

ii. The inferior gluteal nerve and vessels, posterior cutaneous nerve of thigh, sciatic nerve, nerve to quadratus femoris, internal pudendal vessels, pudendal nerve and nerve to obturator internus pass below the piriformis.

Medial Border

The posterior one-third is rough; the middle-third is sharp and the anterior third forms arcuate line, which is continuous with pecten pubis at iliopubic eminence. The linea terminalis (lateral boundary of pelvic inlet) is composed of arcuate line, pecten pubis and pubic crest. Some structures cross it to enter the lesser pelvis (internal iliac vessels, ureter, ovarian vessels in female and vas deferens in male). The round ligament of uterus also crosses the linea terminalis to leave the lesser pelvis.

Surfaces of Ilium

1. The iliac fossa is located on the inner aspect of ilium. It gives origin to iliacus muscle.

2. The sacropelvic surface is located on inner aspect of ilium behind the medial margin.

   i. It is composed of sacral part dorsally and pelvic part ventrally.

   ii. The sacral part presents the auricular surface covered with articular cartilage and non-articular area (iliac tuberosity). The auricular surface articulates with sacrum at sacroiliac joint.

   iii. The iliac tuberosity gives attachment to iliolumbar ligament, dorsal sacroiliac ligament and interosseous sacroiliac ligament.

   iv. The smooth pelvic surface presents preauricular sulcus, which is well marked in female. This sulcus gives attachment to ventral sacroiliac ligament.

3. The gluteal surface is divided into four areas by posterior, anterior and inferior gluteal lines from behind forwards.

   i. The gluteus maximus takes origin from the area behind the posterior gluteal line.

   ii. The gluteus medius takes origin between posterior and anterior gluteal lines.
iii. The gluteus minimus takes origin between anterior and inferior gluteal lines.

iv. The reflected head of rectus femoris take origin from the area between inferior gluteal line and margin of acetabulum.

**Ischium**

This part of hip bone consists of a thick body and a ramus. The body presents two ends (upper and lower), three borders (anterior, posterior and lateral) and three surfaces (femoral, dorsal and pelvic).

i. The upper end of the body is united with ilium and pubis in the formation of acetabulum.

ii. The dorsal part of the upper end is in direct contact with the sciatic nerve.

iii. The lower end of the body forms the ischial tuberosity. The ischial ramus joins with the inferior ramus of pubis to form ischiopubic ramus (refer to description of pubis to know more about ischiopubic ramus).

**Relations of Ischial Tuberosity**

The lower part of the smooth pelvic aspect of the ischial tuberosity is related to the lateral wall of the ischiorectal fossa (pudendal or Alcock's canal). In pudendal nerve block by perineal approach, the needle is inserted along the medial side of ischial tuberosity for the depth of about four centimeter to reach the pudendal canal.

**Attachments to Ischial Tuberosity**

i. The sacrotuberous ligament is attached to its medial margin.

ii. The quadratus femoris muscle takes origin from its lateral margin.

iii. Its gluteal surface is divided by a transverse ridge into upper quadrangular and lower triangular areas. The upper area is unequally divided by an oblique line into a superolateral area for origin of semimembranosus and the superomedial area (placed at lower level compared to the superolateral area) for the origin of semitendinosus and long head of biceps femoris. A
vertical line divides the lower area into a larger lateral area (for origin of ischial part of adductor magnus) and smaller medial area, which is covered with fibrofatty tissue since this area comes in contact with the ground in sitting position. The ischial bursa intervenes between the ischial tuberosity and the gluteus maximus. The inflammation of this bursa is called weaver's bottom.

**Ischial Spine**
The posterior margin of the body presents the ischial spine, which demarcates the greater sciatic foramen from the lesser sciatic foramen.

**Relations and Attachments of Ischial Spine**

i. The sacrospinous ligament is attached to its apex.

ii. The coccygeus and most posterior fibers of levator ani muscle take origin from its pelvic surface. The ureter is related to its pelvic surface.

iii. The internal pudendal vessels and nerve to obturator internus cross its dorsal surface.

In pudendal nerve block by vaginal approach, the ischial spine is the landmark as the pudendal nerve crosses the dorsal aspect of the sacrospinous ligament near the apex of the ischial spine.

**Lesser Sciatic Notch**

i. The superior and inferior gemelli arise from the respective margins of the notch.

ii. The lesser sciatic notch is converted into lesser sciatic foramen by sacrospinous and sacrotuberous ligaments.

iii. The structures passing through the foramen are tendon of obturator internus, nerve to obturator internus, internal pudendal vessels and pudendal nerve.

**Pubis**
The pubis is placed in the anterior part of the hip bone. It consists of the body and superior and inferior rami.

**Body of Pubis**
The body of pubis has pubic crest, pubic tubercle and three surfaces (anterior, posterior and medial).

**Pubic Crest**

i. The upper palpable margin of the body of pubis is called pubic crest. The conjoint tendon is attached to the pubic crest. The rectus abdominis and pyramidalis take origin from it.

ii. The rounded lateral end of the pubic crest is called pubic tubercle, which is a very important bony landmark. The medial end of inguinal ligament is attached to the pubic tubercle. It is partly covered in male by spermatic cord. The hernia that is superomedial to this tubercle is inguinal hernia and the one that is inferolateral to it is femoral hernia.

**Surfaces**

i. The posterior or pelvic surface is related to urinary bladder. This explains involvement of urinary bladder in fracture of the body of pubis. The posterior surface gives origin to pubococcygeus part of levator ani.

ii. The medial surface is known as symphyseal surface because it takes part in pubic symphysis.

iii. The anterior surface gives origin to a number of muscles. The adductor longus takes origin by rounded tendon from the angle between pubic crest and pubic symphysis. The gracilis takes origin along the lower margin of this surface and adductor brevis is attached above the gracilis.

**Superior Ramus**

It is located just above the obturator foramen. It presents three borders (obturator crest, pectineal line and inferior) and three surfaces (pectineal, pelvic and obturator).

**Borders**

i. The pectineal line or pecten pubis is sharp. It extends from pubic tubercle to the iliopubic eminence and provides attachments to conjoint tendon, lacunar ligament and the pectineus muscle.

ii. The anterior border is called obturator crest. It extends from the pubic tubercle to the acetabular notch.

iii. The inferior border is sharp and takes part in the formation of obturator foramen.

iv. Shenton's line is formed by inferior margin of the superior ramus and the medial (lower) margin of femoral neck. It is a smoothly curved line seen in normal radiographs of hip bone.

**Surfaces**

i. The pectineal surface is bounded by obturator crest and pectineal line. It gives origin to pectineus muscle.

ii. The pelvic surface is located between pectineal line and the inferior border. It is related to ductus deferens in male and to round ligament of uterus in female.

iii. The obturator surface is located between obturator crest and inferior border. The obturator groove is
present here. The obturator nerve and vessels exit from the pelvis into the thigh through the obturator canal.

**Inferior Ramus**

It extends from the body of pubis to the ischial ramus, medial to the obturator foramen. The two rami unite to form conjoint ischiopubic ramus. The fusion of the ischial and pubic rami occurs by the age of six to eight years.

**Conjoint Ischiopubic Ramus**

It has two borders (superior and inferior) and two surfaces (outer and inner).

**Borders**

i. The obturator membrane is attached to the upper border.

ii. The lower border of the conjoint ramus is everted in males. It provides attachment to fascia lata and membranous layer of superficial fascia of perineum (Colles’ fascia).

**Surfaces**

1. The inner surface is smooth. It forms the lateral limit of the urogenital triangle of the perineum. This surface is divided into three areas by attachment of two fascial layers, namely, superior fascia of urogenital diaphragm and inferior fascia of urogenital diaphragm (perineal membrane).
   i. The uppermost area gives origin obturator internus (intrapelvic muscle).
   ii. The intermediate area gives origin to muscles of deep perineal pouch (sphincter urethrae in front and deep transversus perinei behind).
   iii. The lower area gives attachment to crus of clitoris or penis in front, ischiocavernosus muscle around the crus and superficial transversus perinei muscle behind.

2. The outer surface gives attachments to adductor magnus, adductor brevis and gracilis. It also gives origin to obturator externus.

**Femur (Fig. 91.3A)**

The femur is the longest and strongest bone in the body. Its length is one-fourth of the height of the individual (approximately 45 cm in a six feet person).

**Articulations of Femur**

The femur articulates with hip bone at hip joint and with patella and tibia at knee joint.

**Parts**

The femur consists of upper end, shaft and lower end.
vi. The anterior surface of neck is marked with longitudinal grooves (produced by the retinacular arteries) and numerous vascular foramina.

Greater Trochanter
The greater trochanter is a large projection from lateral aspect of the upper end of femur. It presents upper border and three surfaces (anterior, lateral and medial).

Clinical insight...
The neck is liable to fractures by slightest trauma (usually in postmenopausal women) because of the osteoporotic changes in the bones. The fracture may be intracapsular or extracapsular.

i. In intracapsular fracture, the proximal fragment loses part of its blood supply hence the union of this fracture is difficult. The injured limb lies in the position of lateral rotation and the leg is shortened. The shaft of femur carrying the trochanters is laterally rotated (by lateral rotators of thigh and psoas major) and is elevated due to the upward pull of rectus femoris, hamstring and adductor muscles on the injured side.

ii. In extracapsular fracture of the neck, the blood supply to the proximal fragment is retained, hence, there is no avascular necrosis of head.

Shenton’s Line (Fig. 91.3B)
It is a radiologically visible line. It is a smoothly curved line (concavity facing downwards) formed by the lower margin of the neck and the lower margin of the superior ramus of pubis. In fracture of the neck, femoral the Shenton’s line is distorted.

Lesser Trochanter
It is a smaller conical projection from posteromedial part of the upper end of femur. It gives insertion to iliopsoas tendon.

Inter trochanteric Line
It gives attachment to capsule of hip joint in its entire extent and upper and lower bands of iliofemoral ligament to its upper and lower parts.

Inter trochanteric Crest
It connects the two trochanters posteriorly. It shows a rounded quadrate tubercle above its middle point. The quadratus femoris is inserted into this tubercle.

Attachments of Capsule of Hip Joint
The capsule of the hip joint is attached anteriorly to the intertrochanteric line. It is attached posteriorly to the middle of the neck of femur because of which posterior surface of neck is partly intracapsular and partly extracapsular.

Shaft of Femur
i. The cylindrical shaft of femur is divisible into upper, middle and lower thirds.

ii. The shaft is convex forwards because the line of gravity of the body passes behind the hip joint and in front of the knee joint. The weakness caused by the forward convexity of the shaft is compensated by linea aspera (a thickened ridge) on the posterior aspect of middle-third of the shaft.

iii. The middle-third of shaft presents three borders medial, lateral and posterior. The posterior border is called linea aspera, which shows medial and lateral lips (enclosing a narrow intermediate area). The borders enclose three surfaces (anterior, medial and lateral).

iv. The upper one-third of shaft shows following features. The medial lip of the linea aspera continues as
spiral line and lateral lip as gluteal tuberosity. The spiral line and gluteal tuberosity enclose the posterior surface (which is the fourth surface on upper one-third).

v. The gluteal tuberosity is a rough linear impression on the lateral edge posterior surface. If there is a conical projection from the gluteal tuberosity it is called third trochanter.

vi. The lower one-third of shaft also has four surfaces like the upper one-third. At the lower end of linea aspera the lateral lip continues as lateral supracondylar line and medial lip as medial supracondylar line. The supracondylar lines enclose the popliteal surface on the lower one-third of the shaft.

vii. The lateral supracondylar line ends in lateral epicondyle. The medial supracondylar line is interrupted, where the femoral vessels cross it (at the lowest osseous-aponeurotic opening). It reappears below this point and ends in adductor tubercle.

**Attachment of Intermuscular Septa to Shaft**
The medial and lateral intermuscular septa (derived from fascia lata) are attached to medial and lateral lips of linea aspera and also to the respective supracondylar ridges. The posterior intermuscular septum is attached to the intermediate line on the linea aspera.

**Muscular Attachments to Shaft**
i. Vastus intermedius arises from upper three-fourth of anterior and lateral surfaces and articularis genu arises below the vastus intermedius.

ii. Vastus lateralis has linear origin commencing at upper end of intertrochanteric line, adjacent greater trochanter, gluteal tuberosity to upper half of lateral lip of linea aspera.

iii. Vastus medialis shows linear origin from lower end of intertrochanteric line, spiral line, medial lip of linea aspera and upper one-fourth of medial supracondylar ridge.

**Attachments to Posterior Aspect of Shaft (Fig. 91.3C)**
i. The gluteal tuberosity gives attachment to deep fibers of gluteus maximus.

ii. The pectineus has linear origin from lesser trochanter to upper end of spiral line.

iii. Adductor brevis has linear insertion into intermediate part of linea aspera starting from the level of lesser trochanter and extending to the upper half of linea aspera.

iv. Adductor longus is inserted into medial lip of linea aspera.

v. Adductor magnus (adductor part) has a long linear origin starting below the attachment of quadratus femoris and extending on gluteal tuberosity, linea aspera and medial supracondylar ridge.

vi. Adductor magnus (ischial part) is inserted into adductor tubercle.

vii. Short head of biceps femoris arises from lateral lip of linea aspera medial to attachment of lateral intermuscular septum.

(To sum up-the attachments of linea aspera from lateral to medial side are, vastus lateralis, lateral intermuscular septum, short head of biceps femoris, adductor magnus, adductor brevis, adductor longus, medial intermuscular septum and vastus medialis).

viii. The origins of medial head of gastrocnemius, lateral head of gastrocnemius and plantaris from lower end of shaft are shown in Figure 91.3C.

**Lower End**
The lower end of the femur bears two large condyles (medial and lateral), which are separated by an intercondylar notch or fossa on posterior aspect. The anterior surface of lower end bears patellar articular area. The anterior, inferior and posterior surface of the condyles are covered with articular cartilage for articulating with superior surface of tibia.
Bones of Lower Limb

Chapter 825

Medial Condyle
i. The medial epicondyle is the most prominent point on the medial condyle. The tibial collateral ligament is attached to it.
ii. Above and behind the medial epicondyle, the medial condyle presents adductor tubercle, which is a palpable landmark. The lower epiphyseal line passes through the adductor tubercle. Any injury to the epiphyseal plate (during childhood) will shorten the limb.
iii. The lateral surface of medial condyle forms the medial boundary of intercondylar notch.

Lateral Condyle
i. The lateral epicondyle is the point of most prominent point on the lateral epicondyle. It gives attachment to fibular collateral ligament.
ii. A smooth impression above and behind the lateral epicondyle gives origin to lateral head of gastrocnemius.
iii. The groove below and behind the lateral epicondyle gives origin to popliteus.
iv. Its medial surface forms the lateral boundary of intercondylar notch.

Intercondylar Notch
The intercondylar notch is intracapsular in location. The anterior cruciate ligament is attached to the posterior part of the inner surface of lateral condyle. The posterior cruciate ligament is attached to the anterior part of the inner surface of medial condyle.

Attachments of Capsule of Knee Joint
The capsule is attached posteriorly to intercondylar line and articular margins of lateral and medial condyles. It is attached medially and laterally to a line one centimeter above the articular margins. The capsule is deficient on anterior aspect.

Growing End
The lower end is the growing end of femur. The direction of nutrient foramen is towards the upper end. The nutrient artery is usually derived from the second perforating branch of profunda femoris artery.

Clinical insight ...

Fractures of Shaft of Femur
When the shaft of femur breaks into two fragments it is difficult to keep the fragments together due to the pull of the muscles attached to the femur. The flexors are inserted into the lesser trochanter, the abductors into the greater trochanter and the adductors into the linea aspera. The gastrocnemius muscles are attached to the lower end of femur.
i. In fracture of the proximal third of shaft (subtrochanteric), the small proximal fragment is flexed by iliopsoas muscle and abducted by gluteus medius and minimus muscles.
ii. In the fracture of middle-third of the shaft (midshaft) the adductor muscles pull the distal fragment upward and medially.
iii. In the fracture of the distal third of the shaft (supracondylar) gastrocnemius muscles pull the distal fragment backward thereby injuring the popliteal artery.
iv. The fracture of adductor tubercle in young age before the fusion of lower epiphysis injures the epiphyseal plate hampering growth in length of the person as the lower epiphyseal line cuts the adductor tubercle.

Patella (Knee-cap)

i. The patella is the largest sesamoid bone in the body. It develops in the tendon of quadriceps femoris.
ii. Normally, the patella lies in front of the knee joint. Sometimes it is placed high (patella alta) or low (patella baja).
iii. The patella functions as both lever and pulley. As a lever the patella magnifies the force exerted by quadriceps femoris during extension of knee. As a pulley the patella alters the direction of the pull of quadriceps for better efficiency. It keeps the quadriceps away from the bones of knee joint so as to protect it during extension movement. However, in flexion movement the patella straddles the knee joint as in this position, it is in contact with both condyles of femur.

Parts of Patella
The patella presents base, apex, three borders (superior or base, lateral and medial) and two surfaces (anterior and posterior).

Attachments
i. The rectus femoris and vastus intermedius are inserted into the base.

Know More ...

Ossification

i. The primary center appears for shaft at 8th week of intrauterine life.
ii. The secondary centers for upper end appear in following order: for head in 1st year, for greater trochanter at third year and for lesser trochanter at 13th year. These three epiphyses fuse with the shaft by 18th year.
iii. The neck ossifies from primary center.
iv. The secondary center for the lower end appears just before birth (9th month of intrauterine life). The presence of this center is a proof of the viability of the newborn that is born dead. This is of medicolegal importance. The lower epiphysis fuses with the shaft by 20th year.
ii. The lateral patellar retinaculum (expansion from vastus lateralis) is attached to lateral border.

iii. The medial patellar retinaculum and the lower fleshy fibers of vastus medialis called vastus medialis oblique are attached to medial border.

iv. The apex gives attachment to ligamentum patellae.

v. The rough anterior surface is related to subcutaneous prepatellar bursa.

vi. The upper larger part of posterior surface is articular. It is divided into larger lateral and smaller medial areas by a vertical ridge. The articular areas articulate with lateral and medial condyles of femur.

vii. The lower non-articular part of posterior surface is rough. This area is related to infrapatellar pad of fat.

Ossification
Patella ossifies from several centers that develop in quadriceps tendon during three to six years. Fusion is complete around the age of puberty.

Tibia (Shin Bone)
The tibia is the medial bone of the leg. It is a strong bone.

Parts
The tibia consists of broad upper end, shaft and narrow lower end. The medial malleolus is a bony projection arising from the medial side of its lower end. It is a palpable landmark at the medial aspect of the ankle.

Articulations of Tibia
i. Knee joint
ii. Superior tibiofibular joint
iii. Middle tibiofibular joint
iv. Inferior tibiofibular joint
v. Ankle joint

Upper End
The upper end of tibia presents lateral and medial condyles and the intercondylar area on the superior aspect. It presents tibial tuberosity on the anterior aspect.

Condyles
i. The superior surface of medial condyle shows oval articular surface for articulation with medial condyle of femur and for the medial meniscus.

ii. Its posterior surface presents a deep groove for the insertion of semimembranosus.

iii. The superior surface of lateral condyle shows circular articular area for articulation with lateral condyle of femur and lateral meniscus.

iv. The inferolateral part of posterior surface of lateral condyle shows a rounded facet for articulation with head of fibula at superior tibiofibular joint.

v. The anterior surface of lateral condyle presents a facet (Gerdy’s tubercle) for attachment to iliotibial tract.

Intercondylar Area (Fig. 91.4)
An intercondylar non-articular area is present between the two articular surfaces on the superior surfaces of the two condyles. There is an elevation in the middle part of this area which is called intercondylar eminence or tubercle. The intercondylar area provides attachment to following intra-articular structures in anteroposterior order.

i. Anterior horn of medial meniscus

ii. Anterior cruciate ligament

iii. Anterior horn of lateral meniscus

iv. Posterior horn of lateral meniscus

v. Posterior horn of medial meniscus

vi. Posterior cruciate ligament.
Tibial Tuberosity

It is an elevation on the anterior surface of upper end of tibia. The ligamentum patellae is attached to its upper smooth part and the subcutaneous infrapatellar bursa is related to its lower rough part.

Medial Surface

It is the subcutaneous surface. Its upper end receives insertion of three muscles representing the three compartments of thigh (sartorius, gracilis and semitendinosus). The pattern created by linear insertions of these tendons resembles the foot of a goose, which in Greek is called pes anserinus (Fig. 91.5). Therefore, these three muscles are called anserine muscles and the bursa in between these tendons is known as anserine bursa. The long saphenous vein (accompanied by saphenous nerve) crosses the lower third of this surface. This vein is often cannulated on this surface, in front of the medial malleolus. The medial surface and anterior border of tibia are used for taking pieces of bone for bone grafting. The upper part of medial surface is the favored site for marrow puncture and intraosseous infusion in very small children.

Clinical insight ...

In Osgood-Schlatter disease in young growing athletes (mostly boys), stress of repeated contraction of quadriceps femoris is transmitted to tibial tuberosity. This leads to strain on secondary center of ossification in the tibial tuberosity, which may cause multiple avulsion fractures. There is excess bone growth in tibial tuberosity producing a painful swelling.

Shaft of Tibia

The shaft presents three borders (anterior, lateral and medial) and three surfaces (lateral, medial and posterior).

i. The sharp anterior border or shin is entirely subcutaneous. It extends from lower end of tibial tuberosity to the anterior margin of medial malleolus.

ii. The medial border extends from medial condyle to posterior border of medial malleolus.

iii. The lateral or interosseous border extends from lateral condyle to anterior margin of fibular notch on lower end of tibia. It gives attachment to interosseous membrane.

Lateral Surface (Fig. 91.6A)

This surface forms the medial boundary of anterior compartment of leg.

i. Its upper two-third gives origin to tibialis anterior muscle.

ii. Its lower-third is crossed by four tendons of the muscles of anterior compartment of leg, deep peroneal nerve and anterior tibial vessels.

Posterior Surface (Fig. 91.6B)

i. It is characterized by an oblique line called soleal line, which gives attachment to fascia covering popliteus and origin to soleus.
ii. A triangular area above the soleal line receives insertion of popliteus.

iii. The posterior surface below soleal line is divided into medial and lateral areas by a vertical line.

iv. A nutrient foramen is located at the upper end of the vertical line. The direction of nutrient canal is towards the lower end.

v. The medial area below the soleal line provides origin to flexor digitorum longus and the lateral area provides origin to tibialis posterior.

**Lower End**

The lower end of the tibia is narrower than its upper end.

i. It projects medially as medial malleolus, which is subcutaneous. The posterior surface of medial malleolus is grooved by tendon of tibialis posterior. The apex of the medial malleolus gives attachment to deltoid ligament of ankle joint.

ii. The anterior aspect of the lower end is crossed by structures in the anterior compartment of leg. From medial to lateral side, they are tibialis anterior, extensor hallucis longus, anterior tibial artery, deep peroneal nerve, extensor digitorum longus and peroneus tertius.

iii. The posterior aspect of the lower end is related to structures that enter the sole from the posterior compartment of leg. From medial to lateral, they are tibialis posterior, flexor digitorum longus, posterior tibial artery, tibial nerve and flexor hallucis longus.

iv. Laterally, it presents fibular notch for articulation with the fibula to form inferior tibiofibular syndesmosis.

v. The inferior surface has articular facet for articulation with the facet on superior surface of talus at the ankle joint.

vi. The lateral surface of medial malleolus has a comma shaped articular facet for articulating with malleolar facet on the medial surface of talus.

**Growing End**

The upper end of tibia is its growing end. The large nutrient foramen points inferiorly. The nutrient artery is derived from posterior tibial artery.

**Fibula**

The fibula is the lateral bone of the leg. Since, it does not transmit weight it is very thin. In shape it resembles a brooch, which means fibula in Greek.
Articulations of Fibula

i. Superior tibiofibular joint
ii. Middle tibiofibular joint
iii. Inferior tibiofibular joint
iv. Ankle joint.

Features
The fibula consists of upper end, shaft and lower end.

Upper End
The upper end has head, neck and styloid process.

i. The head of fibula bears a rounded facet superiorly for articulating with reciprocal facet on lateral condyle of tibia at superior tibiofibular joint.

ii. The styloid process is an upward projection from posterolateral aspect of the head. The fibular collateral ligament is attached to it and the biceps femoris muscle is inserted into it.

iii. The neck of fibula is palpable. The common peroneal nerve can be rolled against the posterolateral surface of the neck. This nerve is injured in fracture of the neck of fibula or due to pressure of tight fitting plaster cast.

Shaft of Fibula
The shaft has three borders, anterior, posterior and medial (interosseous) which give attachment to anterior and posterior intermuscular septa and to the interosseous membrane of the leg respectively. The three borders bound three surfaces, medial, lateral and posterior.

i. The narrow medial surface gives origin to extensor digitorum longus, extensor hallucis longus and peroneus tertius (Fig. 91.6A).

ii. The lateral surface gives origin to peroneus longus and peroneus brevis (Fig. 91.6A).

iii. The peroneal crest or median crest divides the posterior surface into medial and lateral areas. The medial area gives origin to tibialis posterior and lateral area to flexor hallucis longus. The peroneal artery is closely related to median crest. The nutrient foramen is located near the median crest on the posterior surface. It is directed downwards. The fibula is an ideal bone for taking pieces for bone grafting. The bone graft is taken from the site of nutrient foramen so that it will have its own artery in the new location.

Lower End
The lower end projects as lateral malleolus, which is half cm lower than medial malleolus. On its medial surface, there are two features.

i. Anteriorly, there is a triangular articular facet, which articulates with the triangular facet on the lateral surface of body of talus.

ii. Posteriorly, there is malleolar fossa. The upper part of this fossa gives attachment to posterior tibiofibular ligament and the lower part to the posterior talofibular ligament.

Growing End
The upper end of fibula is its growing end. The direction of nutrient foramen is towards the ankle. The nutrient artery is a branch of peroneal artery.

Know More ...

Rule of Ossification
The rule of ossification states that the secondary center that appears first fuses last or the one that appears last fuses first. In the case of fibula the secondary center for lower end appears in first or second year and fuses with the shaft by fifteen to seventeen years. The center for upper end appears by third or fourth year and fuses by seventeenth or nineteenth year. Therefore, the fibula breaks the rule of ossification.

Fractures of Bones of Leg
Both tibia and fibula are frequently fractured in road traffic accidents. The tibia is more exposed hence more vulnerable.

i. The tibial shaft is slightly narrow at the junction of its upper two-third and lower third hence fracture at this site is very common. The union of the fracture at this site is delayed due to inadequate blood supply to the lower one-third of tibia. There are two reasons for this. The nutrient artery enters the tibia at its upper third. The fracture at the junctional site may injure the nutrient artery. Much of the blood supply to the tibia comes from the muscles attached to the shaft via the periosteum. Absence of muscle attachments in the distal third of tibia adds to its poor vascularity.

ii. The fractures of tibial shaft may injure the vessels in the leg causing hemorrhage in the closed fascial compartments. This may lead to vascular insufficiency to the leg and foot.

iii. The fractures of the tibia and fibula involving the ankle joint are known as Pott’s fracture. Depending on the direction of rotational forces different parts of the two bones may be fractured. Fracture of medial and lateral malleoli may occur alone or in combination.

iv. Rupture of interosseous tibiofibular ligament may cause dislocation of ankle joint.

v. Fracture of medial malleolus may be accompanied by rupture of medial ligament (deltoid ligament) of ankle. This results in lateral displacement of talus.

vi. A typical Pott’s fracture is characterized by fracture of medial malleolus, rupture of deltoid ligament, fracture of lower end of fibula and lateral displacement of the entire foot.

Clinical insight ...
Skeleton of Foot

The foot consists of 28 bones, 7 tarsal, 5 metatarsal, 14 phalanges and 2 sesamoid bones (in the tendons of insertion of flexor hallucis brevis).

Tarsal Bones

There are seven small irregular tarsal bones, which articulate with each other and with the metatarsal bones to form segmented levers in the foot. The talus and calcaneus are present in the proximal row of tarsal bones. The cuboid, lateral cuneiform, intermediate cuneiform and medial cuneiform are present in the distal row. The navicular bone is located between the cuneiforms and the talus.

Talus (Figs 91.7A to C)

The talus is the weight bearing bone since it takes part in the ankle joint, subtalar joints and talocalcaneonavicular joint. It is considered as the cornerstone of the medial longitudinal arch of the foot. One peculiar feature of talus is that it has no muscular attachments.

Articulations of Talus

i. Ankle joint
ii. Subtalar joints
iii. Talocalcaneonavicular joint.

Features

i. The talus is shaped like a tortoise with a body, neck and head.
ii. The head is directed forwards, medially and downwards. Its anterior surface articulates with navicular bone. Its inferior surface bears three facets. The posterior and anterolateral facets are for calcaneus. The anteromedial facet is for spring ligament.
iii. The neck is present between the head and body. It has dorsal and plantar surface. The narrow medial end of plantar surface is called sulcus tarsi, which takes part in formation of sinus tarsi along with reciprocal sulcus calcanei. This surface provides attachment to interosseous talocalcaneal and cervical ligaments, which are the contents of sinus tarsi (Figs 91.8A and B).
iv. The body has five surfaces, superior, inferior, lateral, medial and posterior.
v. The superior surface bears trochlear articular surface, which articulates with articular surface of lower end of tibia.
vi. The inferior surface bears articular facet for articulating with posterior facet of calcaneus.
vii. The medial surface has a comma shaped articular surface for articulation with lateral surface of medial malleolus. The deltoid ligament of ankle joint is attached to the nonarticular part of this surface.
viii. The lateral surface has a triangular articular facet for articulating with similar facet on medial surface of lateral malleolus of fibula.
ix. The posterior surface is grooved by tendon of flexor hallucis longus. This groove is flanked by medial and lateral tubercles. When the lateral tubercle is a separate bone, it is called os trigonum (an example of atavistic epiphysis).

Calcaneus

The calcaneus is the largest and the most posterior tarsal bone. It forms the heel of the foot.

Articulations of Calcaneus

i. Subtalar joints
ii. Talocalcaneonavicular joint
iii. Calcaneocuboid joint
Features
The calcaneus presents six surfaces, anterior, posterior, medial, lateral, superior and inferior.

i. The anterior surface presents articular facet for cuboid.

ii. The posterior surface is rough. It is divisible into three areas from above downwards. The upper part is smooth as it is related to a bursa. The middle part receives insertion of tendocalcaneus and plantaris. The lower part is in contact with fibrofatty tissue.

iii. The superior or dorsal surface is characterized by a large concave articular area. It is divisible into three areas. The posterior one-third is rough and covered with fibrofatty tissue. The middle one-third bears a posterior facet for talus. The anterior one-third is divided into anteromedial articular area and nonarticular area. The anteromedial area shows middle and anterior facets for talus. The middle facet is located on sustentaculum tali. The non-articular area is further divided into narrow medial part and wider lateral part. The narrow medial part is called sulcus calcanei, which gives attachment to interosseous talocalcaneal ligament and cervical ligament (Figs 91.8A and B). The lateral area provides origin to extensor digitorum brevis and gives attachment to stem of Y-shaped inferior extensor retinaculum.

iv. The inferior or plantar surface is characterized by anterior tubercle anteriorly. The short plantar ligament is attached to it. Posteriorly, this surface is marked by tuber calcanei or calcaneal tuberosity, which is subdivided into lateral and medial processes. The long plantar ligament is attached to the area between anterior tubercle and calcaneal tuberosity.

v. The lateral surface is subcutaneous. Its anterior part is marked by a small elevation called peroneal trochlea. The inferior extensor retinaculum is attached to peroneal trochlea and tendons of peroneus brevis and longus are in close relation to it on superior and inferior aspects respectively.

vi. The medial surface is marked by a shelf like projection called sustentaculum tali. An articular facet on superior aspect of sustentaculum articulates with the head of talus. The sustentaculum is grooved on inferior aspect by tendon of flexor hallucis longus while the tendon of flexor digitorum longus is related to its medial surface. The medial surface of sustentaculum tali gives attachment to spring ligament, deltoid ligament and few fibers of tibialis posterior muscle and some fibers of deltoid ligament.

Navicular Bone
The navicular bone lies along the medial margin of the foot. The tuberosity is felt along the medial margin of the foot.

Figs 91.8A and B: Subtalar and midtarsal joints and sinus tarsi

Cuboid Bone
It is roughly cubical in shape. It belongs to lateral longitudinal arch of foot.

i. By its anterior surface, it articulates with bases of fourth and fifth metatarsals.

ii. By its posterior surface, it articulates with calcaneus.

iii. The plantar surface is marked by a deep groove (directed medioanteriorly), which lodges the tendon
of peroneus longus. The plantar surface gives attachment to long and short plantar ligaments.
iv. The medial surface has articular facet for lateral surface of lateral cuneiform.

**Cuneiform Bones**
The medial, intermediate and lateral cuneiform bones are wedge-shaped and are part of medial longitudinal arch.

**Articulations**
i. The posterior surfaces of the three cuneiforms articulate with navicular bone.
ii. The distal surface of medial cuneiform articulates with the base of first metatarsal, that of intermediate cuneiform with base of second metatarsal and that of lateral cuneiform with the base of third metatarsal.
iii. The lateral surface of lateral cuneiform articulates with cuboid and base of fourth metatarsal bone.

**Metatarsal Bones**
There are five metatarsal bones, which are numbered from medial-to-lateral side.
i. The first metatarsal is short and stout for weight bearing. The head of the first metatarsal bone makes pressure contact with the ground at the beginning of taking a step. The sesamoid bones in the tendons of flexor hallucis brevis articulate directly with the plantar surface of this bone.
ii. The second metatarsal is the longest and least mobile.
iii. The fifth metatarsal has a tuberosity at its base, which can be palpated along the lateral margin of foot. The tuberosity receives insertion of peroneus brevis. Sometimes the pull of contraction of this muscle may fracture the tuberosity. Sometimes the tuberosity may ossify by separate center and remain separate from the base, in which case it is known as os Vesalius.

**Ossification Centers of Tarsal Bones**
i. The calcaneus is ossified by one primary center that appears in the third month of intrauterine life and a secondary center for posterior surface (which gives attachment to tendocalcaneus) at six to eight years after birth.
ii. The talus is ossified by one primary center that appears in sixth month of intrauterine life.
iii. The center for cuboid appears just before birth
iv. The center for lateral cuneiform appears in the first year, that for medial cuneiform in the second year and that for intermediate cuneiform and navicular in the third year.

**Ossification Centers in Newborn**
The radiograph of knee and foot in full-term newborn usually shows five ossification centers, two around the knee (lower end of femur and upper end of tibia) and three in the foot (calcaneus, talus and cuboid).

**Clinical insight ...**

**Fractures of Bones of Foot**
The fractures of talus and calcaneus are not common. But they may be crushed in landing on the calcaneus from a height. The tuberosity of the fifth metatarsal bone may be avulsed by trivial twisting injuries of the forefoot. Fatigue fractures (march fractures) are common in metatarsal bones. This is due to repeated small bending stresses to the bones. The second metatarsal bone is the most frequently fractured bone in young adults.
The lower limb is subdivided into following regions:

i. Gluteal region
ii. Thigh
iii. Popliteal fossa
iv. Leg
v. Ankle
vi. Foot

SURFACE LANDMARKS

i. The iliac crest, which is palpable in its entire extent, forms the superior limit of the gluteal region. The highest point of the iliac crest is at the level of the space between the spines of L3 and L4 vertebrae.

ii. The anterior superior iliac spine is easy to palpate in thin individuals.

iii. The tubercle of the iliac crest is located 5 cm behind the anterior superior iliac spine. The plane passing through it is known as transtubercular plane and it corresponds to the spine of L5 vertebra.

iv. The posterior superior iliac spine is indicated by a skin dimple, which is located 4 cm lateral to the spine of second sacral vertebra. This landmark is useful in following respects. One can palpate the sacroiliac joint at this site.

v. The pubic symphysis is felt in the lowest limit of abdominal wall in the median plane. The pubic crest, which is the superior margin of the pubis and its lateral end, called pubic tubercle are palpable parts of the pubic bone.

vi. The ischial tuberosity is easily palpable in sitting position. The weight of the body is supported by the ischial tuberosities in this position.

vii. The greater trochanter of femur can be felt a hand’s breadth below the midpoint of the iliac crest.

viii. The condyles of femur are subcutaneous hence easily palpable, when the knee is flexed or extended.

ix. The adductor tubercle is felt above and behind the medial epicondyle of femur. It is continuous with the lower end of medial supracondylar line. The lower epiphyseal line of femur passes through the adductor tubercle.

x. The patella or kneecap moves during flexion and extension of knee joint. Its lateral and medial margins are felt, when the knee is flexed.

xi. The tibial tuberosity is felt 5 cm below the apex of patella. The tibial condyles form visible and palpable landmarks at the medial and lateral sides of ligamentum patellae.

xii. The anterior border of tibia (called shin) is sharp and palpable in its entire extent.

xiii. The medial subcutaneous surface of tibia lies medial to the shin. It is easily accessible and hence used for taking pieces for bone grafting.

xiv. The medial malleolus at the lower end of tibia is subcutaneous and the great saphenous vein runs along its anterior margin.

xv. The head of fibula is subcutaneous at the posterolateral aspect of the knee and is palpable at the level
of the superior margin of tibial tuberosity. The neck of the fibula is palpable distal to the head. The lower end of shaft of fibula is subcutaneous.

xvi. The lateral malleolus is subcutaneous. Its tip extends further distally than that of medial malleolus.

xvii. The posterior, lateral and medial surfaces of calcaneus are palpable. The sustentaculum tali is a shelf like projection from the medial surface of calcaneus. It is felt as a small prominence about a fingerbreadth below the tip of medial malleolus.

xviii. The peroneal trochlea is felt as a small tubercle on the lateral aspect of the calcaneus, 2 cm distal to the tip of lateral malleolus. The tendon of peroneus brevis passes above and the tendon of peroneus longus passes below the peroneal trochlea.

xix. The head of talus is palpable anterior to the medial malleolus if the foot is everted and anteromedial to the lateral malleolus if the foot is inverted.

xx. The head of the first metatarsal bone is a prominent landmark on the medial aspect of distal foot. The tuberosity of the fifth metatarsal bone is palpable at the midpoint of the lateral margin of foot. The shafts of metatarsals and phalanges are palpable on the dorsum of foot.

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**CUTANEOUS NERVE SUPPLY**

**FIGS 92.1A AND B**

The cutaneous nerves of the lower limb are derived from five sources, subcostal nerve (T12), branches of lumbar plexus, branches of sacral plexus and the dorsal rami of lumbar and sacral nerves.

**Gluteal Region (Fig. 94.2)**

The gluteal region is the only part of the lower limb that receives sensory supply from dorsal and ventral rami. The region may be divided into four unequal areas, which receive cutaneous nerves from different sources.

i. The superolateral area receives twigs from the lateral cutaneous branch of subcostal nerve (T12) and of iliohypogastric nerve (L1). These branches course anterior and posterior to the iliac tubercle and supply skin as low as the level of greater trochanter.

ii. The inferolateral area receives branches from lateral cutaneous nerve of thigh (L2, L3), which is a branch of lumbar plexus.

iii. The superomedial area receives branches from the dorsal rami of L1, L2, L3 spinal nerves and of S1, S2, S3 spinal nerves.

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![Fig. 92.1A](image1.png): Cutaneous nerves of anterior aspect of lower limb including those of dorsum of foot and toes

![Fig. 92.1B](image2.png): Cutaneous nerves of posterior aspect of lower limb including those of sole
Surface Features, Cutaneous Nerves, Venous and Lymphatic Drainage of Lower Limb

Chapter iv.

The inferomedial area receives twigs from the gluteal branches of posterior cutaneous nerve of thigh (S1, S2, S3) and a few twigs from the perforating cutaneous nerve (S2, S3). The perforating cutaneous nerve perforates the sacrotuberous ligament and the gluteus maximus muscle.

Thigh

i. The skin of the back of thigh receives branches from the posterior cutaneous nerve of thigh and the lateral cutaneous nerve of thigh. The medial anterior femoral cutaneous nerve of thigh may also supply the back.

ii. As many as six nerves supply the skin of the front of thigh. Direct sensory branches of the lumbar plexus are ilioinguinal nerve, femoral branch of genitofemoral nerve and lateral cutaneous nerve of thigh. The femoral nerve supplies through its medial femoral and intermediate femoral cutaneous branches and the saphenous nerve. The obturator nerve supplies skin of the medial side through its contribution to the subsartorial plexus.

Popliteal Fossa

The skin of the popliteal fossa receives branches mainly from the posterior cutaneous nerve of thigh with a contribution from posterior branch of medial femoral cutaneous nerve.

Back of Leg

The back of the leg receives branches from sural nerve (a branch of tibial nerve in the popliteal fossa) and sural communicating nerve (a branch of common peroneal nerve in the popliteal fossa). A few twigs are supplied from posterior cutaneous nerve of thigh and a branch of medial femoral cutaneous nerve of thigh.

Front of Leg

The front of the leg is supplied mainly from three sources. The saphenous nerve (on medial side) and lateral cutaneous nerve of calf (on lateral side) supply the upper part of the leg. The branches of saphenous nerve (on medial side) and branches of superficial peroneal nerve (on lateral side) supply the lower part of the leg.

Dorsum of Foot

Three nerves basically supply the dorsum of foot. The superficial peroneal nerve supplies the larger intermediate area. The sural nerve supplies the lateral margin of the dorsum and the saphenous nerve the medial side up to the base of great toe.

Dorsum of Toes

A total of five nerves supply the dorsal aspects of the toes. The sural nerve supplies the lateral side of the little toe. The deep peroneal nerve supplies the adjacent sides of first and second toes (first interdigital cleft). Rest of the toes except adjacent sides of first and second toes and the lateral side of the little toe, are supplied by the superficial peroneal nerve. The nail beds of medial three and half toes receive twigs from medial planar nerve and nail beds of lateral one and half of toes receive branches from the lateral planar nerve.

Sole of Foot

The medial calcanean nerve, which is a branch of tibial nerve supplies the skin covering the heel. The cutaneous branches of medial planar and lateral planar nerves supply the rest of the sole including the planar aspects of the toes.

DERMATOMES (FIGS 92.2A AND B)

The ventral rami of lumbar and sacral nerves pleat together to form lumbar and sacral plexuses through which the cutaneous supply of the lower limb is derived. The gluteal region, however, is supplied through the dorsal rami also. In the case of the limbs, dermatome is the area of skin supplied by one ventral ramus through its various cutaneous branches. So, S1 dermatome receives S1 fibers from the cutaneous branches of several peripheral nerves carrying S1 fibers. Only if the sensory rootlets of first sacral nerve are damaged will there be complete sensory loss in S1 dermatome. In injury to the peripheral nerve, the nerve fibers belonging to more than one segment of the spinal cord will be involved and hence the sensory effects will not coincide with the entire cutaneous area of that nerve neither with any dermatome. The embryonic development of the lower limb helps to understand its dermatomal map. The lower limb bud originates against L1 to S3 segments of the spinal cord. When the limb bud elongates it drags down the dermatomes along with the spinal nerves. Due to the medial rotation of the lower limb bud, its borders and surfaces are exactly opposite to that of upper limb. The preaxial digit of the lower limb comes to occupy medial side while the postaxial digit on the lateral side of the foot. The dorsal or extensor surface except the gluteal region comes to lie anteriorly while the ventral or flexor surface faces posteriorly. The preaxial border starts near the midpoint of thigh and descends to the knee. It then curves medially to descend to the medial malleolus and reach the big toe along the medial margin of foot. In broad terms, the lumbar dermatomes lie in succession from L1 to
L5 on the front of the limb. The L4 and L5 lie side by side in the front of leg. The L5 dermatome occupies the middle of the dorsum of foot and middle three toes while the L4 dermatome occupies the medial side of the foot including the big toe. While eliciting Babinski sign the skin in the S1 dermatome of sole is scratched. The S1 dermatome ascends on the back of the leg to be followed by the S2 dermatome up to the gluteal fold and S3 dermatome above it in the gluteal region. The saddle area of the perineum includes S2, S3 and S4 dermatomes. When S2, S3, S4 segments of spinal cord are compressed in conus medullaris lesion, there is saddle anesthesia.

**VENOUS DRAINAGE**

It is essential to know the anatomy of the veins of the lower limb to understand the pathogenesis, diagnosis and surgical treatment of the varicosity of the veins of lower limb. Varicosity is a condition in which veins become tortuous and dilated. The veins of the lower limb are divided into three groups:

1. Superficial or subcutaneous veins in the superficial fascia.
2. Deep veins accompanying the arteries located deep to the deep fascia.
3. Perforating veins (passing through the deep fascia) to connect the superficial and deep veins.

**Superficial Veins**

The superficial veins consist of dorsal venous arch on the dorsum of foot, great or long saphenous vein and small or short saphenous vein.

**Dorsal Venous Arch**

The dorsal venous arch is located on the distal parts of the metatarsal bones. It receives the dorsal digital and dorsal metatarsal veins and communicates with proximally located dorsal venous network. Along the sides of foot there are medial and lateral marginal veins, which drain both the dorsal and plantar aspects of the respective sides in to the dorsal venous arch.

**Great Saphenous Vein (Fig. 92.3)**

The word saphenous, which is Greek in origin, means easily seen. Since the saphenous vein lies in the superficial fascia it is easily seen. The great saphenous vein is the longest vein in the body. It is thick-walled and contains numerous valves, which allow the blood to flow towards heart. The valves divide the long column of blood in short segments so as to reduce the pressure on the distal part of the vein during prolonged standing.

**Formation**

The formation of great saphenous vein is described in two ways.

1. The medial end of venous arch and medial marginal vein of the foot continue as great saphenous vein.
2. The union of dorsal digital vein of the medial side of big toe and the medial end of dorsal venous arch form the great saphenous vein.

**Course and Relations**

i. At the ankle, the great saphenous vein enters the leg at a very constant point. It ascends in the interval between the anterior aspect of the medial malleolus and the tendon of tibialis anterior muscle. Then it remains in contact for a short distance with the distal third of medial subcutaneous surface of the tibia. In this part of its course it is accompanied by saphenous nerve. Further it ascends along the medial border of
tibia to reach the posterior aspect of the medial side of the knee.

ii. At the back of the knee it is about a hands breadth behind the medial border of patella.

iii. In the thigh the vein ascends along the medial aspect of the front of the thigh until it reaches the saphenous opening in the fascia lata. A few branches of medial cutaneous nerve of thigh are closely related to it here.

iv. The great saphenous vein pierces the cribriform fascia at the saphenous opening along with the three superficial branches of the femoral artery (superficial circumflex iliac, superficial epigastric and superficial external pudendal arteries) and lymph vessels.

v. It terminates into the femoral vein after piercing the anterior wall of the femoral sheath. A valve guarding the saphenofemoral junction is located at a point about 3.5 to 4 cm inferolateral to the pubic tubercle.

**Fig. 92.3:** Tributaries and termination of long saphenous vein

**Perforating Veins or Perforators**

There are about five perforating veins, which connect the great saphenous vein to the deep veins of leg and thigh. These veins are called perforators because they perforate the deep fascia. Their unique feature is that they contain unidirectional valves, which allow the blood to flow only from the superficial veins to the deep veins. In this way the perforating veins minimize the load of the superficial veins. The incompetence of the valves of the perforators is one of the causes of dilatation of superficial veins of lower limb.

**Position of Perforating Veins (Fig. 92.4)**

i. Between the medial malleolus and mid-calf there are three ankle perforators of Cockett connecting the posterior arch vein to the venae comitantes of posterior tibial artery. So, these perforators indirectly connect the great saphenous vein to the deep veins of leg.

ii. At the upper end of the calf there is tibial tubercle perforator or Boyd’s perforator that connects the venae comitantes of the posterior tibial artery to the great saphenous vein.

iii. In the intermediate third of thigh one vein called Hunterian perforator or perforator of Dodd connects the great saphenous vein to the femoral vein in the subsartorial canal. This perforator passes through the fascial roof of the canal.

**Surface Marking of Great Saphenous Vein**

Though one can see the long saphenous vein in thin people in its course in the foot and leg it is necessary to know its surface marking in the entire extent because this vein is used for venous cut downs and for coronary artery bypass graft.

i. At the ankle the vein passes upwards about 2.5 cm anterior to the medial malleolus.
ii. In the leg it ascends crossing the medial surface and the medial border of tibia to reach the posteromedial aspect of the knee.

iii. At the knee it lies about a hand’s-breadth posterior to the medial margin of patella.

iv. In the thigh it ascends along the medial aspect of the front of thigh to enter the saphenous opening.

v. The termination of the vein is indicated by the central point of the saphenous opening, which is roughly 4 cm below and lateral to the pubic tubercle. One should know the surface marking of termination of the vein while performing various tests to assess saphenofemoral valve competency.

Small Saphenous Vein

It begins as the continuation of lateral marginal vein of foot or is formed by the union of dorsal digital vein of lateral side of the little toe and lateral end of dorsal venous arch.

Course and Relations (Fig. 92.5)

i. At first the short saphenous vein ascends posterior to the lateral malleolus and then on the lateral side of the tendocalcaneus.

ii. It passes along the middle of the calf and pierces the deep fascia in the lower part of the popliteal fossa to open into the popliteal vein above the level of the back of the knee joint (the termination may show variations. It may join the great saphenous vein in the proximal thigh, or it may bifurcate, one branch joining the great saphenous vein and the other joining the popliteal vein).

iii. In the leg the short saphenous vein is accompanied by sural nerve.

iv. Like the great saphenous vein, this vein too has numerous valves.

Tributaries

At the ankle it receives veins from the sole and dorsum of foot. It receives several cutaneous tributaries of the leg and communications from the great saphenous vein. The perforating vein may connect it to the deep veins of the calf.

Deep Veins

The deep veins accompany the arteries. The contractions of the muscles (soleus and gastrocnemius) supporting the deep veins propel the venous blood upward. Valves are more in deep veins compared to the superficial veins. The deep veins receive blood from superficial veins through perforators.

Major Deep Veins

i. Deep veins of the sole (medial and lateral plantar veins)
ii. Venae comitantes accompanying the dorsalis pedis, posterior tibial and anterior tibial arteries
iii. Popliteal vein
iv. Femoral vein.

Factors Facilitating Venous Return
In the standing position the venous blood has to flow against gravity. The following factors help the venous return.
i. The deep veins of the leg are located in the tight fascial compartment along with the arteries. When the muscles of the calf contract there is rise in the pressure inside the compartment, which compresses the deep veins. The valves open up and blood is propelled in upward direction.
ii. The soleus contains venous sinuses filled with blood and on contraction it squeezes the blood out into the deep veins. For this reason the soleus is regarded as the peripheral heart and the calf muscles collectively work as a venous pump.
iii. During relaxed state of the muscles, the blood is sucked from the superficial to the deep veins through the perforators.
iv. The pulsations of accompanying arteries help in propelling the blood in the veins.
v. The valves in superficial and deep sets of veins allow the blood to flow in upward direction only.
vi. The negative pressure in the thoracic cavity sucks the blood in the venous system towards heart in standing or recumbent positions.

Clinical insight ...

i. The great saphenous vein is often chosen for a venous cut down in an emergency, when the superficial veins elsewhere are collapsed and invisible. A small skin incision is placed just in front of the medial malleolus (taking care not to injure the accompanying saphenous nerve) to expose the great saphenous vein. The vein is cannulated at this site for giving intravenous fluids.

Fig. 92.6: Unilateral varicose vein in a patient

Fig. 92.7: Bilateral varicose veins in legs and thighs

ii. The great saphenous vein is ideally suited for coronary arterial graft as it is a muscular vein. A segment of the patient’s vein from the thigh is removed for this purpose. While suturing in place of the blocked coronary artery, the venous graft is reversed so that its valves do not obstruct the blood flow in coronary artery graft.

iii. In varicosity of lower limb the superficial veins are dilated and tortuous (Figs 92.6 and 92.7). This is common in people, whose jobs require prolonged standing (bus conductors, traffic police, nurses, etc). Incompetency of valves is the basic cause of varicosity. The incompetent valves in perforating veins allow reverse blood flow from the deep into the superficial veins and consequent
LYMPHATIC DRAINAGE

The lymph nodes and lymph vessels of the lower limb are divided into superficial and deep groups.

Superficial Group (Fig. 92.10)

The superficial inguinal lymph nodes are located in the superficial fascia of the inguinal region and are normally palpable. They are arranged into two groups (resembling the alphabet T).

i. The horizontally disposed lymph nodes lie parallel to and just below the inguinal ligament.

ii. The vertically disposed lymph nodes lie along the terminal part of great saphenous vein (before it pierces the deep fascia).

The superficial lymph vessels (running along the superficial veins) drain into these nodes.

Areas of Drainage

i. The medial nodes of the horizontal group receive lymph from the external genitalia in both sexes except the glans penis or clitoris, lower end of vagina in female, terminal part of male urethra, lower part of...
anal canal, medial half of the anterior abdominal wall below the umbilicus and part of fundus of uterus along the tubouterine junction in female.

ii. The lateral nodes of the horizontal group receive lymph directly from the gluteal region and adjoining part of the trunk, lateral half of the anterior abdominal wall below the umbilicus, the entire lower limb except the following areas namely, the lateral part of foot, the heel and lateral part of the back of leg.

Deep Group (Fig. 92.11)
This group includes the deep inguinal nodes and popliteal nodes. The deep nodes lie deep to the deep fascia.

i. The deep inguinal nodes that are located along the medial side of femoral vein in the femoral canal, is called the node of Cloquet. It receives lymph from the glans penis in male and clitoris in female. The other nodes of this group receive lymph from the deeper tissues of the thigh, the popliteal lymph nodes and from the superficial lymph nodes. The efferent vessels from the deep group drain into the external iliac nodes.

ii. The popliteal lymph nodes are embedded in the fat in the popliteal fossa. They are about three to six in number and are disposed in three sets. The most posterior or superficial node lies at the saphenopopliteal junction. The most anterior or deepest node lies between the knee joint and the popliteal artery. The lymph nodes in the intermediate set are located on either side of the popliteal vessels. The popliteal nodes are unique because they are the only deep nodes that receive both superficial and deep lymph vessels. The posterior or superficial node receives superficial vessels from lateral side of foot, the heel and the lateral half of the back of the leg because these lymph vessels travel with small saphenous vein, which opens into popliteal vein. The intermediate set receives deep lymph vessels accompanying the deep blood vessels (anterior and posterior tibial) from the entire leg and foot. The most anterior node receives the lymph from the knee joint. The efferent vessels from the popliteal nodes reach the deep inguinal nodes.
The lymphatic vessels of the lower limb may be blocked by microfilarial parasites (Wuchereria Bancrofti). This usually manifests as massive edema of the lower limb (elephantiasis as seen in a patient (Fig. 92.12).

In inflammatory lesions of the lower limb the inguinal lymph nodes in vertical chain are enlarged and painful.

The malignant melanoma usually affects the medial toes. The melanoma originates from the melanocytes of the skin. Since this cancer spreads by lymphatics there is enlargement of inguinal nodes. Therefore in the treatment of malignant melanoma the affected toe is amputated along with complete removal of the inguinal lymph nodes.

The lesion of prepuce, penis, labia majora, scrotum, lower part of vagina, utero-tubal junction (part of fundus of uterus), lower part of anal canal and distal urethra will cause enlargement of horizontal chain of superficial inguinal lymph nodes. A boil or abscess in the gluteal region will cause inflammation and swelling of lateral nodes of horizontal group.

Enlargement of popliteal lymph nodes occurs in inflammatory lesions of heel, lateral side of the foot and back of leg.

Fig. 92.12: Elephantiasis of left lower limb due to blockage of lymphatic vessels
The thigh extends from the hip to the knee. The proximal extent of the thigh is bounded by the inguinal region or groin anteriorly, perineum medially and the gluteal fold posteriorly. Distally, the thigh extends anteriorly to the front of the knee and posteriorly to the popliteal fossa. The thigh is divided into three osteofascial compartments by intermuscular septa, which pass from the fascia lata to the linea aspera of femur.

Superficial Fascia of Thigh

In the upper part of the front of thigh, the superficial fascia consists of two layers (superficial fatty layer and deep membranous layer). These two layers are continuous in front of the inguinal ligament with corresponding layers of anterior abdominal wall. The membranous layer is fused with the deep fascia of thigh along a horizontal line starting from the pubic tubercle and passing for about 8 cm laterally. This line is referred to as Holden’s line (Fig. 93.2). This line of fascial fusion seals the space between the membranous layer of superficial fascia and the external oblique aponeuroses in the infraumbilical abdominal wall. This explains why the extravasated urine (in rupture of urethra in perineum in male) deep to the membranous layer of superficial fascia in the anterior abdominal wall does not descend into the thigh below this line.

Deep Fascia of Thigh (Fascia Lata)

The deep fascia of the thigh encircles the thigh like a stocking. It has a wide attachment superiorly. It is attached to all the bony prominences at the knee inferiorly.

Superior Attachment

i. On the anterior aspect, fascia lata is attached to the inguinal ligament. The downward pull of the fascia lata on the inguinal ligament is responsible for the upper concavity of the inguinal ligament.

ii. On the lateral aspect, it is attached to the iliac crest.

iii. On the medial side, it is attached to the body and inferior ramus of pubis and the ramus and tuberosity of ischium.

iv. On the posterior aspect, it is attached to the sacrotuberous ligament, sacrum and coccyx.

v. In the gluteal region, it splits to enclose the gluteus maximus muscle.

Inferior Attachment

i. On the anterior aspect, it is attached to the patella, condyles of femur and tibia and head of fibula. The patella is held to the tibial condyles by lateral and medial patellar retinacula (thickened bands of deep fascia) through which lateral and medial vasti are inserted into respective margins of patella.
On the posterior aspect, the fascia lata continues as the popliteal fascia.

**Salient Features of Fascia Lata**

i. The saphenous opening is the deficiency in deep fascia. It is covered by cribriform fascia, which is pierced by multiple structures giving it a sieve-like appearance.

ii. Iliotibial tract is the thickened part of deep fascia laterally extending like a band from the iliac crest to lateral tibial condyle. It splits superiorly to enclose the tensor fascia latae.

iii. The intermuscular septa arising from the deep fascia course internally towards the linea aspera of the femur. The lateral, medial, and posterior intermuscular septa divide the thigh into three osteofascial compartments. The anterior compartment consists of extensor muscles supplied by branches of femoral nerve. The posterior compartment consists of hamstring or flexor muscles supplied by branches of sciatic nerve. The medial compartment consists of adductor muscles supplied by branches of obturator nerve.

**Saphenous Opening**

This is an oval aperture (Fig. 92.3) in the deep fascia of the thigh. It is about 3 cm long and 1.5 cm wide. The
center of the opening lies about 3 to 4 cm inferolateral to the pubic tubercle. It has a sharp falciform margin (Fig. 93.2 on the right side), which bounds it on superior, lateral and inferior aspects. The medial margin however is smooth and sloping and merges with fascia covering the anterior surface of pectineus. It must be appreciated that the falciform margin, which is at a superficial plane forms the anterior relation of the femoral sheath while the medial margin, which is at a deeper plane passes posterior to the sheath. The two margins of the opening are connected by the cribriform fascia, which is so called because of its sieve-like appearance. The long saphenous vein, lymph vessels and superficial external pudendal, superficial epigastric and superficial circumflex iliac arteries (branches of the femoral artery) pierce the cribriform fascia.

**Iliotibial Tract (Fig. 93.3)**

It is a thickened part of fascia lata on the lateral aspect of thigh.

**Attachments**

i. Superiorly, it is attached to the anterior part of iliac crest.

ii. Inferiorly, it is attached to the anterior surface of lateral condyle of tibia on a circumscribed area (Gerdy’s tubercle).

The iliotibial tract crosses in contact with lateral epicondyle of femur to reach its distal attachment.

**Functional Importance**

i. The iliotibial tract provides insertion to tensor fasciae latae and gluteus maximus muscles. The tract extends their insertion to the tibia.

ii. It plays a crucial role to stabilize the knee in extended position (especially during running).

**Clinical insight ...**

**Iliotibial Tract (Band) Syndrome**

This syndrome is characterized by stinging sensation just lateral to the knee joint or along the entire extent of iliotibial tract. The cause is the continuous rubbing of the tract on lateral condyle during running or cycling produces inflammation in the area of contact. Surgical sectioning of the tract relieves the symptoms (if cortisone injection at the site of contact is not effective).

**ANTERIOR COMPARTMENT OF THIGH**

**Femoral Sheath**

The femoral sheath is a funnel-shaped fascial envelope around the femoral vessels as they descend behind the medial half of inguinal ligament in the thigh.

**Formation**

The fascia transversalis forms the anterior wall of the sheath and the fascia iliaca forms the posterior wall. The lateral wall of the sheath is straight while its medial wall is sloping. The femoral sheath closes inferiorly because of the blending of its anterior and posterior walls with the tunica adventitia of femoral vessels.

**Compartments (Fig. 93.4)**

The femoral sheath is divided into three compartments by two anteroposterior septa. The medial compartment is called the femoral canal. The intermediate compartment contains the femoral vein and the lateral compartment contains the femoral artery and femoral branch of genitofemoral nerve.

**Femoral Canal**

The femoral canal is about 2 cm long. It contains the lymph node of Cloquet and fibro-fatty tissue. The canal provides dead space for the expansion of femoral vein during times of increased venous return.
**Femoral Ring**

It is the upper opening of the femoral canal. It is directed towards the abdomen. It can admit the tip of a little finger. It is wider in females due to wider pelvis. The femoral ring is closed by femoral septum, which is made of the extraperitoneal fatty tissue. The boundaries of the femoral ring are of surgical importance. The lateral margin is formed by femoral vein, anterior margin by inguinal ligament, posterior by pectineus muscle and the medial margin by the free margin of lacunar ligament. If an abnormal obturator artery is present, it may be closely related to the free margin of the lacunar ligament (medial boundary of femoral ring).

![Fig. 93.4: Femoral sheath and its contents](image)

(Note that the femoral nerve is outside the femoral sheath)

**Clinical insight ...**

i. The femoral ring is the weak area in the lower part of the anterior abdominal wall. The protrusion of abdominal contents covered by parietal peritoneum through the femoral ring in the femoral canal is called the femoral hernia. It is more common in female because of wider femoral ring. The femoral hernia presents as a globular swelling in the groin. Its distinguishing feature is its relation to the pubic tubercle. It is located inferolateral to the pubic tubercle as against the inguinal hernia, which is superomedial to the tubercle.

ii. The path of the femoral hernia is at first downward, then anterior and then upward (Fig. 93.5). First it enters the femoral canal and then passes through its anterior wall into the saphenous opening, where it turns upwards around the sharp falciform margin of saphenous opening (See Fig. 93.2). It is useful for the surgeon to know the path of the hernia in order to reverse the path while manually reducing the hernia.

iii. The femoral hernia is prone to strangulation because of the compression of the neck of the hernial sac at the narrow femoral ring. The strangulation endangers the blood supply of the herniated intestinal loop. The relief of the strangulated loop is obtained by cutting the lacunar ligament so as to enlarge the femoral ring. The surgeon must be familiar with the anatomical relations of the abnormal obturator artery to the femoral ring while incising the lacunar ligament. If the abnormal obturator artery (Fig. 93.6) is in lateral relation to the ring it is its safe position. If it is in medial relation to the ring (in contact with free margin of lacunar ligament) it is prone to injury and bleeding during enlargement of femoral ring by cutting the lacunar ligament.

**Femoral Triangle**

The femoral triangle (Scarpa’s triangle) is a triangular space in the upper-third of the thigh below the inguinal ligament and medial to the sartorius muscle.

![Fig. 93.5: Path of femoral hernia. (1) Downward; (2) Forward; (3) Upward](image)

![Fig. 93.6: Abnormal obturator artery and its relations to femoral ring](image)

(When the artery is laterally related to femoral ring, it is safe. When it is in medial relation to femoral ring, it is unsafe)
Boundaries (Fig. 93.7)
The inguinal ligament forms the base of the triangle. The medial border of the adductor longus muscle bounds the triangle medially and the medial border of sartorius laterally. The apex of the triangle is the meeting of the adductor longus and sartorius muscles. At the apex, the femoral triangle is continuous with the subsartorial canal. The gutter-shaped floor is formed by four muscles (medial to lateral), adductor longus, pectineus, psoas major and iliacus. The fascia lata forms the roof, which presents some features like saphenous opening and cribriform fascia.

Contents
The main contents of the femoral triangle are, from lateral to medial, femoral nerve and its branches, femoral artery and its branches and femoral vein with its tributaries. The lateral cutaneous nerve of thigh enters the lateral angle of the triangle, usually after piercing the inguinal ligament.

i. The femoral nerve breaks up into three sensory and six muscular branches. The sensory branches are, intermediate and medial femoral cutaneous nerves and the saphenous nerve. The muscular branches supply the sartorius, pectineus and separate branches to the four heads of quadriceps femoris.

ii. The femoral artery enters the base of the triangle at the middinguinal point. Its upper part, along with femoral vein is enclosed in femoral sheath. The femoral artery gives three superficial branches, deep external pudendal artery and profunda femoris artery. Two branches of the profunda femoris artery (lateral and medial circumflex femoral) originate in the femoral triangle.

iii. The femoral vein receives the long saphenous vein besides smaller tributaries.

iv. The deep inguinal lymph nodes, the lateral cutaneous nerve of thigh and the femoral branch of genitofemoral nerve are the other contents of the triangle.

Exit of Contents from Femoral Triangle (Fig. 93.8)
i. The femoral vessels leave through the apex to enter the subsartorial canal.

ii. The profunda femoris vessels leave through the floor via a gap between pectineus and adductor longus muscles.

iii. The medial circumflex femoral vessels pass through the gap between psoas major and pectineus muscles.

iv. The lateral circumflex femoral vessels pass behind the sartorius.

v. The superficial branches of the femoral artery pierce the cribriform fascia.

vi. The saphenous nerve and nerve to vastus medialis leave through the apex. The other muscular branches enter the respective muscles in the triangle itself while the other cutaneous nerves pierce the deep fascia of the triangle.

Relations at Apex of Femoral Triangle
At the apex of the triangle, four vessels and two nerves come in close relation. The femoral vessels passing through the apex are separated by the adductor longus from the profunda vessels. These large sized four vessels are arranged from anterior to posterior in the following order: femoral artery, femoral vein, profunda vein, and profunda artery. The saphenous nerve and nerve to vastus medialis also pass through the apex. All these structures are involved in a stab injury or bullet injury at the apex.

Fig. 93.7: Boundaries of femoral triangle, muscles in its floor and its main contents

Fig. 93.8: Sites of exit of vessels through femoral triangle (Note that stab wound at the apex of the triangle will injure four blood vessels)
The subsartorial canal is also called the adductor canal or Hunter’s canal. It is located in the middle third of the medial side of the front of thigh. It is triangular on cross-section.

**Extent**

This canal extends from the apex of femoral triangle to the tendinous opening in the adductor magnus-through which femoral vessels enter the popliteal fossa.

**Boundaries (Fig. 93.9)**

The subsartorial canal has anterolateral, anteromedial (roof) and posterior boundaries.

i. The vastus medialis is the anterolateral boundary.

ii. The fibrous roof covered with sartorius forms the anteromedial boundary. Between the fibrous roof and the sartorius lies the subsartorial plexus of nerves.

iii. The adductor longus above and adductor magnus below form the posterior boundary.

**Main Contents**

i. Femoral artery

ii. Femoral vein

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**Clinical insight ...**

A number of anatomical structures give rise to swelling in the groin. Therefore while examining a case of lump in the groin a clinician recollects the following anatomical structures in the femoral triangle, which may give rise to swelling in the groin.

i. The subcutaneous fatty tissue may form a lipoma.

ii. The femoral and inguinal herniae present as swelling. The pubic tubercle helps in distinguishing the swelling of femoral hernia from that of inguinal hernia. The femoral hernia is inferolateral to the pubic tubercle while inguinal hernia is superomedial to the pubic tubercle. This relationship corresponds to the positions of superficial ring and saphenous opening in relation to the pubic tubercle.

iii. The dilatation or aneurysm of femoral artery forms a pulsatile swelling.

iv. An injury to the femoral vein (for instance during venipuncture) may result in hematoma.

v. The great saphenous vein may dilate at its termination.

vi. The femoral nerve may give rise to neuroma.

vii. Pus arising from tuberculosis of thoracic vertebrae tracks down along the psoas sheath to present as a swelling (psoas abscess) in the groin.

viii. The inguinal lymph nodes enlarge due to inflammatory lesions or malignancy in the areas of their drainage.

ix. The ectopic testis in the femoral triangle presents as a lump in the groin.

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**Exit of Contents**

The main contents enter through the apex of the femoral triangle but they leave by different routes.

i. The femoral artery and vein leave through the posterior wall at the tendinous opening in the adductor magnus.

ii. The saphenous nerve leaves by piercing the roof.

iii. The nerve to vastus medialis leaves by entering the vastus medialis (anterolateral boundary).

**Subsartorial Plexus of Nerves**

The subsartorial plexus supplies the skin of the medial side of thigh. It is located between the fibrous roof and the sartorius. It is formed by twigs from the saphenous nerve, medial cutaneous femoral nerve and anterior division of obturator nerve.

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**Clinical insight ...**

For treating the aneurysm of popliteal artery, surgeons ligate the femoral artery in subsartorial canal. This procedure is based on the fact that there are adequate anastomotic channels around the knee through which blood reaches the...
Femoral Nerve
The femoral nerve is a branch of lumbar plexus, which is housed inside the psoas major muscle located on the posterior abdominal wall. The dorsal branches of the ventral rami of second, third and fourth lumbar spinal nerves join to form the femoral nerve (root value-L2, L3, L4).

Course (Fig. 93.10)
The femoral nerve emerges from the lateral margin of psoas major muscle and descends to reach the iliac fossa, where it lies between the iliacus and psoas major muscles. It supplies branches to iliacus at this level. It enters the femoral triangle behind the inguinal ligament lying outside the femoral sheath. Here, it is in lateral relation to the femoral artery, which is inside the femoral sheath. In the femoral triangle, the femoral nerve lies in the groove between psoas and iliacus. The femoral nerve divides into anterior and posterior divisions just below the inguinal ligament. Hence, it has very short trunk in the femoral triangle.

Branches in Femoral Triangle
The branches are divided according their origin from the trunk, anterior division and posterior division of femoral nerve.

Muscular
i. From the trunk—to pectineus
ii. From anterior division—to sartorius
iii. From posterior division—to four parts of quadriceps femoris.

Cutaneous
i. From anterior division—medial (or medial anterior) and intermediate (or anterior lateral) femoral cutaneous nerves of thigh
ii. From posterior division—saphenous nerve.

Clinical insight...

Saphenous Nerve
It is a branch of the posterior division of femoral nerve. It is the longest cutaneous nerve in the body.

Course
The saphenous nerve leaves the femoral triangle along with femoral vessels through the apex to enter the subsartorial canal. The saphenous nerve lies anterior to the femoral vessels at the apex of femoral triangle. During its course through the subsartorial canal, it crosses in front of the femoral artery to become the medial relation of the artery. It leaves the subsartorial canal along with saphenous branch of descending genicular artery by piercing the fibrous roof at popliteal artery even if femoral artery is ligated. For surgical approach to the femoral artery in the subsartorial canal a skin incision is placed along the line of anterior border of middle-third of sartorius. The superficial and deep fasciae are divided and the sartorius is retracted. The fibrous roof of the canal is incised to expose the femoral artery.

(Note that the femoral nerve extends up to the base of great toe)
the lower end of the canal. In its further course, it descends vertically along the medial side of knee lying behind the sartorius. The saphenous nerve pierced the deep fascia of leg between the tendons of sartorius and gracilis to become superficial. In the leg, it descends with the great saphenous vein along the medial side, passes in front of the medial malleolus to enter the dorsum of the foot, where it reaches up to the base of big toe.

**Branches**

i. In the thigh, the saphenous nerve gives a twig to the subsartorial plexus. Its infrapatellar branch contributes to the patellar plexus along with medial, intermediate and lateral femoral cutaneous nerves of thigh.

ii. In the leg, it supplies the skin of medial side of front of leg and the medial side of ankle.

iii. In the foot, it supplies the skin of the medial side of the dorsum of foot up to the base of big toe.

**Saphenous Nerve Graft**

The superficially located saphenous nerve is favored for nerve grafting.

**Femoral Artery**

The femoral artery is the chief artery of the lower limb.

**Extent (Fig. 93.11)**

It begins as the continuation of the external iliac artery at the midinguinal point. After coursing through the femoral triangle and subsartorial canal it leaves the thigh through adductor hiatus or tendinous opening in the adductor magnus muscle, where it enters the popliteal fossa to continue as popliteal artery.

**Surface Marking**

To draw the femoral artery on the surface, the thigh is kept in a position of slight flexion, abduction and lateral rotation. The upper two-third of a line drawn from the midinguinal point to the adductor tubercle represents the femoral artery in the thigh. The upper one-third of this line represents the femoral artery in femoral triangle while the middle-third represents the femoral artery in the subsartorial canal.

**Femoral Pulse (Fig. 93.12)**

The femoral pulse is felt in the femoral triangle just below the midinguinal point (a point half way between the anterior superior iliac spine and pubic symphysis). Bilateral weak femoral pulse compared to the radial pulse is indicative of coarctation (narrowing) of arch of aorta. The femoral pulse may be reduced or obliterated by atherosclerotic changes or emboli in proximal arteries. The femoral artery can be compressed against the iliopubic eminence.

**Relations in Femoral Triangle**

i. Anterior relations from superficial to deep are the skin, superficial fascia with inguinal lymph nodes, fascia lata and anterior wall of femoral sheath.

ii. The posterior relations are the posterior wall of the femoral sheath, nerve to pectineus and tendon of psoas major muscle. This tendon separates the artery from the capsule of hip joint. At this site the artery can be
compressed against the iliopubic eminence through the skin.

iii. The femoral nerve and its branches form the lateral relation.

iv. The femoral vein lies medial to the artery except at the apex, where it lies posterior to the artery.

**Relations in Subsartorial Canal**

The saphenous nerve crosses the femoral artery anteriorly to come on its medial side. The femoral vein, which is posterior to the artery in the upper part of the canal, becomes its lateral relation distally. The artery is related posteriorly to the adductor longus and magnus muscles.

**Branches in Femoral Triangle (Fig. 93.13)**

Three superficial and three deep branches originate in femoral triangle.

i. The superficial branches are superficial epigastric, superficial external pudendal and superficial circumflex iliac arteries.

ii. The deep branches are deep external pudendal, profunda femoris and the muscular branches.

**Branches in Subsartorial Canal (Fig. 93.13)**

i. Muscular branches

ii. Descending genicular artery leaves the canal by descending in the substance of the vastus medialis. It divides into an articular and a saphenous branch. The latter accompanies the saphenous nerve as it emerges through the roof of the subsartorial canal.

**Clinical insight ...**

i. Since the femoral artery is relatively superficial in position in the thigh; it is easy to approach the artery for various procedures. To inject radio-opaque dye in the arteries of abdomen (aortic angiography, celiac angiography, superior and inferior mesenteric angiography etc.) the catheter is introduced through the femoral artery. It is also a favored vessel for coronary angiography or for coronary angioplasty. The route of the catheter is as follows – femoral artery → external iliac artery → common iliac artery → abdominal aorta → thoracic aorta → arch of aorta → ascending aorta → coronary ostia. The complication that may occur after the procedure of femoral puncture is thrombus formation at puncture site. Therefore after this procedure routinely the dorsalis pedis pulse of the patient is tested.

ii. The femoral angiography (Fig. 93.14) is performed to visualize the femoral artery and its branches in suspected cases of femoral artery occlusion.

iii. Sudden occlusion in the femoral artery usually occurs due to emboli from the heart (myocardial infarction or...
Femoral Vein

The femoral vein begins at the tendinous opening in the adductor magnus as the continuation of popliteal vein. It ascends in the subsartorial canal and then enters the femoral triangle. After traversing the intermediate compartment of the femoral sheath the femoral vein continues upward as the external iliac vein just medial to the midinguinal point.

Relations

The femoral vein has changing relation to the femoral artery in its course at various levels.

i. At the tendinous opening the femoral vein is lateral to the femoral artery.

ii. In the subsartorial canal the vein, gradually crosses posterior to the artery so that at the apex of the femoral triangle it lies posterior to the femoral artery.

iii. At the base of the femoral triangle, the femoral vein lies medial to the femoral artery.

Valves in Femoral Vein

The femoral vein contains four to five valves, the most constant being the saphenofemoral valve (competency of this valve is tested by Trendelenburg test).

Tributaries

i. Great saphenous vein
ii. Profunda femoris vein
iii. Lateral circumflex femoral vein
iv. Medial circumflex femoral vein.

Muscles of Anterior Compartment

The psoas major and iliacus muscles are described with posterior abdominal wall (chapter 84). The pectineus muscle is described with medial compartment of thigh (chapter 94).

Tensor Fasciae Latae

This muscle is located at the junction of thigh and gluteal region at the lateral side (Fig. 93.3). It shares its insertion with gluteus maximus muscle and shares its nerve supply and actions with gluteus medius and minimus muscles. The muscle is enclosed in the upper part of iliotibial tract.

Attachments

i. The tensor fasciae latae takes origin from the outer lip of the iliac crest in front of the iliac tubercle.

ii. It is inserted into the iliotibial tract through which it gains attachment to the lateral condyle of tibia.

Nerve Supply

The superior gluteal nerve supplies the muscle.

Actions

i. The tensor fasciae latae assists the gluteus medius and minimus muscles in abduction and medial rotation of the thigh.

ii. It stabilizes the knee joint in standing position and helps in extension of the knee joint through the iliotibial tract.

Sartorius (Fig. 91.5)

The word sartorius is derived from the Latin word sartor meaning tailor. Hence, sartorius is called the tailor’s muscle. While using sewing machine, the tailors adopt a position in which both hip and knee joints are flexed. The sartorius is a very long strap like muscle composed of parallel muscle fibers.

Attachments

i. The sartorius takes origin from the anterior superior iliac spine.
ii. It is inserted into the upper part of the subcutaneous medial surface of the shaft of tibia. The tendinous insertion of sartorius is separated on the posterior aspect by bursa anserina from the insertions of gracilis and semitendinosus.

Relations
The sartorius courses obliquely in lateromedial direction from its origin to insertion. Its medial margin forms the lateral boundary of femoral triangle and it covers the fibrous roof of the subsartorial canal.

Nerve Supply
The femoral nerve in femoral triangle supplies the muscle.

Actions
i. The sartorius is the only muscle that flexes both the hip and knee joints.
ii. It helps in lateral rotation of thigh.

Quadriceps Femoris
It is a very bulky muscle, which almost fills the anterior compartment of thigh. It has four components having separate names (rectus femoris, vastus lateralis, vastus medialis and vastus intermedius). Each component has a separate origin but a common insertion.

Origin
i. The rectus femoris has two heads of origin. The straight head arises from the anterior inferior iliac spine. The reflected head arises from the groove above the margin of acetabulum (Fig. 91.2A). The two heads unite to form a bipennate muscle, which passes vertically downwards superficial to the other components to join them. The rectus femoris crosses the hip and knee joints.
ii. The vastus lateralis (the largest component) takes a linear origin from the upper part of intertrochanteric line, anterior border of greater trochanter, lateral lip of gluteal tuberosity and upper part of lateral lip of linea aspera. Because of its bulk the vastus lateralis is preferred for the intramuscular injection.
iii. The vastus medialis takes linear origin from lower part of intertrochanteric line, spiral line, entire length of medial lip of linea aspera and upper one-fourth of medial supracondylar line.
iv. The vastus intermedius arises from the lateral and anterior surfaces of the femoral shaft. Its lowest fibers called articularis genu, arise from the front of the lower part of the shaft of femur (Fig. 91.3A).

Insertion (Fig. 93.15)
The four parts of quadriceps femoris unite to form a common tendon (quadriceps tendon), which is inserted into the margins of patella. The insertion is prolonged over the front of patella as the strong ligamentum patellae to the tuberosity of tibia.

Details of Insertion
i. The rectus femoris and vastus intermedius are inserted into the upper margin of patella.
ii. The lower fleshy fibers of vastus medialis insert in to the medial margin of patella (this part of vastus medialis is known as vastus medialis oblique as against its remaining part, which is known as vastus medialis longus). Moreover the attachment of vastus medialis extends longer (than that of vastus lateralis to the lateral margin of patella).
iii. The medial and lateral patellar retinacula are the expansions from the sides of patella to the respective condyles of tibia. The patella, which is a sesamoid bone in the tendon of quadriceps femoris, increases the power of the muscle by holding the tendon of quadriceps away from the distal end of femur. This brings the tendon in line with the tibial tuberosity thereby increasing its leverage.
iv. The combination of quadriceps tendon, patella and ligamentum patellae is known as patellofemoral complex.
v. Articularis genu is inserted in to the synovial membrane of the suprapatellar bursa of knee joint.
Actions

i. The quadriceps femoris muscle is a powerful extensor of the knee joint. It straightens the lower limb (extends) during the act of standing from sitting position. The tone of the quadriceps muscle is very important to the stability of the knee joint.

ii. The tendinous expansions of medial and lateral vasti form the patellar retinacula, which blend with the capsule of knee joint to reinforce it.

iii. The rectus femoris acts on the hip joint. It is the flexor of hip joint.

iv. The articularis genu retracts the synovial membrane superiorly during extension of the knee joint so as to prevent it getting caught between femur and patella.

Nerve Supply

All parts of quadriceps femoris are separately innervated by femoral nerve. The articularis genu receives a twig from the nerve to vastus intermedius.

Testing Function

The quadriceps femoris is tested with the subject in supine position and knee joint partially flexed. When the subject is asked to extend the knee against resistance the normal quadriceps muscle is seen and felt.

Clinical insight ...

i. Patellar tendon reflex is elicited by tapping ligamentum patellae with a knee hammer. The positive response consists of extension of the leg at knee joint. The reflex consists of afferent limb (femoral nerve), efferent limb (femoral nerve) and the spinal center (L2, L3 and L4 segments). The reflex is lost in injury to femoral nerve or injury to spinal reflex center.

ii. The disuse atrophy of quadriceps femoris results due to immobilization of knee joint on account of any cause (knee disorders or plaster cast). Reduction in size of the quadriceps femoris due to atrophy is found out by measuring the circumference of each thigh. For preventing the disuse atrophy active exercises (physiotherapy) are started as early as possible in patients in whom lower limb is immobilized.

Know More ...

Normally, between the oblique line of quadriceps muscle and the straight line of patellar ligament there is valgus angle opening on lateral side. The supplement of the valgus angle is called the quadriceps angle or Q angle (normal value is around 10–12°). Wider pelvis in female increases the obliquity of femur and increases the Q angle. In fact it is the Q angle that is responsible for the natural tendency of patella to dislocate laterally. To counteract this tendency the vastus medialis oblique muscle pulls the patella medially in addition to the bony factors. If the value of Q angle is greater than 15° there is lateral pull on patella. This causes the patella to rub against the lateral condyle of femur resulting in patellar pain initially and later its dislocation laterally.
### GLUTEAL REGION

The gluteal region or buttock is a prominent bulge at the lower back produced by the subcutaneous fat and the bulky gluteus maximus muscle.

#### Boundaries (Fig. 94.1)

The gluteal region is bounded superiorly by the iliac crest and superomedially by the sacrum. Inferiorly, the gluteal sulcus separates it from the thigh. Medially, there is natal cleft. A line joining the anterior superior iliac spine to the front of the greater trochanter of femur limits the region laterally.

#### Communications

i. The gluteal region communicates with the pelvic cavity through the greater sciatic foramen.

ii. It communicates with the ischiorectal fossa through the lesser sciatic foramen.

iii. Inferiorly, it is continuous with the posterior compartment of thigh.
**Superficial Fascia**

The superficial fascia of the gluteal region is thick and filled with fat. A number of cutaneous nerves are present in the superficial fascia (Fig. 94.2).

**Deep Fascia**

The deep fascia splits to enclose the gluteus maximus muscle, above which it continues as a single sheet covering the outer surface of gluteus medius muscle (gluteal aponeurosis). On the lateral aspect, the deep fascia is thickened to form iliotibial tract. The tensor fasciae latae muscle is enclosed in the two layers of iliotibial tract. Thus, in the gluteal region the deep fascia splits twice to enclose two muscles, both of which insert in to the iliotibial tract lower down in the thigh.

**Gluteus Maximus**

The gluteus maximus (Fig. 94.3) is the largest and the most superficial muscle of the gluteal region. It has a coarse texture due to a large number of fibrous septa in its substance.

**Origin**

The gluteus maximus takes origin from the outer surface of ilium behind the posterior gluteal line, posterior surface of adjacent sacrum and coccyx and the sacrotuberous ligament.

**Insertion**

i. Three fourth of the muscle is inserted by tendinous fibers into the posterior aspect of iliotibial tract.

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**Fig. 94.2:** Cutaneous nerves of gluteal region shown on left side and gluteus maximus and tensor fasciae latae on other side

**Fig. 94.3:** Structures under cover of gluteus maximus
(Note the continuity of gluteal region and posterior compartment of thigh)
ii. The deeper one-fourth of the muscle is inserted into the gluteal tuberosity of femur (Fig. 91.3C).

**Nerve Supply**
The inferior gluteal nerve supplies the muscle.

**Actions**

i. The gluteus maximus is a powerful extensor of thigh on the trunk or of trunk on the thigh at the hip joint in such activities as running, climbing steps and rising from sitting position (for these actions it acts from the origin).

ii. It is the lateral rotator of thigh.

iii. Acting from its insertion, it can straighten the trunk after stooping by rotating the pelvis backward on the head of femur (this action is in association with hamstring muscles).

iv. It maintains the upright position of trunk by preventing the pelvis from rotating forward on the head of femur (thus retaining the center of gravity behind the hip joint).

v. It stabilizes the knee joint through iliotibial tract.

**Testing Function**
The subject lying in prone position is asked to raise the thigh against resistance. Inability to do so indicates weakness of the muscle.

**Structures Under Cover (Fig. 94.3)**

**Bony Structures**

i. Ischial spine

ii. Ischial tuberosity

iii. Greater and lesser sciatic foramina

iv. Greater trochanter of femur

**Ligaments**

i. The sacrotuberous ligament extends from the ischial tuberosity to the lower lateral part of sacrum and coccyx and both posterior iliac spines. It is regarded as the continuation of biceps femoris muscle. The perforating cutaneous nerve from the sacral plexus pierces this ligament to enter the gluteal region.

ii. The sacrospinous ligament extends from the tip of ischial spine to the lower lateral part of sacrum and coccyx. It lies deep to sacrotuberous ligament and is regarded as the aponeurotic posterior part of coccygeus muscle. The pudendal nerve passes over the apex of the ligament to enter the lesser sciatic foramen.

**Bursae**

i. A large trochanteric bursa separates the gluteus maximus from the greater trochanter.

ii. The gluteofemoral bursa is present between the tendon of gluteus maximus and origin of vastus lateralis.

iii. The ischial bursa lies between the gluteus maximus and the lower medial part of ischial tuberosity. This bursa may become inflamed due to excessive friction producing ischial bursitis (weaver’s bottom).

**Muscles**

i. Gluteus medius and deep to it the gluteus minimus

ii. Piriformis

iii. Tendon of obturator internus with fleshy bellies of gemelli muscles

iv. Quadratus femoris and the tendon of obturator externus deep to it

v. Origin of hamstring muscles from the ischial tuberosity

**Nerves**
The following seven branches of the sacral plexus (inside the pelvic cavity) enter the gluteal region via greater sciatic foramen.

i. Sciatic nerve

ii. Posterior cutaneous nerve of thigh

iii. Superior gluteal nerve

iv. Inferior gluteal nerve

v. Nerve to obturator internus

vi. Nerve to quadratus femoris

vii. Pudendal nerve

**Arteries**
The following arteries are seen in the gluteal region:

i. The superior and inferior gluteal arteries (accompanying the corresponding nerves) and internal pudendal artery are the branches of internal pudendal artery.

ii. The medial circumflex femoral artery, which is the branch of profunda femoris artery, enters from the thigh.

**Gluteus Medius and Minimus**

These two muscles have common nerve supply and actions.

i. The gluteus medius takes origin from the outer surface of ilium between the anterior and posterior gluteal lines (Fig. 91.2A). It is inserted into the lateral aspect of greater trochanter along an oblique ridge (Fig. 91.3A).

ii. The gluteus minimus is entirely under cover of gluteus medius. It arises from the outer surface of ilium between anterior and inferior gluteal lines and is inserted in the greater trochanter on the anterolateral ridge. The
reflected head of rectus femoris and the capsule of hip joint are located under cover of gluteus minimus.

**Nerve Supply**
Both gluteus medius and minimus muscles are supplied by superior gluteal nerve.

**Actions**

i. The gluteus medius and minimus muscles abduct the thigh at the hip joint, when the limb is free to move.

ii. Their anterior fibers bring about medial rotation and flexion of thigh.

iii. Their important function is to support the pelvis in walking. When a person stands on one foot and the foot of the opposite side is raised from the ground to take a step, the contraction of the glutei medius and minimus muscles of the supported side raises the contralateral pelvis a little (Fig. 94.4). In this way, the contraction of the muscles on one side prevents the pelvis of the opposite side from sinking down, when the foot on that side is off the ground. These actions on the right and left sides of pelvis occur alternately during walking and depend on the integrity of three factors, namely, the normal glutei medius and minimus, normal hip joint and intact femoral neck with normal angulation with the shaft (125°).

**Testing Function**
The subject lies prone with knee flexed at 90°. The subject is asked to push the foot outward against resistance. Inability to do so means weakness of gluteus medius and minimus muscles.

**Short Lateral Rotators of Thigh**
There are four muscles, which fall in this category, piri-formis, obturator internus with gemelli, obturator externus and quadratus femoris. These short muscles are collectively called the short lateral rotators of thigh at the hip joint. However, their main function is to act as ligaments, which retain the head of femur in the acetabulum.

**Piriformis (Fig. 86.3)**
This muscle is located partly in the pelvis and partly in the gluteal region.

**Origin**
Its origin is inverted E-shaped from the anterior or pelvic surface of the sacrum.

**Course and Relations**

i. In its intra-pelvic course the piriformis turns laterally towards the greater sciatic foramen, through which it enters the gluteal region.

ii. Inside the pelvis its important anterior relations are rectum, sacral plexus and branches of internal iliac artery.

iii. The piriformis almost fills the greater sciatic foramen. It is regarded as the key muscle of the gluteal region (Fig. 94.3) because the nerves and blood vessels entering the gluteal region are arranged in relation to it at the greater sciatic foramen. The superior gluteal nerve and vessels are related to the upper margin of the piriformis. The inferior gluteal nerve and vessels, sciatic nerve, posterior cutaneous nerve of thigh, nerve to quadratus femoris, nerve to obturator internus, pudendal nerve, nerve to obturator internus and internal pudendal vessels are related to its lower margin. When the sciatic nerve divides inside...
the pelvis, its common peroneal component passes through or above the piriformis but the tibial component passes below the piriformis.

**Insertion**
The muscle is inserted into the superior border of the greater trochanter of femur.

**Nerve Supply**
The intrapelvic part of the piriformis receives direct branches from the ventral rami of the fifth lumbar and upper two sacral nerves.

**Actions**
It laterally rotates the extended thigh and abducts the flexed thigh.

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**Obturator Internus (Fig. 86.1)**
The obturator internus muscle is partly intrapelvic and partly gluteal in location. Its intrapelvic part is described with muscles of the pelvis (in chapter 86).

**Origin**
It takes origin from the inner surface of obturator membrane and the surrounding bones (ischium, ilium and pubis).

**Course and Relations**
The tendon of the obturator internus muscle enters the gluteal region through the lesser sciatic foramen. The tendon provides the insertion for the superior gemellus and for the inferior gemellus. The obturator internus tendon and the two gemelli together constitute triceps coxae. They are related anteriorly to the sciatic nerve (Fig. 94.3).

**Insertion**
The common tendon of triceps coxae passes horizontally across the capsule of the hip joint to reach its insertion on the upper part of medial surface of greater trochanter.

**Nerve Supply**
The nerve to obturator internus supplies the obturator internus muscle.

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**Gemelli**
There are two gemelli, superior gemellus and inferior gemellus.

**Origin**
The superior gemellus takes origin from the posterior aspect of ischial spine and the inferior gemellus from the uppermost part of ischial tuberosity.

**Insertion**
Both the gemelli insert into the tendon of obturator internus. Their insertion is extended along with obturator internus to the medial surface of greater trochanter.

**Nerve Supply**
The superior gemellus is supplied by nerve to obturator internus and the inferior gemellus is supplied by nerve to quadratus femoris.

**Action**
They laterally rotate the extended thigh and abduct the flexed thigh.

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**Quadratus Femoris**
This is a small quadrilateral muscle lying between the inferior gemellus and superior margin of adductor magnus.

**Origin**
It takes origin from the lateral border of ischial tuberosity and passes behind the neck of the femur and the capsule of hip joint.

**Insertion**
It is inserted into the quadrate tubercle located on the upper part of intertrochanteric crest of femur.

**Nerve Supply**
The quadratus femoris is supplied by nerve to quadratus femoris, a branch of sacral plexus.

**Action**
This muscle is the lateral rotator of thigh.

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**Obturator Externus**
This muscle is described with the medial compartment of thigh. Only its tendon appears in the gluteal region in close

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**Clinical insight ...**

**Piriformis Syndrome**
In piriformis syndrome, the sciatic nerve is compressed due to spasm or hypertrophy of the piriformis muscle at the greater sciatic foramen.
contact with the back of the neck of femur on way to its insertion into the trochanteric fossa of femur.

**Nerves in Gluteal Region**

i. The superior gluteal nerve (L4, L5, S1) arises from sacral plexus in pelvis and enters the gluteal region via the greater sciatic foramen above the piriformis and in company with superior gluteal vessels. Lying in the interval between gluteus medius and minimus it supplies the gluteus medius, gluteus minimus and tensor fasciae latae. An inadvertent intramuscular injection in the superomedial quadrant of the gluteal region may injure the superior gluteal nerve.

ii. The inferior gluteal nerve (L5, S1, S2) arises from the sacral plexus and enters the gluteal region through the greater sciatic foramen below the piriformis along with the inferior gluteal vessels. It supplies the gluteus maximus muscle.

iii. The nerve to quadratus femoris (L4, L5, S1) is a branch of sacral plexus. It enters the gluteal region through the greater sciatic foramen by passing below the piriformis. It descends initially behind the dorsal surface of ischium and in front of sciatic nerve, and then in front of the superior gemellus and tendon of obturator internus muscle. It supplies gemellus inferior and quadratus femoris. It may also give an articular twig to the hip joint.

iv. The nerve to obturator internus (L5, S1, S2) is a branch of sacral plexus. It enters the gluteal region through the greater sciatic foramen along with pudendal nerve and internal pudendal vessels. It supplies a branch to the superior gemellus. It crosses the dorsal surface of the base of ischial spine and enters the lesser sciatic foramen to supply branches to the pelvic surface of obturator internus muscle.

v. The pudendal nerve (S2, S3, S4) is a branch of the sacral plexus. It has a very short course in the gluteal region. It crosses the sacrospinous ligament to enter the lesser sciatic foramen. The internal pudendal artery, which is a branch of the internal iliac artery, accompanies the nerve. The internal pudendal vessels are sandwiched between the nerve to obturator internus laterally and pudendal nerve medially (Figs 94.3 and 94.5). The pudendal nerve and the internal pudendal artery are described in detail in the chapter on perineum.

vi. The posterior cutaneous nerve of thigh (S1, S2, S3) is also known as posterior femoral cutaneous nerve. It arises from the sacral plexus and contains fibers from the dorsal divisions of S1 and S2 ventral rami and from ventral divisions of S2 and S3 ventral rami. It enters the gluteal region by passing below the piriformis. Its course is divided into four parts, gluteal, posterior thigh, popliteal fossa and leg. In the gluteal region, it lies on the superficial aspect (posterior) of the sciatic nerve immediately deep to the gluteus maximus. In the thigh, it descends lying superficial to the long head of biceps femoris and deep to the deep fascia of thigh. It enters the popliteal fossa, where it pierces the deep fascia. It descends in the superficial fascia to the level of middle of the calf along with short saphenous vein. It supplies a few cutaneous branches for the supply of the skin of the inferolateral part of gluteal region. Its perineal branch pierces the fascia lata and Colles’ fascia to enter the superficial perineal pouch. It supplies the skin of the posterior aspect of scrotum or labia majora. The cutaneous twigs are distributed to the skin of the back of thigh, popliteal fossa and the upper half of the back of leg.

vii. The perforating cutaneous nerve (S2, S3) is a branch of sacral plexus. It enters the gluteal region by perforating the sacrospinous ligament and supplies the skin of the posteroinferior area of gluteal region (Fig. 94.2).

viii. The sciatic nerve enters the gluteal region via the greater sciatic foramen. A detailed account of sciatic nerve follows later.

**Vessels of Gluteal Region (Fig. 94.5)**

The branches of internal iliac artery enter the gluteal region. Some of these branches anastomose with the branches of femoral artery. These anastomoses establish collateral circulation whenever necessary.

i. The superior gluteal artery is a branch of the posterior division of internal iliac artery. It enters the gluteal region along with the corresponding nerve above the
piriformis. It divides into superficial and deep branches. The superficial branch supplies the gluteus medius and maximus. The deep branch divides into upper and lower branches. The upper or ascending branch anastomoses with superficial and deep circumflex iliac and ascending branch of lateral circumflex and iliolumbar arteries near the anterior superior iliac spine. The lower or descending branch takes part in trochanteric anastomosis.

i. The inferior gluteal artery is a branch of anterior division of internal iliac artery. Along with inferior gluteal nerve it enters the gluteal region below the piriformis. It gives muscular branches mainly to gluteus maximus muscle. Its most important branch is, an accompanying artery to sciatic nerve, which sinks into the substance of the sciatic nerve. It also gives anastomotic branches that take part in trochanteric and cruciate anastomosis.

POSTERIOR COMPARTMENT OF THIGH

The posterior compartment of thigh contains a group of muscles called hamstrings. The tendons of these muscles are found in the region of ham (poples) in the lower part of the back of the thigh (popliteal region).

Characteristics of Hamstring Muscles

To be called a hamstring the muscle must have the following four features.

1. Origin from ischial tuberosity (Fig. 94.6)
2. Insertion into either tibia or fibula
3. Nerve supply by tibial part of sciatic nerve
4. Action as extensor of hip joint and flexor of knee joint

Contents of Posterior Compartment

1. Hamstring muscles
   i. Long head of biceps femoris
   ii. Semitendinosus
   iii. Semimembranosus
   iv. Ischial part of adductor magnus
2. Short head of biceps femoris
3. Sciatic nerve
4. Posterior cutaneous nerve of thigh.

There is no major artery in the back of thigh as the hamstrings and short head of biceps femoris are supplied by perforating branches of profunda femoris artery.

Biceps Femoris

This muscle has two heads. The long head is a true hamstring muscle while the short head is not.

Attachments

i. The long head takes origin from the muscular impression on the superomedial area of the ischial tuberosity along with semitendinosus (Fig. 94.7) and the short head takes origin from the lateral lip of linea aspera of femur.

ii. The two heads unite in the thigh and form a tendon, which can be palpated in the superolateral boundary of popliteal fossa. The tendon splits around the fibular collateral ligament and is inserted into the head of fibula.
Nerve Supply
i. The long head is supplied by tibial part of sciatic nerve high up in the thigh.
ii. The short head is supplied by the common peroneal or lateral part of the sciatic nerve at the lower level.

Actions
i. The long head of biceps femoris produces extension of hip joint and flexion of knee joint.
ii. The short head produces only flexion of knee joint.

Nerve Supply
The semitendinosus is supplied by tibial part of the sciatic nerve.

Semimembranosus
This muscle is so called because it splits into membranous slips at its insertion.

Attachments
i. The semimembranosus originates from the supero-lateral area of ischial tuberosity by a broad flat tendon.
ii. It ends in a tendon, which forms the superomedial boundary of the popliteal fossa and is inserted mainly into a groove at the back of the medial condyle of tibia.

Extensions from the Insertion (Fig. 94.8)

i. Oblique popliteal ligament of knee joint
ii. Fascia covering the popliteus muscle
iii. A slip for attaching to the deep fascia of leg

Nerve Supply
The tibial or medial part of the sciatic nerve supplies the muscle.

Adductor Magnus
The ischial part of adductor magnus is described along with adductor group of muscles in chapter 95.

Actions of Hamstrings
The hamstring muscles extend the thigh at the hip and flex the leg at knee joint. With knee semiflexed the biceps femoris acts as lateral rotator of knee. With knee semiflexed...
the semitendinosus and semimembranosus act as medial rotators of knee joint.

Testing Function of Hamstrings
While testing the hamstring muscles the subject lies prone with knee extended. The subject is asked to flex the knee against resistance in this position.

Clinical insight ...

Pulled Hamstrings
The professional runners are prone to this painful condition, in which the attachment of hamstrings to the ischial tuberosity is torn. The extension of hip and flexion of knee is essential for running. So, the runners are liable to overstrain these muscles.

SCIATIC NERVE
The sciatic nerve is the thickest nerve in the body. It is about 1.5 to 2 cm wide. The sciatic nerve extends from the pelvis to the upper angle of popliteal fossa (at the level of the junction of lower and middle thirds of thigh), where it divides into terminal branches, which are called tibial and common peroneal (common fibular) nerves. The sciatic nerve supplies the muscles of the posterior compartment of the thigh and through its terminal branches it supplies all the muscles of the leg and foot. It has a wide sensory supply, which includes the entire leg and foot except the area supplied by the saphenous nerves.

High Division
Occasionally, the sciatic nerve divides into terminal branches high up inside the pelvis or in the gluteal region or in the upper thigh.

Root Value
The sciatic nerve is the largest branch of the sacral plexus (L4, L5, S1, S2, S3), which is located in the pelvis in front of the piriformis muscle.

Components
The sciatic nerve has two components, which are enclosed in a common connective tissue covering.

The tibial component is medial. It consists of ventral divisions of L4, L5, S1, S2, and S3 ventral rami. The common peroneal component is lateral. It consists of dorsal divisions of L4, L5, S1 and S2 ventral rami of spinal nerves.

Exit from Pelvis
i. Normally, the sciatic nerve exits from pelvis to enter the gluteal region through the greater sciatic foramen below the piriformis.

ii. In intra-pelvic division of sciatic nerve, the common peroneal component either pierces the piriformis or passes above it and the tibial component passes below the piriformis (Figs 94.9A and B).

Course and Relations in Gluteal Region
From the lower margin of the piriformis, the sciatic nerve descends to enter the posterior compartment of thigh. It passes downwards through the inferomedial quadrant of the gluteal region.

Anterior Relations (Fig. 94.10)
(from above downwards)

i. Dorsal surface of body of ischium close to acetabulum separated by nerve to quadratus femoris
Posterior Relation
The sciatic nerve is covered posteriorly by the gluteus maximus.

Surface Marking (Fig. 94.11)
- To represent the gluteal course of the sciatic nerve two points are marked. The upper point corresponds to a point about 2 to 2.5 cm lateral to the midpoint of a line joining the posterior superior iliac spine and the ischial tuberosity. The lower point is marked midway between the greater trochanter and ischial tuberosity. A thick curved line (with outward convexity) joining the two points represents the nerve.
- To represent the sciatic nerve in the thigh, a straight line is drawn from the lower point (mentioned above) to meet the upper angle of popliteal fossa.

Arterial Supply (Fig. 94.3)
The sciatic nerve receives a special artery called companion artery of sciatic nerve (arteria nervi ischiadici), a branch of inferior gluteal artery. This artery enters the substance of the sciatic nerve. When the sciatic nerve is cut in above knee amputation (AKA), the companion artery is secured and ligated to avoid profuse bleeding. Its embryological importance is that it is an example of the axis artery of lower limb.
Branches in the Gluteal Region
Articular branch to the hip joint.

Branches in the Thigh
i. Muscular branches arise from its medial side (tibial part) for long head of biceps femoris, semitendinosus, semimembranosus and ischial part of adductor magnus.
ii. Muscular branch arises from its lateral side (common peroneal part) to short head of biceps femoris. Therefore, the medial side of sciatic nerve is considered its side of danger and lateral side as its safe side.

Clinical insight ...

i. Sciatica is caused by compression of the lower lumbar and upper sacral nerve roots or by pressure on the sacral plexus. The patient experiences radiating pain down the posterior aspect of thigh, posterior and lateral sides of leg and lateral part of foot.
ii. The sleeping foot is due to temporary compression of the sciatic nerve against femur, at the lower border of gluteus maximus, when a person sits on the hard edge of a chair for a long time.
iii. For anesthetic block of sciatic nerve, the site chosen for injection is a few centimeter inferior to the midpoint of the line joining posterior superior iliac spine and apex of greater trochanter.

Effects of Injury to Sciatic Nerve
(in posterior dislocation of hip joint)

i. Paralysis of the muscles of posterior compartment of thigh, posterior compartment of leg and foot.
ii. Sensory loss below the knee with sparing of the skin supplied by saphenous nerve and deep peroneal nerve.

Effects of Injury to Tibial Component of Sciatic Nerve

i. Paralysis of all the muscles of posterior compartment of leg and of sole of the foot leading to inability to stand on the toes (due to loss of plantarflexion of foot).
ii. Loss of Achilles tendon reflex.
iii. Sensory loss on the sole of the foot, which may lead to trophic ulcers on the sole.

Effects of Injury to Common Peroneal Component of Sciatic Nerve

i. Paralysis of the muscles of anterior and lateral compartments of leg resulting in inability to stand on heel (foot drop due to involvement of deep peroneal nerve) and inability to evert foot (due to involvement of superficial peroneal nerve).
ii. Sensory loss on the anterolateral side of leg and dorsum of foot except for the area supplied by saphenous nerve (medial side of lower part of leg and medial border of foot as far as the root of great toe).

Intragluteal Injections
The intramuscular injections in gluteal region (Fig. 94.12) are commonly used for administration of antibiotics or iron, etc. The gluteal muscles provide a large surface area for absorption of drugs. Injecting in the superomedial quadrant endangers the superior gluteal nerve and vessels. Injecting in inferomedial quadrant endangers the sciatic nerve and inferior gluteal nerve and vessels. Sometimes only the lateral part of the sciatic nerve may be injured causing effects of common peroneal nerve injury like foot drop. Therefore, superolateral quadrant is a safe site for intramuscular injection. The point of injection is just posteroinferior to the anterior superior iliac spine.
ADDUCTOR COMPARTMENT OF THIGH

The adductor or medial compartment of thigh contains six muscles, obturator nerve, obturator vessels and the profunda femoris vessels.

Arrangement of Muscles
The muscles are arranged in three strata:

i. The muscles in the superficial stratum are the pectineus, adductor longus and gracilis.
ii. The muscles in the intermediate stratum are the obturator externus and adductor brevis.
iii. The muscle in the deep stratum is the large adductor magnus.
The adductor muscles collectively are called rider’s muscles.

Pectineus
The pectineus is a composite (or hybrid) muscle that belongs to medial and anterior compartments of thigh. It is located in the medial part of the floor of femoral triangle.

Attachments (Fig. 91.2A)

i. The pectineus takes origin from the pecten pubis of the superior ramus of pubis.
ii. It is inserted into the posterior aspect of femur on a line extending from the lesser trochanter to the linea aspera.

Relations
i. The anterior surface of the pectineus is directed towards the femoral triangle. The posterior wall of femoral sheath and the femoral vessels contained in it forms its immediate anterior relation.
ii. The posterior surface of pectineus is related to the capsule of the hip joint, obturator externus and the adductor brevis from above downward. The anterior division of obturator nerve descends between the posterior surface of the pectineus and the obturator externus and adductor brevis muscles.
iii. The adductor longus lies on its medial side and the profunda femoris vessels enter the gap between the two.
iv. The psoas major lies on the lateral side of pectineus and the medial circumflex femoral vessels enter the gap between the two.

Nerve Supply
The pectineus receives double nerve supply.

i. A branch from the femoral nerve from its anterior aspect
ii. A branch from the anterior division of obturator nerve (or by accessory obturator nerve when present) from its posterior aspect

Actions
Pectineus is a flexor of the thigh and assists in adduction of the thigh.
Adductor Compartment of Thigh and Hip Joint

Adductor Longus
It is a triangular muscle.

Attachments
i. The adductor longus arises from the front of the body of pubis (just below the pubic tubercle) by a narrow tendon. If the tendinous origin of the adductor longus is ossified, it forms a sesamoid bone (rider's bone).
ii. The tendon widens at its aponeurotic insertion on the linea aspera.

Relations (Fig. 93.7)
i. The medial margin of adductor longus forms the medial margin of the femoral triangle. It also forms the medial-most part of the floor of femoral triangle, where it lies edge to edge with pectineus on lateral side.
ii. Its anterior relations are as follows. Near its origin it is crossed by spermatic cord in male. In the femoral triangle and subsartorial canal, it is related to femoral vessels (Fig. 93.11).
iii. Its posterior relations are profunda femoris vessels, anterior branch of obturator nerve and adductor brevis muscle.

Nerve Supply
Anterior division of obturator nerve supplies the adductor longus muscle.

Actions
i. It is an adductor and medial rotator of thigh at the hip joint.
ii. It is an accessory flexor of leg at the knee joint.

Gracilis
This muscle derives its name from the Latin word gracilis meaning slender. The gracilis is this and flat muscle. It is the most superficial of the adductor muscles.

Attachments
i. The gracilis takes origin from the medial margin of the lower half of the body of pubis and the lower part of conjoint ischiopubic ramus. It descends vertically to become tendinous at the level of medial condyle of femur.
ii. It is inserted by a narrow, flattened tendon into the upper part of medial surface of tibia between the insertions of sartorius and semitendinosus (Fig. 91.5).

Nerve Supply
The anterior division of obturator nerve supplies it.

Gracilis Graft
Being easily accessible and functionally a weak muscle, the gracilis is suitable for muscle graft to replace the damaged muscle in somewhere else in the body. It is important to know that the entry point of the neurovascular bundle of gracilis is at its upper end. This is to facilitate inclusion of the neurovascular bundle along the graft.

Clinical insight ...

Obturator Externus
Though this muscle lies in the adductor compartment and is innervated by obturator nerve it does not function like other five muscles (adductor longus, adductor brevis, adductor magnus, pectineus and gracilis).

Attachments
i. The obturator externus takes origin from the external surface of the obturator membrane and the bony margins of the obturator foramen.
ii. Its tendon passes through the gluteal region behind the neck of the femur (with which it is in intimate contact) for insertion into the trochanteric fossa.

Nerve Supply
The posterior division of obturator nerve supplies it.

Actions
i. The obturator externus is a lateral rotator of thigh.
ii. Its tendon spirals round the back of neck of femur. This enables it to act like a ligament steadying the head of femur in the acetabulum.

Adductor Brevis (Figs 91.2A and 91.3C)
This muscle is triangular in shape.

Attachments
i. It takes origin from the external aspect of body and inferior ramus of pubis.
ii. It expands into an aponeurosis at its insertion along a line extending from the base of the lesser trochanter to upper part of linea aspera just behind the attachment of upper part of adductor longus.
Relations
i. The adductor brevis lies between the pectineus and adductor longus in front and the adductor magnus behind.
ii. It is sandwiched between the anterior and posterior divisions of obturator nerve.

Vascular Relations
i. The medial circumflex femoral artery runs along the upper margin of adductor brevis between it and obturator externus.
ii. The first to third perforating arteries (branches of profunda artery) arise in relation to the adductor brevis muscle, first at the level of its upper border, the second in front of it and the third at its lower border.

Nerve Supply
It is usually supplied by anterior division of obturator nerve but may receive a branch from the posterior division as well.

Actions
It is the adductor of thigh.

Adductor Magnus (Fig. 95.1)
This is a large composite or hybrid muscle, which has two functionally different parts, (adductor part and ischial or hamstring), which have different origin, insertion and nerve supply.

Attachments of Adductor Part
The adductor part of the muscle takes origin from the ischiopubic ramus.
i. The short, horizontal fibers from the pubic ramus insert into the gluteal tuberosity. This part of the muscle is called adductor minimus.
ii. The middle oblique fibers from the ischial ramus insert by a broad aponeurosis into the linea aspera and the proximal medial supracondylar line.

Osseo-aponeurotic Openings
The long insertion of the adductor part of adductor magnus is interrupted by five osseo-aponeurotic openings, bridged by tendinous arches attached to the linea aspera.
i. The upper four openings are small and transmit the four perforating branches of profunda femoris artery.
ii. The lowest opening is large and called adductor or tendinous hiatus (Fig. 93.11). It transmits the femoral vessels into the popliteal fossa. This opening lies on the medial supracondylar line of femur at the junction of middle and lower thirds of thigh.

Attachments of Ischial Part
The ischial part is located posterior to the adductor part.
i. Its vertically orientated fibers take origin from the inferolateral quadrant of the ischial tuberosity (Fig. 94.6).
ii. The muscle ends in the lower third of thigh into a rounded tendon, which can be palpated proximal to its insertion into the adductor tubercle of femur.

Relations
i. The anterior relations of adductor magnus are as follows. The muscular relations are the pectineus, adductor brevis and adductor longus muscles from above downwards. The neurovascular relations are the posterior division of obturator nerve, profunda vessels and the femoral vessels in the lower part of adductor canal.
ii. The posterior relations of adductor magnus are the sciatic nerve and the hamstring muscles.

Nerve Supply
i. The adductor part receives branches from the posterior division of the obturator nerve.
ii. The ischial part receives branches from the tibial component of the sciatic nerve.
Actions
i. The adductor part adducts and medially rotates the thigh.
ii. The ischial part (like other hamstring muscles) extends the hip joint and flexes the knee joint.

Obturator Nerve (Fig. 95.2)
The obturator nerve is a branch of the lumbar plexus, located on the posterior abdominal wall. Its root value is L2, L3 and L4 (ventral divisions of ventral rami of spinal nerves). It emerges from the medial margin of the psoas major muscle and crosses the pelvic brim anterior to the sacroiliac joint to enter the pelvic cavity.

Course inside Pelvis
i. The obturator nerve courses forwards on the lateral pelvic wall along the upper margin of obturator internus muscle. In female, it is related to lateral surface of the ovary.
ii. The obturator artery (a branch of anterior division of internal iliac artery) accompanies the obturator nerve. The neurovascular bundle thus formed enters the obturator canal.
iii. The obturator nerve terminates into anterior and posterior divisions in the obturator canal.
iv. The terminal branches leave via the obturator foramen to enter the medial compartment of thigh along with the obturator artery.

Course and Distribution of Anterior Division
The anterior division of the obturator nerve descends at first, in front of the obturator externus muscle and then in front of adductor brevis. It passes behind the pectineus and adductor longus muscles.

Branches
i. Articular branch supplies the hip joint.
ii. Muscular branches supply the pectineus, adductor longus, adductor brevis and gracilis.
iii. Vascular filament enters the subsartorial canal to supply the femoral artery.
iv. Distal to adductor longus it enters the adductor canal, where it supplies femoral artery and contributes a cutaneous branch to communicate with the branches of medial femoral cutaneous nerve and saphenous nerve to form subsartorial plexus (which supplies the skin of medial side of the thigh).

Course and Distribution of Posterior Division
The posterior division of the obturator nerve passes through the obturator externus muscle and descends on the anterior surface of adductor magnus lying behind the adductor brevis. Distal to the lower limit of the adductor magnus the posterior division continues in the popliteal fossa as the slender genicular branch.

Branches
i. Muscular branches supply the obturator externus, adductor brevis (if it does not receive supply from anterior division) and the adductor part of adductor magnus.
ii. The genicular branch passes through the lower part of adductor magnus to enter popliteal fossa. It supplies the articular capsule of the knee joint and after piercing the oblique popliteal ligament supplies the interior of the knee joint.

Clinical insight ...

i. Bilateral obturator neurectomy (cutting the nerve) is performed to relieve severe adductor spasm. Because the thighs are held in adducted position in adductor spasm, the lower limbs cross each other like the scissors. This is seen in some neurological disorders.
ii. The pain due to disease of hip joint may be referred to knee joint and to the medial side of the thigh. This is because of the common nerve supply of the joints through the articular branches of obturator nerve and of cutaneous supply to the medial side of thigh (through its contribution to subsartorial plexus).
Blood Vessels in Adductor Compartment

The following three blood vessels enter the adductor compartment of thigh.

i. The obturator artery enters through the obturator foramen from the pelvis.

ii. The profunda femoris artery enters through the gap between the pectineus and adductor longus muscles from the femoral triangle.

iii. The medial circumflex femoral branch of the profunda femoris artery enters through the gap between the pectineus and the psoas major muscle from the femoral triangle.

Obturator Artery

i. The obturator artery is a branch of anterior division of internal iliac artery. It accompanies the obturator nerve in the pelvis and like the nerve divides into anterior and posterior branches in the obturator canal.

ii. The branches of obturator artery along with branches of the medial circumflex femoral artery form an arterial arcade between the obturator membrane and the obturator externus muscle. This arterial arcade supplies the muscles in the medial compartment.

iii. The obturator artery sends an articular branch called acetabular branch to the hip joint through the acetabular notch, which reaches the head of femur via the ligament of the head of femur.

Profunda Femoris Artery (Deep Femoral Artery)

This is the main artery providing blood to all the muscles of thigh. Though it originates in the front of thigh in the femoral triangle its main course is in the adductor compartment. Its branches, however, enter all the compartments and take part in the chain of arterial anastomoses in the back of thigh.

Origin of Profunda Femoris (Fig. 95.3)
The profunda femoris artery arises from the lateral aspect of the femoral artery in the femoral triangle about 3.5 to 4 cm below the inguinal ligament. However, the point of origin may be variable.

Course and Branches in Femoral Triangle

i. From its origin, the profunda femoris gradually turns medially to pass posterior to the femoral vessels. In this course, it lies on the anterior aspect of pectineus muscle.

ii. It leaves the femoral triangle through the gap between the pectineus and adductor longus to enter the adductor compartment.

iii. The following branches of profunda femoris artery arise in the femoral triangle, medial circumflex femoral artery, lateral circumflex femoral artery and muscular branches.

Course and Branches in Medial Compartment

i. At the level of the apex of femoral triangle, the profunda femoris artery and accompanying vein are separated from the femoral vessels by adductor longus. The gunshot or stab injury at this level may injure all the four blood vessels.

ii. In its further descent the profunda femoris lies at first between the adductor longus in front and adductor brevis behind. Beyond the lower limit of adductor brevis it lies between the adductor longus in front and adductor magnus behind.

iii. At the level of midthigh it enters the adductor magnus to continue as the fourth perforating artery.

iv. The first to third perforating arteries arise in relation to the adductor brevis muscle, first at the level of its upper border, the second in front of it and the third at its lower border.

Medial Circumflex Femoral Artery (MCFA)

This artery usually arises from the posteromedial aspect of the profunda femoris artery in the femoral triangle.

Course

The medial circumflex femoral artery takes a circuitous route as it passes through three regions, femoral triangle, medial compartment of thigh and gluteal region. It leaves
Adductor Compartment of Thigh and Hip Joint

the femoral triangle by passing between the psoas major and pectineus muscles. It travels in posterior direction between the obturator externus and adductor brevis and then enters the gluteal region, where it passes between the quadratus femoris and upper margin of adductor magnus (Fig. 95.4).

Branches

i. Transverse branch takes part in cruciate anastomosis by anastomosing with the first perforating artery, inferior gluteal artery and the transverse branch of lateral circumflex femoral artery.

ii. Ascending branch passes up in the gluteal region on the tendon of the obturator externus and takes part in trochanteric anastomosis along with superior gluteal and lateral femoral circumflex arteries. The ascending branch forms a vascular ring around the femoral neck by anastomosing with ascending branch of the lateral circumflex femoral artery. The retinacular branches from this vascular ring provide blood to the head and neck of the femur. The medial circumflex femoral artery is in fact the chief arterial source to the head of the femur.

iii. Acetabular artery enters the acetabulum along with a similar branch from obturator artery to supply the femoral head.

Lateral Circumflex Femoral Artery

This is a lateral branch arising near the root of profunda femoris artery. It leaves the femoral triangle by passing deep to the sartorius and passes deep to rectus femoris, where it divides into following three branches.

i. Ascending branch runs along the intertrochanteric line lateral to the hip joint and anastomoses with the superior gluteal artery (a branch of internal iliac artery) and deep circumflex iliac artery (a branch of external iliac artery) at the spinous anastomosis. Through these connections the branches of internal and external iliac arteries communicate with branches of profunda artery. It also forms an anastomotic ring around the femoral neck with ascending branches of medial circumflex femoral artery.

ii. Descending branch runs down along the anterior border of vastus lateralis. It supplies the vastus lateralis and its one long branch descends in the substance of vastus lateralis to anastomose with lateral superior genicular branch of popliteal artery (in anastomosis around knee joint).

iii. Transverse branch passes laterally anterior to the vastus intermedius and pierces the vastus lateralis to reach the posterior aspect for taking part in cruciate anastomosis.

Perforating Arteries (Fig. 95.4)

Out of the four perforating arteries upper three are the branches of profunda femoris artery and the fourth one is the continuation of the profunda femoris artery.

The upper three perforating arteries pierce the insertion of adductor magnus (lying very close to the femur) to reach the flexor compartment. In the flexor compartment they supply the hamstring muscles and communicate with each other by anastomotic branches. They pierce the origin of short head of biceps femoris and the lateral intermuscular septum to terminate in the vastus lateralis in the extensor compartment. Additionally the first perforator takes part in cruciate anastomosis. The second perforator gives a nutrient branch to the femur and the fourth perforator anastomoses with the superior muscular branches of the popliteal artery.

Know More ...

Anastomoses of Profunda Femoris Artery

i. Spinous anastomosis at anterior superior iliac spine

ii. Trochanteric anastomosis in the gluteal region

iii. Cruciate anastomosis in the upper part of thigh at the level of lesser trochanter

iv. Vertical anastomotic chains between branches of perforating arteries in the middle of thigh

v. In the lower part of thigh, the branches of popliteal artery anastomose with fourth perforating and lateral circumflex femoral arteries.
HIP JOINT OR COXAL JOINT

The hip joint is an example of multiaxial ball and socket type of synovial joint. Its primary functions are to support the body weight in standing and to transmit the forces during movements of trunk upon the femur during walking and running. The range of movements in all directions is possible in this joint because the long and narrow neck of the femur makes an angle with the shaft called neck shaft angle or angle of inclination.

Articular Surfaces

The bones taking part in the hip joint are the head of femur and the acetabulum of the hip bone. Figure 95.5 shows the radiological appearance of the hip joint.

Acetabulum

The acetabulum (in Latin means cup) is a cup-shaped cavity formed by the union of ilium, ischium and pubis.

i. The rim of the acetabulum presents a notch in its lower part. This notch gives attachment to the transverse acetabular ligament and to the ligament of head of femur.

ii. The fibrocartilaginous labrum acetabulare deepens the acetabulum. The labrum, which is attached to the rim of acetabulum and to the transverse acetabular ligament, forms a tight fit around the neck of femur.

iii. The horseshoe shaped articular surface (lunate surface) of acetabulum is covered with articular cartilage. It is thickest and widest superiorly, where the maximum body weight is transmitted to the femur.

iv. The nonarticular part of acetabulum is known as acetabular fossa. It is filled with Haversian pad of fat, which is intracapsular but extrasynovial.

Head of Femur

The spherical femoral head is covered by hyaline articular cartilage, except for a rough pit where the ligament of the head of femur is attached. The articular cartilage is thickest in the center and thins out towards the periphery.

Fibrous Capsule

The capsule is very strong and surrounds the joint tightly. It is attached medially to the margins of the acetabulum and laterally to the femur.

i. Anteriorly, it is attached to the inter-trochanteric line so that entire anterior surface of neck is intracapsular.

ii. Posteriorly, it is attached to the posterior surface of the neck a short distance medial to the intertrochanteric crest. Thus, the posterior surface of the neck is partly intracapsular.

Major Parts of Capsule

i. Zona orbicularis is the inner part of the capsule consisting of circularly arranged fibers. It forms a tight collar for the neck of the femur.

ii. Retinacula are the longitudinal fibers on the anterior surface of the neck. These fibers originate from the capsular attachment to intertrochanteric line and proceed towards the femoral head in close contact with the anterior surface of the femoral neck and produce grooves on the femoral neck. Their main function is to support the retinacular arteries running towards the head.
Ligaments (Fig. 95.6)

The fibrous capsule covers the joint. The capsule is strengthened in three places to form the iliofemoral, pubofemoral and ischiofemoral ligaments.

i. The iliofemoral ligament (ligament of Bigelow) is the thickest and a very powerful ligament. Its shape is like inverted Y. It stretches from the anterior inferior iliac spine to the intertrochanteric line of femur. Since the line passing through the center of gravity lies slightly behind the hip joints, there is a tendency for the body to fall backward. The iliofemoral ligament prevents this tendency. It also prevents excessive extension and its lateral oblique band limits the adduction and lateral rotation.

ii. The pubofemoral ligament is triangular in shape. It is attached to the iliopubic eminence, superior pubic ramus and obturator crest. It blends with the capsule and deep surface of the medial band of iliofemoral ligament. This ligament limits abduction and lateral rotation of thigh.

iii. The ischiofemoral ligament reinforces the back of the capsule. It is attached to the ischium below the lower margin of acetabulum. From this attachment the fibres spiral superolaterally to merge with the fibrous capsule. The ischiofemoral ligament limits the medial rotation of thigh.

iv. The transverse acetabular ligament converts the acetabular notch into the acetabular foramen through which pass acetabular branch of obturator artery, acetabular branch of medial circumflex femoral artery and articular branch of anterior division of obturator nerve.

v. The ligament of the head of femur extends from the acetabular notch to the fovea on the head of femur. It carries the articular vessels and nerves to the head of the femur.

Synovial Membrane (Fig. 95.7)

The synovial membrane lines the inner surface of the fibrous capsule. It covers the intracapsular part of the neck as far as the articular margin of the head of femur. It also covers the acetabular labrum, ligament of the head of femur and Haversian pad of fat inside the acetabular fossa. The synovial fold surrounding the ligament of the head of femur carries the blood vessels and nerves entering the joint through the acetabular foramen. The synovial membrane lining the intracapsular part of the neck is raised into folds by the retinacular fibers. Occasionally, the synovial membrane may protrude through as opening in the anterior part of capsule between iliofemoral and ischiofemoral ligaments to become continuous with psoas bursa.

Relations of Joint (Fig. 95.8)

1. Anteriorly, the joint is related to the muscles in the floor of the femoral triangle, femoral nerve and femoral vessels.
i. The pectineus separates the femoral vein from the hip joint.

ii. The iliopsoas separates the femoral artery and femoral nerve from the hip joint.

iii. The femoral artery can be palpated through the tendon of psoas against the inferolateral part of the head of femur.

iv. The sartorius, lateral cutaneous nerve of thigh and the rectus femoris are the other anterior relations.

2. Superiorly, the joint is related to the reflected head of rectus femoris medially and the gluteus minimus laterally. Above these, the gluteus medius and tensor fasciae latae are related.

3. Inferior relations are the obturator externus muscle and lateral part of pectineus muscle.

4. The posterior relations of the hip joint are very important. The short lateral rotator muscles in the gluteal region cover the posterior aspect of the capsule. From above downward they are: piriformis muscle, obturator internus with two gemelli and the quadratus femoris muscle. The obturator internus tendon with gemelli separates the sciatic nerve from the hip joint (the sciatic nerve is an “at risk posterior relation” as it is injured in posterior dislocation of the hip joint). The obturator externus tendon lies in close contact with the posterior surface of the neck and separates the joint from the quadratus femoris. Superficial to these intimate relations the gluteus maximus is related.

**Arterial Supply (Fig. 95.9)**

i. The area of femoral head around the fovea is supplied by acetabular branch of obturator artery and acetabular branch of medial circumflex femoral artery. The acetabular branches reach the head via ligament of the head of femur. This source is of little significance.

ii. The rest of the head and the neck receive blood from arterial circle around the capsular attachment, in which the medial circumflex femoral artery is the chief source. The retinacular arteries arise from this vascular ring, pierce the capsule and run along the neck of femur to supply it and its head. The arterial supply of the head and neck is solely dependent on the retinacular arteries. The rupture of these arteries (due to intracapsular fracture of the femoral neck) results in avascular necrosis of the head of femur.

iii. The nutrient artery of the femur gives a few branches to the head and neck of femur.

**Nerve Supply**

The joint receives articular twigs from femoral nerve via a branch to rectus femoris, nerve to quadratus femoris,
anterior division of obturator nerve and from superior gluteal nerve.

**Movements**
The movements of hip joint occur around three axes, transverse, anteroposterior and vertical.

**Flexion and Extension**
These movements occur around transverse axis. The range of flexion is greater. The flexion is limited when the anterior surface of thigh touches the anterior abdominal wall. The extension is limited when the thigh and trunk are in the same vertical line.

**Adduction and Abduction**
These movements occur around anteroposterior axis. Adduction is limited by contact with the opposite thigh. In abduction, the thigh moves laterally. Abduction is very crucial during walking. The abduction movement in the supported hip joint enables the pelvis on the opposite side to lift up (in preparation of taking a step).

**Medial and Lateral Rotation**
Rotation takes place around the vertical axis. The axis of rotation does not pass through the shaft of femur because of the presence of neck-shaft angle. It passes through the head and the lateral condyle of the femur when the limb is on the ground. During medial rotation, the medial condyle of femur turns backwards with concomitant forward movement of the greater trochanter. In lateral rotation, the lateral condyle of femur moves backwards with concomitant backward movement of the greater trochanter.

**Muscles Responsible for Movements** *(Table 95.1)*

<table>
<thead>
<tr>
<th>Movement</th>
<th>Main muscles</th>
<th>Accessory muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>Iliopsoas</td>
<td>Pectineus, sartorius, rectus femoris</td>
</tr>
<tr>
<td>Extension</td>
<td>Gluteus maximus</td>
<td>Hamstring muscles</td>
</tr>
<tr>
<td>Adduction</td>
<td>Adductors longus, brevis and magnus</td>
<td>Pectineus and gracilis</td>
</tr>
<tr>
<td>Abduction</td>
<td>Gluteus medius and gluteus minimus</td>
<td>Tensor fasciae latae</td>
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<tr>
<td>Medial rotation</td>
<td>Gluteus medius and gluteus minimus</td>
<td>Tensor fasciae latae and adductor muscles</td>
</tr>
<tr>
<td>Lateral rotation</td>
<td>Obturator externus, obturator internus, gemelli, quadratus femoris</td>
<td>Piriformis, gluteus maximus, sartorius</td>
</tr>
<tr>
<td>Circumduction</td>
<td>Sequential contraction of all muscles responsible for above movements</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 95.9: Arterial supply of head and neck of femur (medial circumflex femoral artery is chief source)**

**Palpation of Bony Landmarks in Clinical Examination of Hip Joint**
The anterior superior iliac spine, ischial tuberosity and greater trochanter are useful bony landmarks. Of these, the first two are easily palpable.

**Greater Trochanter**
The greater trochanter is located a hand’s-breadth below the tubercle of iliac crest. Upward displacement of greater trochanter indicates shortening of the limb due to fracture dislocations in hip region.

**Methods of Palpation**

1. Nelaton’s line is drawn with the patient lying on the normal side, from the anterior superior iliac spine to the most prominent part of ischial tuberosity. Normally the tip of greater trochanter is at or just be-low this line.
2. Schoemaker’s line is a straight line that extends from the tip of greater trochanter to the anterior superior iliac spine and upwards over the anterior abdominal wall to reach the umbilicus. If the greater trochanter is elevated the line reaches below the umbilicus.
The fracture of the neck of femur is very common in elderly due to osteoporotic changes in the neck. Postmenopausal women, who develop osteoporosis, are more prone to this fracture on trivial trauma. This fracture is of two major types (Figs 95.10A and B). Intracapsular fracture includes subcapital, transcervical and basal. In this type of fracture, the retinacular arteries are injured leading to delay in healing or nonunion of fracture. Its serious complication is avascular necrosis of head of the femur with resultant loss function of the hip joint. The extracapsular fracture of the neck (e.g. intertrochanteric fracture) is relatively less serious as the retinacular arteries are saved hence healing is faster.

The characteristic feature of intracapsular fracture of the neck of femur is the shortening of the affected limb. The limb is held in laterally rotated position with toes pointing laterally (Fig. 95.11). The shortening of the limb occurs as the muscles attaching the hip bone and femur pull the femur upwards. The lateral rotation of the limb is explained as follows. The head of femur separates from the shaft (carrying the trochanter)

**Clinical insight ...**

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**Contd...**

**Figs 95.10A and B:** Arterial supply of head of femur in extracapsular and intracapsular fracture of neck of femur

**Fig. 95.11:** Fracture of neck of right femur resulting in upward and posterior displacement of greater trochanter (indicated by arrow)
Fig. 95.13: Dislocation in prosthetic hip joint indicated by arrow

Figs 95.12A to C: Clinical importance of neck-shaft angle (angle between long axis of neck and long axis of shaft of femur)

Contd...

...in intracapsular fracture. So the shaft of femur can rotate independent of the head. The gluteus maximus and short lateral rotator muscles rotate the femur laterally. The psoas major becomes a lateral rotator after fracture due to shift in the axis of its action.

iii. The neck-shaft angle is also known as angle of inclination (Figs 95.12A to C). The normal neck-shaft angle is 125° in adult and 160° in children. When there is increase in the angle it is called coxa valga. It is found in congenital dislocation of hip joint. Coxa valga limits the adduction movement of the hip joint. If the angle is reduced it is called coxa vara. It is seen in fracture of neck of femur and it limits the abduction at the hip joint.

iv. Figure 95.13 depicts the radiograph of a patient with dislocation of prosthetic hip joint on right side. In hip replacement the diseased head of the femur is replaced by metallic head fixed to patient’s femoral shaft by bone cement and a plastic socket replaces the patient’s acetabulum.
POPLITEAL FOSSA

The popliteal fossa is a diamond-shaped hollow situated behind the knee joint. It is an important region because it gives passage to the main vessels and nerves from the thigh to the leg.

**Boundaries (Fig. 96.1)**

The popliteal fossa presents superomedial, superolateral, inferomedial and inferolateral boundaries. Additionally, it has a roof facing posteriorly and a floor facing anteriorly.

i. The tendon of biceps femoris forms the superolateral boundary.

ii. The tendons of semitendinosus and semimembranosus muscles form the superomedial boundary.

iii. The lateral head of gastrocnemius and plantaris muscles form the inferolateral boundary.

iv. The medial head of gastrocnemius forms the inferomedial boundary.

v. The floor or anterior wall (Fig. 96.2) is divisible into three parts. Its upper part is formed by the popliteal surface of femur. The intermediate part is the capsule of the knee joint (oblique popliteal ligament). The lower part is the thick fascia (derived from semimembranosus insertion) covering the popliteus muscle.

vi. The roof or the posterior wall is the deep fascia called the popliteal fascia. The small saphenous vein, superficial lymphatics and posterior cutaneous nerve of thigh pierce the roof.

**Contents**

i. Popliteal artery and its branches

ii. Popliteal vein and its tributaries

iii. Terminal branches of the sciatic nerve (tibial and common peroneal nerves)

iv. Posterior cutaneous nerve of thigh
v. Descending genicular branch of the posterior division of the obturator nerve
vi. Popliteal lymph nodes
All the above mentioned contents are packed in popliteal fat.

Popliteal Artery (Fig. 96.3)
The popliteal artery is the continuation of femoral artery at the level of tendinous opening in the adductor magnus. It is the deepest structure in the popliteal fossa as it is located in close contact with the floor of the fossa. The popliteal artery runs obliquely across the fossa with a lateral inclination to reach the distal border of the popliteus muscle, where it terminates into anterior and posterior tibial arteries. The popliteal artery is used for measuring blood pressure in lower limb.

Surface Marking
The popliteal artery is marked on the popliteal fossa by joining the following three points.
1. The upper point is 2.5 cm medial to the midline at the junction of middle and lower thirds of thigh.
2. The middle point is at the level of knee joint in the midline.
3. The lower point is in the midline on the back of leg at the level of tibial tuberosity.

Clinical insight ...

Popliteal Pulse (Figs 96.4A and B)
The popliteal pulse is the most difficult to feel among the peripheral pulses because it is the deepest content of the popliteal fossa. The best position to feel the popliteal pulse is the patient in either supine or prone position with knee joint flexed at 120°. The fingertips of both hands are placed in the popliteal fossa to compress the artery against popliteal surface of femur (with the thumbs resting on patient’s patella). In blood pressure measurement in lower limb the BP cuff is tied around patient’s thigh and the Korotkoff sounds are heard by keeping the diaphragm of the stethoscope on the popliteal fossa.

Relations
1. Anteriorly, the popliteal artery is related to the floor of popliteal fossa. Since it is very close to the popliteal surface of femur, it may be torn in the supracondylar fracture of femur. Below this it is very close to the capsule of the knee joint and hence endangered in posterior dislocation of knee joint.
2. Posteriorly, at the middle of the fossa the artery is crossed by the popliteal vein and tibial nerve from lateral to medial side, as a result of which the relations of the neurovascular structures differ at three levels of the popliteal fossa (Fig. 96.5).
   i. At the upper end the mediolateral arrangement is popliteal artery, popliteal vein and tibial nerve.
   ii. At the site of crossing the anteroposterior arrangement is popliteal artery, popliteal vein and tibial nerve.
   iii. At the lower end, the mediolateral relation is tibial nerve, popliteal vein and popliteal artery.

Relation to Popliteal Lymph Nodes
One popliteal lymph node lies between the popliteal artery and the capsule of the knee joint and a few lymph nodes surround the popliteal vessels.
Branches of Popliteal Artery (Fig. 96.3)

i. The superior muscular branches supply the muscles in the thigh (hamstrings).

ii. The sural arteries supply the soleus, gastrocnemius and plantaris muscles.

iii. The lateral and medial superior genicular arteries, lateral and medial inferior genicular arteries and middle genicular artery supply the knee joint.

Genicular Anastomosis

The arterial anastomosis around the knee joint is called the genicular anastomosis. It maintains adequate blood flow during flexion of knee joint when the popliteal artery is compressed. The following genicular branches of popliteal artery anastomose with branches of anterior tibial, posterior tibial, femoral and profunda femoris arteries.

i. The superior medial genicular artery anastomoses with inferior medial genicular artery and with descending genicular branch of femoral artery.

ii. The inferior medial genicular artery anastomoses with superior medial genicular and with saphenous branch of descending genicular artery.

iii. The superior lateral genicular artery anastomoses with inferior lateral genicular artery and with descending branch of lateral circumflex femoral artery.

iv. The inferior lateral genicular artery anastomoses with superior lateral genicular artery, anterior and posterior tibial recurrent branches of anterior tibial artery and circumflex fibular branch of posterior tibial artery.

Clinical insight ...

The swellings in the popliteal fossa originate not only from structures in the fossa but also from structures associated with the knee joint (as the knee joint is a very close anterior relation of popliteal fossa). This is the reason why knee joint is examined in a case of popliteal swelling and popliteal fossa is examined in the case of knee joint disorders.

i. The popliteal aneurysm due to dilatation of popliteal artery presents as a pulsatile midline swelling in the popliteal fossa. This may cause edema of leg due to compression of popliteal vein. The stasis of blood in the aneurysm may favor formation of thrombosis and emboli, which may enter the distal arteries causing pain and ulceration and gangrene in the toes. The operative treatment of popliteal aneurysm consists of exposing and clamping the popliteal artery. Another method of treatment is to use saphenous vein graft to replace the dilated part of the popliteal artery. Yet another time-honored method pioneered by John Hunter is to ligate the femoral artery in the subsartorial canal. This method is based on the anatomical fact that arteries taking part in genicular anastomosis enlarge to provide collateral arterial supply to the leg (if femoral artery is ligated).

ii. Popliteal abscess is a painful swelling that presents as a red swelling in the popliteal fossa. It usually arises from the inflammation of popliteal lymph nodes.

iii. Varicosity of the terminal part of the small saphenous vein may present as swelling.

iv. A cystic swelling in popliteal fossa is usually due to inflammation of the bursae around the knee joint or due to protrusion of the synovial membrane through the fibrous capsule of knee joint. Examples of cystic swelling are, Baker’s cyst and semimembranosus bursitis (refer to semimembranosus bursa of knee joint).
**Popliteal Vein**

The popliteal vein is located superficial (posterior) to the popliteal artery.

**Formation**

The popliteal vein begins at the distal border of the popliteus muscle by the union of venae comitantes accompanying the anterior and posterior tibial arteries.

**Relations (Fig. 96.5)**

The popliteal vein has triple relation to the popliteal artery. The vein lies medially in the lower part, it crosses superficially (posteriorly) in the middle part (between the two heads of gastrocnemius) and lies laterally at the upper part.

**Termination**

The popliteal vein continues as the femoral vein at the adductor opening.

**Tributaries**

i. Small saphenous vein

ii. Veins accompanying the branches of the popliteal artery.

**Tibial Nerve in Popliteal Fossa**

The tibial nerve (L4, L5, S1, S2, S3) is the larger of the two terminal branches of sciatic nerve. It enters the popliteal fossa through its upper angle. It bears triple relation to the popliteal vessels. In the upper part, it lies lateral to the vessels. In the middle of the fossa it crosses the vessels superficially (posteriorly) and in the distal part it lies medial to the vessels. At the distal margin of popliteus muscle, it continues in the posterior compartment of leg as the tibial nerve in company with posterior tibial vessels.

**Branches (Fig. 96.6)**

i. The branches supplying the knee joint are superior medial, inferior medial and middle genicular nerves. The middle genicular artery, middle genicular nerve and genicular branch of posterior division of obturator nerve pierce the oblique popliteal ligament to supply intra-articular structures.

ii. The sural nerve is the only cutaneous nerve that arises from tibial nerve. It descends between the heads of gastrocnemius and after leaving the fossa pierces the deep fascia of leg to become superficial. It supplies the posterior part of leg and lateral border of foot including the lateral margin of little toe. Since, it is easily accessible it is favored for nerve grafting.

iii. The tibial nerve provides five muscular branches. The muscles supplied by branches from lateral side are, lateral head of gastrocnemius, plantaris, soleus and popliteus. A branch arising from the medial side supplies the medial head of gastrocnemius. The nerve to popliteus has peculiar course. It passes down lying on the posterior surface of the popliteus muscle and winds round its distal margin to supply the muscle from its anterior or deep aspect. Apart from popliteus muscle, the nerve to popliteus also supplies the superior tibiofibular joint, interosseous membrane, inferior tibiofibular joint, medullary branch to tibia and a branch to the tibialis posterior muscle.

**Surface Marking**

The nerve can be represented by a straight vertical line starting from the upper angle of popliteal fossa to a point in the midline at the level of tibial tuberosity.

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**Clinical insight ...**

**Effects of Injury to Tibial Nerve in Popliteal Fossa**

The tibial nerve is rarely injured in popliteal fossa because of its relatively protected position. However, if injured, all the muscles of calf and intrinsic muscles of foot are paralyzed. This results in talipes calcaneovalgus deformity of foot (foot is everted and dorsiflexed). The patient walks on the heel. The sensory loss mainly affects the sole.
Common Peroneal Nerve (Fig. 96.6)
The common peroneal nerve (dorsal branches of L4, L5, S1, S2) is the smaller terminal division of the sciatic nerve. It enters the popliteal fossa through the upper angle and lies medial to the biceps femoris tendon. It follows this tendon to the back of the head of the fibula. It then curves forward lying in close contact with the lateral side of the neck of the fibula, where it divides into its terminal branches, deep to the peroneus longus muscle.

Palpation of Common Peroneal Nerve
It is palpated by rolling it against the neck of the fibula.

Branches in Popliteal Fossa
The common peroneal nerve has no muscular branches but gives two articular and two cutaneous branches in the popliteal fossa.
1. The articular branches are the superior lateral genicular and inferior lateral genicular nerves, which accompany the corresponding arteries and supply the knee joint.
2. The lateral cutaneous nerve of the leg and sural (peroneal) communicating nerve are the cutaneous branches for the leg and foot.

Branches at the Neck of Fibula
i. The recurrent genicular nerve arises just before its termination. This branch passes through the tibialis anterior muscle along with anterior tibial recurrent artery, supplies a twig to the muscle and reaches the knee joint.
ii. The terminal branches of the common peroneal nerve are the superficial peroneal nerve and the deep peroneal nerves. The superficial peroneal nerve enters the peroneal compartment of the leg while the deep peroneal nerve enters the anterior compartment of the leg.

Surface Marking
The common peroneal nerve is indicated on the surface by a line starting from the upper angle of the popliteal fossa along the tendon of biceps femoris to the back of the head of the fibula.

Clinical insight ...

Effects of Injury to Common Peroneal Nerve
i. The common peroneal nerve is superficial hence it is unprotected compared to the tibial nerve. It is a commonly injured nerve in the lower limb. It may be injured in fracture of the neck of the fibula or due to direct pressure of a tightly applied plaster cast. It is affected in Hensen’s disease and becomes tender and thickened.
ii. Injury to common peroneal nerve leads to paralysis of dorsiflexors of the ankle joint and evertors of foot supplied through its deep peroneal and superficial peroneal branches, respectively. The paralysis of the above muscles results in foot drop deformity (inverted and plantarflected foot). The patient walks on the toes.
iii. There is sensory loss on the dorsum of foot and toes excluding the medial and lateral margins of the foot and the lateral side of the little toe.

Popliteal Lymph Nodes
The popliteal nodes belong to the deep group of lymph nodes. They are usually five to six in number. They are embedded in the fat of the popliteal fossa.

i. One lymph node is present at the sapheno-popliteal junction. This node receives superficial lymph vessels draining the lateral side of the foot including the little toe, lateral side of heel and lateral side of the back of the leg (this is one example where deep lymph nodes receive superficial lymph vessels).
ii. One lymph node is present between the popliteal artery and the capsule of the knee joint. It receives lymph from the joint.
iii. The remaining nodes are grouped around the popliteal vessels. They receive lymph vessels draining all the deep structures below the knee.
iv. The efferent vessels from the popliteal nodes travel with the popliteal vessels and so pass through the
adductor hiatus. Then they accompany the femoral vessels to reach the deep inguinal nodes.

Clinical insight ...

**Palpation of Popliteal Lymph Nodes**
The popliteal lymph nodes are enlarged in injury to deeper tissues of the foot. Palpation of popliteal lymph nodes is as follows. The deep fascia of the popliteal fossa can be relaxed by passively flexing the knee. The examiner holds the knee with hands and explores the fossa for enlarged lymph nodes with the fingers of both hands.

**KNEE JOINT**
The knee joint is the largest and the most complicated synovial joint in the body. It is classified as a modified hinge joint with a mobile transverse axis. In addition to flexion and extension it allows a small degree of rotation. In fact the knee joint is composed of three articulations, right and left condylar joints between the tibial and femoral condyles and a saddle joint between the patella and the patellar surface of the femur. The knee joint is a major weight-bearing joint. Its stability depends on its ligaments and quadriceps mechanism.

**Articular Surfaces**
There are three articular surfaces covering the three bones taking part in the knee joint. These articular surfaces are not congruent with each other.

i. Proximal articular surface on the lower end of femur
ii. Distal articular surface on the upper end of tibia
iii. Patellar articular surface.

**Proximal or Femoral Articular Surface**
The femoral articular surface covers the posterior, inferior and anterior surfaces of the medial and lateral condyles of femur. The articular surfaces of the two condyles are continuous with each other anteriorly but are separated by intercondylar notch posteriorly. This articular surface is divisible into three parts.

i. The patellar articular surface or trochlear surface is present on the anterior aspect. It is subdivided into larger lateral and smaller medial areas by a vertical groove. The larger lateral articular surface is elevated (compared to the medial). A small semilunar area of the articular surface on the medial condyle adjoining the anterior margin of intercondylar fossa comes in contact with the medial articular facet of patella in full flexion.
ii. The tibial articular surface on the medial femoral condyle is longer in anteroposterior axis and is obliquely set compared to the articular surface on the lateral femoral condyle.
iii. The tibial articular surface on the lateral femoral condyle is straight, less curved and smaller by about two centimeter than the corresponding surface on the medial condyle.

**Distal or Tibial Articular Surfaces**
The distal articular surfaces are present on the upper surfaces of the condyles of tibia as the lateral and medial condylar surfaces separated by a rough non-articular area. They are slightly concave centrally but flat peripherally, where they come in contact with the corresponding menisci.

i. The articular surface on medial tibial condyle is oval and its anteroposterior diameter is greater than the transverse diameter.
ii. The articular surface on the lateral tibial condyle is circular and its posterior part extends on the posterior aspect of the lateral condyle, where the tendon of popliteus glides.

**Patellar Articular Surface**
The posterior surface of patella bears a large articular area, which is divided by a vertical groove into larger lateral and smaller medial areas. Near the medial margin of the patella there is a narrow semilunar strip for contact with medial condyle of femur in full flexion. The rest of the lateral and medial areas are divided into three facets on each side. These facets come in contact with femur one by one as the knee passes from the position of full extension to that of flexion.

**Fibrous Capsule**
The unique feature of the capsule of the knee joint is that it is deficient in the anterior part of the joint. The strong quadriceps femoris tendon, patella and ligamentum patellae take the place of the deficient capsule.

**Upper Attachment (Figs 96.7A and B)**

i. Anteriorly, the capsule is attached to the expansions of vastus lateralis and vastus medialis muscles called the lateral and medial patellar retinacula, which are attached to the lateral and medial margins of patella and to the margins of ligamentum patellae.
ii. Posteriorly, the line of attachment of the capsule can be traced starting from the medial and posterior aspects of medial condyle of femur just beyond the articular surface. Then the line of attachment goes laterally along the posterior margin of intercondylar
notch to the posterior and lateral aspects of lateral condyle along the upper margin of the popliteal groove (thus ensuring that the origin of the popliteus becomes intracapsular).

**Lower Attachment (Figs 96.7A and B)**

i. Anteriorly, the capsule blends with the patellar retinacula through which it is attached to the anterior margins of tibial condyles and to the sides of the tibial tuberosity.

ii. Posteriorly, the capsular attachment begins at the medial margin of medial condyle of tibia just beyond the articular surface. Then, it is traced along the posterior margin of medial condyle, intercondylar area, posterior margin of lateral condyle and the lateral margin of lateral condyle. There is a gap in the capsular attachment behind the lateral condyle for the exit of the tendon of popliteus.

**Ligaments**

The following six ligaments provide support to the joint.

**Coronary Ligaments**

These ligaments are short parts of thickened fibrous capsule extending between the outer margins of menisci to the periphery of tibia condyles. They are lax ligaments. All the ligaments of knee joint are tightened in extension except coronary ligaments.

**Ligamentum Patellae**

The ligamentum patellae or patellar ligament is the continuation of the central part of the tendon of quadriceps femoris. It is attached to the lateral and medial patellar retinacula on either side.

i. It extends from the apex of the patella to the tibial tuberosity.

ii. Posteriorly, it is related to a large infrapatellar pad of fat above and deep infrapatellar bursa below.

iii. This ligament is used for eliciting patellar reflex or knee jerk by tapping it with a knee hammer.

**Oblique Popliteal Ligament**

The oblique popliteal ligament is a broad band, which strengthens the capsule posteriorly. It is an expansion from the tendon of insertion of semimembranosus (Fig. 94.8). It extends from the posterior aspect of the medial condyle of tibia to the lateral part of intercondylar line and lateral condyle of femur. The popliteal artery is in close contact with this ligament. The structures piercing the ligament are, middle genicular artery, middle genicular nerve and geniculate branch of obturator nerve.

**Arcuate Popliteal Ligament**

This is Y-shaped ligament. Its stem is attached to the styloid process of head of fibula. Its posterior limb is attached to posterior end of the intercondylar area of tibia and the anterior limb extends to the lateral condyle of femur deep to the fibular collateral ligament.

**Tibial Collateral Ligament (TCL)**

This ligament is the thickening of the medial part of the capsule (Fig. 96.8A). It forms a very strong flat band, about eight to nine centimeter long.

**Attachments (Fig. 96.8B)**

i. Its upper attachment is to the medial epicondyle of femur.

ii. It is divided into superficial and deep layers inferiorly. The deep layer is fused with the capsule and is attached to the articular margin of medial condyle of tibia. The superficial layer is attached to the medial surface of tibia between the medial border of tibia and the insertions of sartorius, gracilis and semitendinosus.
**Popliteal Fossa and Knee Joint**

**Chapter**

**Relations**

i. Superficially, it is related to the tendons of sartorius, gracilis and semitendinosus.

ii. On the deeper side, it is related to the inferior medial genicular artery and nerve. The most important relation is that the medial meniscus is fused with the deep aspect of tibial collateral ligament.

**Fibular Collateral Ligament (FCL)**

This ligament (Fig. 96.8A) is rounded, cord like and short.

**Attachments (Fig. 96.8C)**

It extends from the lateral epicondyle of femur to the lateral surface of the head of fibula.

**Know More...**

**Morphology**

The fibular collateral ligament represents the upper part of peroneus longus muscle.

**Relations**

i. Superficially, the tendon of biceps femoris (which is split by the ligament) overlaps the ligament.

ii. Its deep relations are the tendon of popliteus, which separates it from the lateral meniscus and the inferior lateral genicular nerve and vessels.
Functions
The tibial and fibular collateral ligaments are taut in extension of knee joint.

i. The fibular collateral ligament prevents adduction (medial rotation) of tibia on the femur.

ii. The tibial collateral ligament prevents the abduction (lateral rotation) of tibia on the femur.

Clinical Insight...

Testing Integrity of Collateral Ligaments
The patient is seated on a high stool with legs hanging down but not touching the ground. The lower end of femur is grasped firmly with one hand. The tibia is moved in lateral or medial direction. Abnormal degree of lateral movement of tibia suggests rupture of tibial collateral ligament while excessive medial movement of tibia means rupture of fibular collateral ligament.

Intra-articular Structures (Figs 96.9 and 96.10)
The following structures are present inside the knee joint.

i. Cruciate ligaments

ii. Semilunar cartilages or menisci

iii. Ligaments of Wrisberg and Humphrey

iv. Infrapatellar pad of fat

v. Synovial membrane

vi. Tendon of popliteus

Cruciate Ligaments
There are two cruciate ligaments inside the knee joint. The anterior and posterior cruciate ligaments cross each other like the letter X. They are named anterior and posterior depending on their attachment to the tibia. The cruciate ligaments bind the tibia and the femur to each other. Since the ligaments invaginate the synovial membrane from behind their anterior aspects are covered with synovial membrane. The anterior cruciate ligament is located anterolateral to the posterior cruciate ligament.

Anterior Cruciate Ligament

i. Its tibial end is attached to the anterior part of intercondylar area of tibia. The femoral end is attached to the posterior part of the medial surface of lateral condyle in the intercondylar notch (Fig. 96.11A).

ii. The direction of the anterior cruciate ligament (ACL) from its tibial to femoral ends is superior, posterior and lateral.

iii. This ligament prevents posterior dislocation of femur on tibia or anterior dislocation of tibia on femur (when the extended femur is weight bearing as in walking uphill or ascending stairs). The ACL is the key stabilizer of knee joint. It tightens maximally during extension movement, when it provides a pivot (for screw home movement).

iv. It is supplied by middle genicular artery.
Posterior Cruciate Ligament

i. Its tibial end is attached to the posterior part of the intercondylar area of tibia and the femoral end is attached to anterior part of the lateral surface of the medial condyle in the intercondylar notch (Fig. 96.12A).

ii. The direction of the posterior cruciate ligament (PCL) from its tibial to femoral end is superior, anterior and medial. PCL is the key stabilizer in weight bearing flexed knee for example in descending stairs or walking downhill.

iii. It prevents anterior dislocation of femur on tibia or posterior dislocation of tibia on femur.

iv. It is supplied by middle genicular artery.

Drawer Test for ACL (Fig. 96.11B)
The patient lies in supine position of the body with the knee and hip joints flexed. The ankle joint is firmly held to immobilize it. The tibia is pulled forwards. If there is excessive forward movement of tibia, it is called anterior drawer sign. This sign indicates injury to anterior cruciate ligament.

Rupture of Anterior Cruciate Ligament
Isolated rupture of anterior cruciate ligament commonly occurs if the extended knee is twisted (rotated) with force. The patient experiences acute pain and feels that the knee joint is suddenly giving way. There is swelling of the knee joint. The anterior drawer sign is positive. Hemarthrosis (blood inside the joint) of knee joint is usually due to rupture of anterior cruciate ligament.
Menisci or Semilunar Cartilages (Fig. 96.13A)

They are crescent shaped plates of fibrocartilage placed on articular surface of tibial condyles. There are two menisci, medial and lateral. The menisci divide the joint cavity into two chambers in each half, meniscofemoral above and meniscotibial below:

i. The menisci are wedge-shaped plates with thick peripheral and thin inner margins. The peripheral margin of the meniscus is attached to the fibrous capsule and tibial condyles by the coronary ligaments.

ii. Each meniscus has two horns, anterior and posterior and two surfaces, superior and inferior. The transverse ligament of knee connects the anterior horns of the two menisci to each other.

Medial Meniscus

It is a C-shaped cartilage. The two ends of the C represent the two horns of the meniscus, which are attached to the intercondylar area of tibia. Its periphery is fused with the fibrous capsule in the region of tibial collateral ligament. This close proximity of the meniscus and the ligament makes the medial meniscus less mobile and more prone to tears.

Lateral Meniscus

It is circular in shape. The points of attachments of the anterior and posterior horns of the lateral meniscus to the intercondylar area are very close to each other (within the points of attachments of the two horns of medial meniscus). The intracapsular tendon of popliteus intervenes between the lateral meniscus and the fibrous capsule. The peripheral attachment of the lateral meniscus to the capsule is lax hence the lateral meniscus is more mobile compared to medial. Since a few fibers of popliteus are attached to the posterior horn of lateral meniscus the muscle pulls the meniscus back if the femur is rotated laterally. In this way, the popliteus protects the lateral meniscus from injuries.

Meniscofemoral Ligaments

The meniscofemoral ligaments (MEL) are two ligaments that connect the posterior horn of lateral meniscus to the intercondylar surface of medial condyle of femur. They pass one in front and other behind the posterior cruciate ligament to gain attachment to the medial condyle of femur (in front and behind the femoral attachment of PCL). These ligaments are referred to as anterior meniscofemoral ligament of Humphrey and the posterior meniscofemoral ligament of Wrisberg. The MFL ligaments are distinctly visible in MRI image of knee joint (Fig. 96.13B).

Nutrition

i. The peripheral thick part of the meniscus is vascular and is supplied by the capsular blood vessels.

ii. The inner thin part is avascular and is nourished by synovial fluid.

Functions

i. The menisci make the tibial articular surface more concave and congruent with the femoral condylar surface.

ii. They act as shock absorber.

iii. They help in evenly spreading the synovial fluid on the articular surfaces.

iv. The menisci divide the joint cavity into two chambers for independent movements. The flexion and extension takes place in meniscofemoral compartment while the rotation occurs in the meniscotibial compartment.
Chapter Synovial Membrane (Fig. 96.16)

The knee joint has the most extensive synovial membrane. It lines the inner surface of the capsule and covers the nonarticular parts of tibial and femoral condyles inside the joint. The synovial membrane is attached to the margins of patella. Above the patella, the synovial membrane extends upward deep to the tendon of quadriceps femoris for a short distance to form the suprapatellar bursa. The articularis genu attached to the synovial membrane of this bursa holds it in position. From the margins of patella, the synovial membrane covers the inner aspects of lateral and medial patellar retinacula. Below the patella, it extends deep to ligamentum patellae from which it is separated by infrapatellar pad of fat.

Anteriorly, the synovial membrane extends from the deep surface of the ligamentum patellae in the posterior direction covering the deep surface of the infrapatellar pad of fat. This layer of synovial membrane forms the right and left
alar folds on either side. It also forms an infrapatellar fold in the midline. The infrapatellar and alar folds with the infrapatellar pad of fat provide soft packing between the three bones in the anterior part of the joint cavity. The infrapatellar fold is attached to the most anterior point of the intercondylar notch of the femur. Posteriorly, the synovial membrane lines the posterior part of fibrous capsule and the posterior edges of the menisci. It extends anteriorly as a fold inside the intercondylar notch to cover the anterior and lateral aspects of the cruciate ligaments. This fold of synovial membrane is attached to the margins of intercondylar area of tibia and provides a partial partition between the two halves of the joint.

**Bursae in Relation to Knee Joint**

Several bursae are found around the knee joint, of which four are in communication with the joint cavity. The bursae are divided into three groups according to their location.

**Anterior Group**

i. Subcutaneous prepatellar bursa is present between the lower part of patella and the skin. When inflamed it gives rise to a painful swelling called prepatellar bursitis or housemaid’s knee (Fig. 96.17).

ii. Subcutaneous infrapatellar bursa occupies the space between the ligamentum patellae and the skin. Inflammation of this bursa gives rise to clergyman’s knee (Fig. 96.17).

iii. Deep infrapatellar bursa lies between the ligamentum patellae and tibial tuberosity.

iv. Suprapatellar bursa is the extension of joint cavity superiorly behind the tendon of quadriceps femoris. Effusion in the knee joint distends this bursa, which is described as water on the knee. On physical examination, the patella appears to float over the femur.

**Lateral Group**

i. Bursa between the lateral head of gastrocnemius and the joint capsule.

ii. Bursa between the tendon of biceps femoris and fibular collateral ligament.

iii. Bursa between the tendon of popliteus and the fibular collateral ligament.

iv. Popliteus bursa between the lateral condyle of tibia and the tendon of popliteus communicates with the joint cavity.

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**Fig. 96.16:** Parasagittal section through knee joint to depict synovial membrane

**Fig. 96.17:** Anatomical basis of (A) Housemaid’s knee (prepatellar bursitis) and (B) Clergyman’s knee (inflammation of subcutaneous infrapatellar bursa) due to frequent adoption of specific postures
Medial Group

i. A bursa between the medial head of gastrocnemius and the fibrous capsule is known as Brodie’s bursa. It communicates with the joint cavity.

ii. A bursa between the tibial collateral ligament and the tendons of sartorius, gracilis and semitendinosus is called bursa anserine. The term pes anserinus is derived from the foot of the goose appearance of insertion of these three tendons on the medial surface of tibia. This bursa is in communication with joint cavity.

iii. Bursa between the superficial and deep parts of tibial collateral ligament.

iv. Bursa between the insertion of semimembranosus and medial condyle of tibia may communicate with the knee joint. Semimembranosus bursitis is a chronic inflammation of the bursa, which may present as a cystic swelling in the medial part of the popliteal fossa. Baker’s cyst is a fluctuant swelling in the popliteal fossa either due to inflammation of this bursa or due to projection of synovial membrane from a diseased joint.

Relations of Knee Joint (Fig. 96.18)

i. Anteriorly, the joint is related to the tendon of quadriceps femoris, patella and ligamentum patella. The medial patellar retinaculum related anteromedially and the lateral patellar retinaculum anterolaterally.

ii. The tendon of semimembranosus and superficial to it sartorius and gracilis tendons, form the posteromedial relation.

Fig. 96.18: Transverse section of right knee joint to show its relations “At risk” structures are tibial nerve and popliteal vessels

Fig. 96.19: MRI of knee showing close relation of popliteal artery to the joint
popliteal lymph nodes, popliteal vein and tibial nerve are also related posteriorly. The medial and lateral heads of gastrocnemius overlap the vessels and the tibial nerve.

**Nerve Supply**
The articular branches of femoral, obturator, common peroneal and tibial nerves supply the knee joint.

i. The femoral nerve supplies through its branches to vasti.

ii. The posterior division of the obturator nerve supplies through its descending articular branch.

iii. The tibial nerve gives three genicular branches, superior medial, middle and inferior genicular in the popliteal fossa.

iv. The common peroneal nerve gives two genicular branches, superior lateral and inferior lateral in the popliteal fossa. The common peroneal nerve also gives recurrent genicular branch, which arises at its bifurcation deep to the peroneus longus muscle.

**Know More ...**

**Arterial Supply**
The knee joint receives plenty of blood supply through a complex anastomosis around the knee.

i. The right and left superior and inferior genicular branches of the popliteal artery anastomose amongst each other to form bilateral vertical and upper and lower transverse anastomoses.

ii. The superior part of this anastomosis receives a branch from descending branch of lateral circumflex femoral artery laterally and the descending genicular branch of femoral artery medially.

iii. The inferior part of the anastomosis receives the circumflex fibular branch of posterior tibial artery and the anterior and posterior tibial recurrent branches from the anterior tibial artery.

iv. The middle genicular branch of popliteal artery does not take part in the anastomosis since it enters the knee joint by piercing the oblique popliteal ligament.

**Movements**
The knee joint permits flexion, extension, lateral rotation and medial rotation.

i. The flexion-extension occurs on a mobile transverse axis, which shifts forward during extension and backward during flexion. In this movement the femoral condyles move on the tibia and the menisci in the meniscofemoral compartment.

ii. The rotation occurs around a vertical axis in the meniscotibial compartment. There are two types of rotation in the knee joint. The conjunct rotation (about 20-30°) is part of locking-unlocking mechanism. The adjunct rotation (about 50-70°) occurs in the semiflexed knee. Active muscle contraction is necessary for adjunct rotation.

**Extension**
The anteroposterior diameter of lateral condyle of femur is less than that of medial condyle. Therefore, the lateral femoral condylar surface comes in contact with the articular surface of tibial condyle earlier than that of the medial condyle in the process of extension. A small part of medial condylar articular surface of femur remains without making contact with the tibial articular surface. To achieve full congruity between the articular surfaces of the medial condyles of tibia and femur, the femur rotates medially on the tibia or the tibia rotates laterally on the femur. The femur can rotate on the tibia when the foot is on the ground while the tibia can rotate on the femur if the foot is off the ground. The 20 to 30° of rotation at the final stage of extension is part and parcel of the movement of extension hence called conjunct rotation. It is also described as screw home movement or locking mechanism. In this position the joint is maximally congruent and the ligaments are taut. A person is able to stand for hours together without strain to the quadriceps femoris when the knee joint is locked and the center of gravity lies in front of the transverse axis of the joint. The muscle responsible for extension is quadriceps femoris assisted by tensor fasciae latae.

**Flexion**
From a fully extended knee the flexion begins by unlocking movement, which consists of lateral rotation of femur or medial rotation of tibia (depending on whether the foot is on or off the ground). This rotation is integral at the beginning of flexion hence it is conjunct rotation though it requires contraction of popliteus muscle (key of knee joint). The hamstring group of muscles assisted by gastrocnemius, plantaris and popliteus brings about the flexion.

**Rotation in Semiflexed Knee**
In the semiflexed knee about 50 to 70° of adjunct rotation is possible with the help of active contraction of muscles. Popliteus, semitendinosus and semimembranosus are the medial rotators while the popliteus and biceps femoris are the lateral rotators.

**Radiological Anatomy**

i. In the anteroposterior view of the radiograph of knee, the adductor tubercle may be seen above the medial
condyle of femur. The tibial and femoral condyles can be visualized with the shadow of patella overlying the femur. The intercondylar tubercles of tibia can be seen projecting in the joint space. The shadow of the infrapatellar fat pad may be visible. Fabella (a sesamoid bone in lateral head of gastrocnemius at its origin) is visible on lateral projection. The patella is best visible in the lateral view.

ii. MRI and ultrasound are the best tools to study internal anatomy of knee joint.

**Clinical insight**

i. Knee joint replacement is performed when joint function is totally lost due to degenerative disease.

ii. Runner’s knee or patellofemoral pain syndrome is a very common condition in athletes. Symptoms of runner’s knee include pain near the patella after sitting for a long stretch with knees flexed.

iii. In posterior dislocation of knee joint the popliteal artery is in danger of injury (Fig. 96.20).
COMPARTMENTS OF LEG

The leg is the part of the lower limb extending between the knee and ankle. It is divided into three osteofascial compartments by bones of leg (tibia and fibula) and intermuscular septa (Fig. 97.1). The compartments are named anterior (extensor), lateral (proneal) and posterior (flexor).

Deep Fascia of Leg

i. The deep fascia of the leg is continuous above with the fascia lata. It is strengthened in the region of knee by expansions from the tendons of sartorius, gracilis and semitendinosus medially and biceps femoris laterally. The deep fascia is attached to the condyles of tibia, head of fibula, tibial tuberosity and patella. The patella is attached to the tibial condyles by the medial and lateral patellar retinacula, which are thickened bands of deep fascia, reinforced by tendons of vastus medialis and lateralis respectively.

ii. At the anterior and medial borders of tibia the deep fascia is continuous with the periosteum covering the subcutaneous medial surface of the tibia.

iii. The intermuscular septa pass from the deep aspect of the deep fascia towards the fibula. The anterior intermuscular septum intervenes between the lateral and anterior compartments. It is attached to the anterior border of fibula. The posterior intermuscular septum intervenes between the lateral and posterior compartments. It is attached to the posterior border of fibula.

iv. At the ankle the deep fascia is modified to form flexor, extensor and peroneal retinacula, which help in strapping down the tendons at the ankle.

Boundaries Anterior Compartment (Fig. 97.1)

i. The anterior intermuscular septum is the lateral boundary.

ii. The lateral surface of tibia is the medial boundary.

iii. The interosseous membrane and the narrow anteromedial surface of fibula form the posterior boundary.

iv. The deep fascia of leg is the anterior boundary.

Fig. 97.1: Cross-section through middle of leg to show boundaries and contents of osteofascial compartments
### Contents (Fig. 97.2)

i. There are four muscles in this compartment namely tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius.

ii. The anterior tibial artery and accompanying veins are the main vessels. In addition there is a perforating branch of peroneal artery, which pierces the interosseous membrane to gain entry into the anterior compartment.

iii. Deep peroneal nerve

### Tibialis Anterior

i. The Tibialis Anterior (TA) muscle takes origin from the upper two-thirds of the lateral surface of tibia and adjacent interosseous membrane.

ii. It is inserted into the medial surface of medial cuneiform bone and the base of first metatarsal bone.

The anterior tibial recurrent artery (a branch of anterior tibial artery) and recurrent genicular nerve (a branch of common peroneal nerve at its bifurcation) pass through the upper part of tibialis anterior.

### Nerve Supply

The muscle receives twigs from the deep peroneal nerve and recurrent genicular nerve.

### Actions

i. The tibialis anterior is the dorsiflexor of foot at the ankle joint.

ii. It is the invertor of the foot at the midtarsal and subtalar joints.

iii. It provides support to medial longitudinal arch of the foot.

### Testing Function of Tibialis Anterior

The subject is asked to dorsiflex the foot against resistance of examiner’s hand placed across the dorsum of the foot.

### Extensor Hallucis Longus

i. Extensor Hallucis Longus (EHL) takes origin from the medial part of the anteromedial surface of the middle two-fourths of fibula and adjacent interosseous membrane. The tendon of the muscle emerges between the extensor digitorum longus and tibialis anterior in the lower part of leg.

ii. It is inserted into the base of terminal phalanx of the great toe.

### Nerve Supply

It is supplied by the deep peroneal nerve.

### Actions

It produces the dorsiflexion of foot at the ankle and dorsiflexion of the great toe. It is an important support of medial longitudinal arch.

### Testing Function of Extensor Hallucis Longus

The subject attempts to dorsiflex the great toe against resistance.

### Extensor Digitorum Longus

i. Extensor Digitorum Longus (EDL) takes origin from the upper three-fourths of the anteromedial surface of the fibula, adjacent interosseous membrane and anterior intermuscular septum. The extensor digitorum longus divides into four tendons on the dorsum of foot.

ii. The tendons of second-to-fourth toes fuse with the tendons of extensor digitorum brevis and together they form the dorsal digital expansion. At the proximal interphalangeal joint each dorsal digital expansion divides into three slips. The median slip is attached to the base of middle phalanx and the collateral slips unite before inserting into the base of terminal phalanx.

### Nerve Supply

It is supplied by the deep peroneal nerve.

### Actions

It produces the dorsiflexion of foot and dorsiflexion of lateral four toes.
Testing Function of Extensor Digitorum Longus
The subject is asked to dorsiflex the toes against resistance.

Peroneus Tertius
i. It takes origin from the lower part of anteromedial surface of fibula (in continuation with the extensor digitorum longus)
ii. It is inserted into the dorsal surface of the base of fifth metatarsal bone.

Nerve Supply
It is supplied by the deep peroneal nerve.

Actions
It produces dorsiflexion and weak eversion of foot.

Anterior Tibial Artery (Fig. 97.2)
i. The anterior tibial artery is the smaller terminal branch of the popliteal artery in the back of the leg at the distal margin of the popliteus.
ii. It enters the anterior compartment by passing through the gap above the superior margin of the interosseous membrane.
iii. It descends in contact with the anterior surface of the interosseous membrane and is flanked by venae comitantes.
iv. The anterior tibial artery continues as the dorsalis pedis artery in front of the ankle.
v. The artery is deeply placed in the upper two-thirds of the leg but becomes superficial in the lower-third.

Relations
i. Posteriorly, the proximal two-third of the artery rests directly on the interosseous membrane but its lower-third is in contact with the lateral surface of tibia and front of ankle joint.
ii. Anteriorly, the proximal three-fourths is covered by tibialis anterior, extensor hallucis longus and extensor digitorum longus muscles. In the lower part of the leg, the tendon of extensor hallucis longus crosses the anterior tibial artery in front. Below this level, it is superficial and covered by fasciae and extensor retinaculum.
iii. Medially, it is related to the tibialis anterior muscle and lower down to the tendon of extensor hallucis longus.
iv. Laterally, it is related to the neck of fibula followed by extensor digitorum longus in the upper-third and the extensor hallucis longus in the middle-third. At the ankle the extensor digitorum longus lies laterally

Branches
i. The posterior tibial recurrent artery arises before the anterior tibial artery enters the anterior compartment. It takes part in genicular anastomosis.
ii. The anterior tibial recurrent artery passes through the tibialis anterior muscle and takes part in genicular anastomosis.
iii. The anterior medial malleolar artery takes part in medial malleolar network.
iv. The anterior lateral malleolar artery takes part in lateral malleolar network.
v. Besides the named branches, there are numerous muscular branches.

Surface Marking
The anterior tibial artery is represented by a line, which begins about 2.5 cm inferior to the medial side of the head of fibula and ends at the midpoint between the malleoli.

Anterior Tibial Pulse
The anterior tibial pulse is felt at the midpoint of the front of the ankle.

Deep Peroneal Nerve (Fig. 97.2)
The deep peroneal nerve is one of the terminal branches of the common peroneal nerve. It begins in the substance of the peroneus longus muscle in the lateral compartment at the lateral side of the neck of fibula.

Entry into Anterior Compartment
The deep peroneal nerve enters the anterior compartment by piercing the anterior intermuscular septum, which intervenes between the lateral and anterior compartments.

Course in Anterior Compartment
i. Initially the deep peroneal nerve courses medi ally, lying deep to the extensor digitorum longus. It reaches the lateral side of the anterior tibial vessels. The neurovascular bundle thus formed travels down on the anterior surface of the interosseous membrane between the extensor digitorum longus and extensor hallucis longus on the lateral side and tibialis anterior on the medial side.
ii. In the lower part of the leg the tendon of extensor hallucis longus crosses the neurovascular bundle from lateral to medial side.
iii. The deep peroneal nerve is called the nervus hesitans due to its peculiar relations to the anterior tibial artery. The nerve changes its relation to the artery during its course as follows. At first it is lateral in position. Then it gradually comes in front of the artery but at the lower level again goes back in lateral position (as if the nerve hesitates to cross the artery).

Branches in Anterior Compartment
i. Muscular branches to the four muscles of the compartment.
ii. Articular branch to the ankle joint.
Entry into Dorsum of Foot
The deep peroneal nerve passes deep to the superior extensor retinaculum to enter the dorsum of foot midway between the malleoli. Here it lies between the tendons of extensor hallucis longus medially and extensor digitorum longus laterally.

Course and Branches on Dorsum of Foot
i. The deep peroneal nerve terminates immediately on entering the dorsum of the foot into lateral and medial branches (Fig. 97.8).

ii. The medial terminal branch courses distally to reach the first interdigital cleft. During its course, it gives articular branches to the adjacent intertarsal joints, muscular branch to first dorsal interosseous muscle and dorsal digital nerves to the skin of first interdigital cleft (adjacent sides of first and second toes).

iii. The lateral terminal branch passes distally deep to the extensor digitorum brevis and enlarges into a pseudo-ganglion, which gives a muscular branch to the extensor digitorum brevis and three-minute interosseous branches to the tarsal and metatarsophalangeal joints of the middle three toes. The first interosseous branch also supplies the second dorsal interosseous muscle.

Peroneal Compartment
The peroneal or the lateral compartment of the leg is smallest of the three compartments.

Boundaries
i. Anteriorly, it is bounded by the anterior intermuscular septum (Figs 97.1 and 97.2).

ii. Posteriorly, it is bounded by posterior intermuscular septum.

iii. Medially, it is bounded by lateral surface of the fibula.

iv. The deep fascia of leg bounds it on lateral side.

Contents
i. Peroneus longus and brevis muscles.

ii. Termination of common peroneal nerve at the neck of fibula.

iii. Deep peroneal nerve in its upper part of the compartment.

iv. Superficial peroneal nerve is the nerve of lateral compartment.

v. The recurrent genicular branch of common peroneal nerve takes origin here (Fig. 97.2).

Peroneus Longus (Fig. 97.3)

i. The peroneus longus takes origin from the head and upper two-thirds of the lateral surface of fibula. Between these two attachments there is a gap through which the common peroneal nerve passes.

ii. The muscle becomes tendinous in the lower part of the leg. Its long tendon changes direction around the

Clinical insight...
1. The deep peroneal nerve injury produces motor and sensory effects as follows:
   i. Paralysis of extensor (dorsiflexors) of ankle joint (muscles of anterior compartment) leads to a deformity called foot drop in which dorsiflexion at the ankle is lost.
   ii. There is sensory loss in the first interdigital cleft.

2. Anterior compartment syndrome develops as a result of strenuous exercise, which leads to marked swelling of the muscles of the compartment. This may impede venous return leading to more accumulation of fluid inside the compartment, which has unyielding walls. Other common causes of fluid accumulation is bleeding due to fracture of the tibia. The pressure in the closed space tends to compress the contents.
   i. The compression of anterior tibial artery may lead to arterial insufficiency, which results in serious complication of gangrene of the leg or foot.
   ii. The compression of deep peroneal nerve may cause severe pain in the leg and weakness of the muscles of the compartment.

To relieve the compression (to prevent serious complications) the deep fascia of the leg is surgically incised (fasciotomy) along the whole length of the compartment.

3. Shin splints results from overexertion or traumatic injury to the tibialis anterior muscle. Some people, who are not used to exercise, after a long walk, experience pain in the front of leg. Sudden exercise may cause micro-trauma to tibialis anterior or tears in the periosteum of tibia.
lateral malleolus, where it is strapped by the superior peroneal retinaculum. On the lateral side of the calcaneus, it is strapped by the inferior peroneal retinaculum. It courses forwards in the foot below the peroneal trochlea of calcaneus to reach the lateral margin of foot, where it changes direction to enter the groove on the plantar surface of cuboid. Further it crosses the sole from lateral-to-medial side to reach its insertion on medial cuneiform and base of first metatarsal bone (Fig. 99.16).

**Special Features of Peroneus Longus**

i. This muscle has a very long tendon, which changes direction at two places in its course, first at the lateral malleolus and second at the cuboid bone

ii. The tendon crosses across the sole from lateral-to-medial side deeply grooving the cuboid bone

iii. The common peroneal, deep peroneal and superficial peroneal nerves lie deep to it at the neck of fibula. The superficial peroneal nerve passes through the substance of peroneus longus for a short distance.

**Peroneus Brevis**

The peroneus brevis lies deep to the peroneus longus muscle.

i. The peroneus brevis takes origin from the lower two-thirds of the lateral surface of fibula.

ii. The tendon of peroneus brevis is in direct contact with the lateral malleolus (while that of peroneus longus lies superficial to it). After passing under the peroneal retinacula the tendon courses forwards above the peroneal trochlea to insert into the lateral aspect of the tuberosity of the base of the fifth metatarsal bone.

**Synovial Sheath of Peroneal Tendons**

The tendons of peroneus longus and brevis are very close to each other as they pass deep to the peroneal retinacula. They are covered with a common synovial sheath from the lateral malleolus to peroneal trochlea. Beyond this point there is a separate synovial sheath for each tendon up to its insertion (Fig. 97.9). The reason for two synovial sheaths at this level is that, deep to inferior peroneal retinaculum, separate osteofascial spaces are formed due to the presence of a septum from the inferior peroneal retinaculum to the peroneal trochlea.

**Nerve Supply**

The peroneus longus and brevis muscles are supplied by superficial peroneal nerve.

**Actions**

i. The peroneus longus and brevis muscles produce eversion of foot at subtalar and midtarsal joints.

ii. They assist in extreme plantarflexion of foot at ankle joint.

iii. The tendon of peroneus longus acts as a pulley that supports the arches of foot from above.

**Testing Function of Peroneal Muscles**

The subject in the supine position is asked to evert the foot against resistance, when the foot is raised from the bed. Isolated weakness of peroneal muscles thus found, may be the earliest sign of peroneal muscular atrophy.

**Superficial Peroneal Nerve**

The superficial peroneal nerve is one of the terminal branches of the common peroneal nerve deep to the peroneus longus muscle at the neck of fibula (Fig. 97.3).

i. From this level it travels downwards in the intermuscular plane between the two peroneal muscles, which it supplies.

ii. At the junction of upper two-thirds and lower one-third of the leg, it pierces the deep fascia of the leg to enter the superficial fascia.

iii. The superficial peroneal nerve divides into medial and lateral branches in the lower part of leg. Both the terminal branches cross in front of the extensor retinaculum to enter the dorsum of foot.

**Branches in Leg**

i. Muscular branches to peroneus longus and peroneus brevis muscles

ii. Cutaneous branches to lateral part of leg.

**Distribution on Dorsum of Foot (Fig. 99.1)**

i. The medial terminal branch divides into two dorsal digital nerves, which supply the medial side of great toe and adjacent sides of second and third toes.

ii. The smaller lateral branch divides into two dorsal digital branches for the adjacent sides of third and fourth and fifth toes.

iii. The medial and lateral terminal branches supply the skin of the larger intermediate area of the dorsum.

**Posterior Compartment of Leg**

The posterior compartment is the largest osteofascial compartment of leg. Superiorly, it is continuous with the
Compartments of Leg and Retinacula Around Ankle

popliteal fossa. And inferiorly, it is continuous with the sole of foot deep to the flexor retinaculum.

**Boundaries (Fig. 97.1)**

i. The anterior boundary is formed by the posterior surfaces of tibia and fibula and the interosseous membrane.

ii. The posterior boundary is the deep fascia of the leg.

iii. Its lateral boundary is the posterior intermuscular septum.

iv. Its medial boundary is the attachment of the deep fascia to the medial border of tibia.

**Subdivisions**

The posterior compartment is subdivided into two parts (superficial and deep) by a transverse septum (which is attached to the soleal line of tibia above, medial border of tibia medially, posterior border of fibula laterally and is continuous with the flexor retinaculum below).

i. The superficial subdivision of the compartment contains gastrocnemius, soleus and plantaris muscles, which are the superficial muscles of the calf.

ii. The deep subdivision contains flexor digitorum longus, flexor hallucis longus, tibialis posterior and popliteus muscles including the tibial nerve, posterior tibial artery and peroneal artery. The tibialis posterior is the deepest muscle lying on the interosseous membrane. Between it and the long flexors of the toes there is a fascial layer spanning between the tibia and the fibula.

**Gastrocnemius**

The gastrocnemius is a bulky muscle with two heads.

**Attachments**

i. The lateral head arises from the lateral aspect of lateral condyle of femur by a tendon. Occasionally a sesamoid bone, called fabella develops in the tendon of lateral head.

ii. The medial head arises from the upper and posterior part of medial condyle behind the adductor tubercle and the adjacent part of the popliteal surface of femur just above the medial condyle. The tendinous origin of medial head is separated from the capsule of knee joint by a bursa.

iii. The gastrocnemius tendons join the plantaris and soleus to form a common tendon called tendocalcaneus by which it is inserted into the middle one-third of the posterior surface of calcaneus.

**Nerve Supply**

The medial and lateral heads receive separate branches from the tibial nerve in the popliteal fossa.

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**Clinical insight ...**

**Tennis Leg**

It is a painful calf injury in which there is a tear of medial belly of gastrocnemius at its musculotendinous junction due to overstretched.

**Plantaris**

It is a fusiform muscle with small belly and long tendon, lying under cover of the lateral head of gastrocnemius. The plantaris is a vestigial muscle. The plantar aponeurosis is its degenerated part.

**Attachments**

i. The plantaris arises from the lower-third of lateral supracondylar ridge of femur.

ii. It is inserted into the calcaneus through the tendocalcaneus.

**Nerve Supply**

A branch from tibial nerve in the popliteal fossa supplies it.

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**Clinical insight ...**

**Tendon Grafting**

The plantaris tendon is used for tendon grafting in the repair of ruptured long tendons.

**Soleus**

It is a very powerful muscle situated deep to the gastrocnemius. It is a multipennate muscle that is shaped like the sole of the foot.

**Attachments**

i. The soleus has a broad, horseshoe-shaped origin from the upper one-third of the posterior surface of fibula, soleal line of tibia, middle-third of the medial border of tibia and the tendinous arch posterior to the neurovascular structures of the compartment.

ii. The massive muscle belly ends in a tendon, which fuses with the tendon of gastrocnemius and plantaris to form tendocalcaneus by which it is inserted into the calcaneus.

**Nerve Supply**

The branches of tibial nerve in the popliteal fossa supply the muscle.

**Tendocalcaneus (Achilles tendon)**

The tendocalcaneus is the thickest and strongest tendon in the body. Its length is 15 cm. It begins in the middle of calf though its anterior aspect receives muscle fibers of soleus almost to its lower end. About four centimeter above the calcaneus, it becomes flattened and is inserted into the posterior surface of calcaneus. This tendon is very
important in conserving the energy and releasing it in the next stage in gait cycle. Unlike the other long tendons at the ankle the tendocalcaneus is not enveloped in the synovial sheath. It is related to two bursae.

i. The calcaneal bursa, between the calcaneus and the tendocalcaneus is prone to inflammation in long distance runners.

ii. There is a bursa between the tendocalcaneus and the skin (adventitious bursa).

Actions of Superficial Calf Muscles

i. The gastrocnemius and soleus muscles cause plantarflexion of foot at the ankle joint. In flexed position of knee the gastrocnemius cannot act on the ankle joint, so soleus alone is the plantarflexion in flexed knee.

ii. The gastrocnemius and soleus together provide the main propulsive force in walking and running, though gastrocnemius is more active in these movements. The gastrocnemius is an example of white muscle composed mainly of the fast fatigue-susceptible type of muscle fibers.

iii. Gastrocnemius is the flexor of knee joint.

iv. Soleus is a postural muscle. It is a red muscle consisting mainly of slow fatigue resistant muscle fibers.

v. Gastrocnemius and soleus together make a calf muscle pump for facilitating venous return from the lower limb. The soleus is regarded as the peripheral heart because it houses large venous sinuses, which are connected to the superficial veins by perforating veins. These veins pass through soleus. Thus, contraction of soleus helps in sucking the blood into the perforating veins and propelling it towards the deep veins of the posterior compartment.

Testing Function of Gastrocnemius and Soleus

i. On asking the subject to plantarflex against resistance with knee in extended position, one can feel the contraction of the gastrocnemius.

ii. For soleus, the subject is asked to plantarflex against resistance with knee in flexed position.

Clinical insight ...

i. The sprain and rupture of tendocalcaneus (Fig. 97.4) are common injuries. The rupture causes sudden pain in the calf. Due to retraction of the muscle bellies of gastrocnemius proximally, a gap can be felt in the tendon. There is loss of plantarflexion of the foot. The ruptured tendon can be sutured and strengthened using fascia lata.

ii. The ankle jerk or Achilles tendon reflex is elicited as follows. On tapping the tendon with knee hammer, there is reflex contraction of gastrocnemius with resultant plantarflexion of the foot. The nerve responsible for this is the tibial nerve and the spinal center is S1 segment. So, in paralysis of gastrocnemius the patient will not be able to stand on the toes and there will be loss of ankle jerk.

Posterior Tibial Artery

The posterior tibial artery is a terminal branch of the popliteal artery at the lower margin of popliteus muscle. The venae comitantes and the tibial nerve are closely associated with the artery. The neurovascular structures enter the posterior compartment by passing under the tendinous arch.

Course and Relations (Fig. 97.5)

The posterior tibial artery passes vertically downwards in the posterior compartment and divides into lateral and medial plantar arteries deep to the flexor retinaculum.
i. Anteriorly, the artery rests on the posterior surfaces of tibialis posterior and flexor digitorum longus muscles, posterior aspect of tibia and the capsule of the ankle joint.

ii. Posteriorly, it is separated by the transverse septum from the superficial calf muscles.

iii. Distally, it is covered by skin and fasciae and hence lies very close to the surface.

iv. Its terminal part is deep to the flexor retinaculum and abductor hallucis, where it divides into medial and lateral plantar arteries.

Relation to Tibial Nerve
The tibial nerve is at first medial to the artery but gradually changes to posterior position and in the lower part it lies posterolateral to the artery.

Surface Marking
The posterior tibial artery corresponds to a line from the midline on the back of the leg at the level of the neck of fibula to a point midway between the tendocalcaneus and medial malleolus.

Posterior Tibial Pulse (Fig. 97.6)
The posterior tibial pulse can be felt behind and below the medial malleolus between the tendons of flexor hallucis longus and flexor digitorum longus.

Branches
i. Circumflex fibular artery passes through the substance of the soleus and winds round the lateral side of the neck of fibula. It takes part in genicular anastomosis.

ii. Nutrient artery of the tibia arises near the origin of posterior tibial artery and enters the nutrient foramen of tibia just below the soleal line.

iii. Muscular branches are for the deep muscles of the back of leg.

iv. Communicating branch joins with the branch of peroneal artery.

v. Medial malleolar branch takes part in medial malleolar network.

vi. Medial calcanean branches pierce the flexor retinaculum and supply the skin of the heel.

vii. The peroneal artery (Fig. 97.5) is a large branch that arises very close to the beginning of the posterior tibial artery. It travels the entire length of the posterior compartment lying in close contact with the medial crest of the fibula in a fibrous tunnel between the tibialis posterior and flexor hallucis longus muscles. It terminates on the lateral aspect as the lateral calcanean branches, which take part in the lateral malleolar network. The branches of the peroneal artery are, muscular to the peroneal muscles, nutrient artery to the fibula, communicating branch to join with communicating branch of posterior tibial artery and the perforating branch, which passes through the lower part of the interosseous membrane to enter the anterior compartment of leg. The perforating artery after reaching anterior aspect of the leg anastomoses with the lateral malleolar branch of anterior tibial artery and with the lateral tarsal artery (a branch of dorsalis pedis) to form lateral malleolar network. The perforating branch is sometimes enlarged in which case it may replace the dorsalis pedis artery.

Posterior Tibial Veins
The veins accompanying the posterior tibial artery (venae comitantes) are the posterior tibial veins. These veins begin deep to the flexor retinaculum by the union of veins accompanying the lateral and medial plantar arteries. The tributaries of the posterior tibial veins are the veins from the muscles, especially the venous plexus in the soleus and peroneal veins. The perforating veins connecting these veins to the great saphenous vein are provided with unidirectional valves, so that blood flows from the superficial to the deep veins. The venae comitantes of the posterior
and anterior tibial arteries unite at the lower margin of popliteus muscle to form popliteal vein.

Clinical insight ...

Deep Vein Thrombosis (DVT)
The deep veins of the leg are clinically very important because they are prone to thrombosis if the lower limb is immobilized for any reason (plaster cast on leg or postoperative period). If the thrombus is detached it may enter venous circulation and reach the pulmonary arteries via right side of heart causing fatal pulmonary embolism (refer to chapter 92).

Tibial Nerve
The tibial nerve in the popliteal fossa continues as the tibial nerve of posterior compartment of leg at the distal border of popliteus muscle. It enters the posterior compartment along with posterior tibial vessels deep to the tendinous arch of origin of the soleus.

Course and Relations
The relations of tibial nerve are similar to those of the posterior tibial artery.

i. The tibial nerve is closely applied to the anterior surface of the deep transverse septum throughout its course.

ii. It lies medial to the posterior tibial vessels deep to the fibrous arch of soleus muscle.

iii. Below this level, the tibial nerve crosses the accompanying vessels posteriorly from medial to lateral direction.

iv. At the ankle, the tibial nerve is lateral to the posterior tibial artery.

v. It divides deep to the flexor retinaculum into lateral and medial plantar nerves.

Branches
i. The muscular branches are given to tibialis posterior, flexor digitorum longus and flexor hallucis longus. The soleus may also receive a branch in the leg.

ii. The articular branches supply the ankle joint.

iii. The medial calcanean branches pierce the flexor retinaculum to supply the skin over the heel.

Clinical insight ...

Effects of Lesion of Tibial Nerve in Leg
Being deep in location, injury to tibial nerve is less common in both popliteal fossa and posterior compartment of leg. When injured it shows following effects:

i. The deep muscles of posterior compartment (tibialis posterior, flexor hallucis longus and flexor digitorum longus) and the muscles of sole are paralyzed.

ii. There is sensory loss on the sole.

iii. There is loss of sensation on the sole. As a consequence, trophic ulcers may develop on sole.

Popliteus (Fig.96.2)
The popliteus is located in the lower part of the floor of popliteal fossa. This muscle is important in unlocking a locked knee joint. So it is referred to as the key to the knee joint.

Attachments
i. The popliteus takes origin from the anterior end of the popliteal groove on the lateral condyle of femur. Its origin is tendinous and is located inside the capsule of knee joint (a few of its fibers arise from the back of lateral meniscus). The intracapsular tendon of popliteus intervenes between the lateral meniscus and the fibular collateral ligament. The long tendon enclosed in synovial sheath, pierces the posterior part of fibrous capsule, below the arcuate popliteal ligament.

ii. The popliteus tendon expands in a triangular fleshy belly, which is inserted into the posterior surface of the tibia above the soleal line.

Relations
i. The posterior surface of the popliteus is covered with a strong fascia, which is an extension from the insertion of semimembranosus muscle. This surface is related to the popliteal vessels and tibial nerve.

ii. Its anterior surface is in contact with the tibia.

Events at Distal Margin of Popliteus
i. The popliteal artery terminates into anterior and posterior tibial arteries.

ii. The popliteal vein is formed by union of anterior and posterior tibial veins (venae comitantes).

iii. The tibial nerve enters into the posterior compartment of leg.

iv. The nerve to popliteus winds round this margin to reach the anterior surface of the muscle.

Nerve Supply
i. The nerve to popliteus is a branch of the tibial nerve in the popliteal fossa. This nerve reaches the lower (distal) margin of the muscle to wind round it to reach its anterior surface. The branches of the nerve enter the anterior aspect of the popliteus.

ii. The nerve to popliteus also supplies a few twig to tibialis posterior muscle.

iii. It supplies articular branches to proximal and distal tibiofibular joints.

iv. It also supplies the interosseous membrane of leg.

Actions
i. The popliteus rotates the tibia medially on the femur when the foot is off the ground and it rotates the femur on the tibia laterally when the foot is on the ground. This movement is known as unlocking as it occurs at the beginning of flexion of a fully extended or locked knee joint.
ii. It is the flexor of knee joint and the lateral rotator of the semiflexed knee.

iii. It protects the lateral meniscus from injury.

**Flexor Digitorum Longus (FDL)**

This deep muscle of leg is the long flexor of lateral four digits.

**Origin**

It takes origin from the posterior surface of the tibia (Fig. 97.7) below the soleal line and medial to the tibial origin of tibialis posterior.

**Course**

The tendon of flexor digitorum longus crosses superficial to the tendon of tibialis posterior in the lower part of the leg. At the ankle, it passes behind the flexor retinaculum and then enters the sole. In the sole, the tendon turns laterally to cross superficial, the tendon of flexor hallucis longus.

**Connections of Flexor Digitorum Longus**

i. The tendon of flexor digitorum longus receives some fibers from the tendon of flexor hallucis longus during the crossing. This connection is called William Turner’s slip which serves the purpose of strengthening the flexor digitorum longus muscle.

ii. Its tendon also receives the insertion of flexor digitorum accessorius on its lateral side. This connection serves to straighten the pull of action of flexor digitorum longus on the toes.

**Insertion**

The common tendon splits into four digital tendons for four lateral toes. Each digital tendon gives origin to the lumbrical muscle of the foot. Finally, the digital tendon enters the fibrous flexor sheath, pierces the tendon of flexor digitorum brevis and is inserted into the plantar surface of the base of terminal phalanx of lateral four toes.

**Nerve Supply**

The tibial nerve supplies the muscle in the leg.

**Actions**

i. The flexor digitorum longus causes the plantarflexion of lateral four toes at metatarsophalangeal and interphalangeal joints.

ii. It assists the plantarflexion at ankle joint and provides support to the arches of foot.

**Flexor Hallucis Longus (FHL)**

This muscle is much larger than the flexor digitorum longus.

**Origin**

This muscle arises from the posterior surface of the fibula (Fig. 97.7) below the origin of soleus and from the fascia covering the tibialis posterior. It also takes origin from the lower part of the interosseous membrane below the distal attachment of tibialis posterior.

**Course**

i. In the leg, the tendon of flexor hallucis longus passes obliquely downward and medially. It lies in a groove on the lower end of the tibia, and then passes deep to the flexor retinaculum.

ii. After entering the sole it crosses the posterior surface of the talus and then the sustentaculum tali of the calcaneus.

iii. It crosses the tendon of flexor digitorum longus in the second layer of the sole and in doing so, gives a fibrous slip (William Turner’s slip) to the digitorum tendon.

**Insertion**

The tendon of flexor hallucis longus is inserted into the base of the distal phalanx of the great toe.

(Note that the flexor hallucis longus tendon grooves in succession, the posterior aspect of lower end of tibia, posterior surface of talus and inferior surface of sustentaculum tali)

**Nerve Supply**

The tibial nerve supplies the muscle in the leg.

**Actions**

i. The muscle causes plantarflexion of the great toe and of the ankle joint.
Section 08

Lower Limb

ii. Additional action is to provide support to the medial longitudinal arch of foot.

Tibialis Posterior

It is the most anterior or deeply placed muscle in the posterior compartment. Though it is located between the two long flexor muscles, it is overlapped by both, but especially the flexor hallucis longus.

Origin

The tibialis posterior takes origin from the upper two-thirds of the posterior aspect of the interosseous membrane and adjacent parts of the posterior surfaces of both bones of the leg.

Course

In the distal part of the leg its tendon passes deep to the tendon of flexor digitorum longus. Then it passes in a groove behind the medial malleolus enclosed in a synovial sheath and goes deep to the flexor retinaculum to reach the sole. In the sole, it lies inferior to the plantar calcaneonavicular ligament (spring ligament).

Insertion

The main insertion of the tibialis posterior tendon is on the tuberosity of the navicular bone. The remaining part of the tendon sends slips of attachments to sustentaculum tali and the plantar surface of all the tarsal bones except the talus and to the bases of second-to-fourth metatarsal bones.

Nerve Supply

The tibial nerve supplies the tibialis posterior muscle in the posterior compartment. It may also receive a twig from nerve to popliteus.

Actions

i. The tibialis posterior is the chief inverter of foot at calcaneocuboid, subtalar and midtarsal joints.
ii. It is a weak plantarflexor of the foot at the ankle.
iii. It gives the main support to the medial longitudinal arch.

Synovial Sheaths of Flexor Tendons

The synovial sheath for tibialis posterior extends from the level of four centimeters above the medial malleolus to just proximal to its insertion into the navicular bone. The sheath for the flexor hallucis longus extends from the malleolar level proximally to the base of first metatarsal bone distally. The sheath for the flexor digitorum longus extends from just above the medial malleolus to the level of navicular bone. The inflammation of the synovial sheaths around the tendons gives rise to tenosynovitis.

Know More ...

| Segmental Innervation of Some Muscles of Lower Limb |
|-----------------|--------|
| Iliopsoas       | L2, L3 |
| Sartorius       | L2, L3 |
| Adductor muscles| L2, L3, L4|
| Quadriceps femoris | L2, L3, L4 |
| Tibialis anterior and posterior | L4, L5 |
| Gluteus minimus and medius | L4, L5, S1 |
| Gluteus maximus | L4, L5, S1, S2 |
| Hamstrings      | L4, L5, S1, S2 |
| Gastrocnemius   | L4, L5, S1, S2 |
| Soleus          | L5, S1, S2 |
| Flexor hallucis and digitorum longus | S1, S2 |
| Extensor hallucis longus | L5 |

RETINACULA AROUND ANKLE

The deep fascia of the leg shows thickened bands called retinacula around ankle to strap down tendons, which cross the joint to enter the sole or dorsum of foot. These retinacula are named according to the compartments of the tendons, which pass deep to them. The tendons belonging to muscles of anterior or extensor compartment, pass deep to extensor retinaculum. The tendons belonging to posterior or flexor compartment pass deep to flexor retinaculum and those belonging to lateral or peroneal compartment pass deep to peroneal retinaculum.

Extensor Retinacula (Fig. 97.8)

There are two thickened bands in front of the ankle called superior and inferior extensor retinacula. The function of these bands is to hold the extensor tendons strapped to the ankle joint. In the absence of the retinacula, the tendons will jump forward during dorsiflexion movement.

Superior Extensor Retinaculum

The superior extensor retinaculum is attached laterally to the lower part of subcutaneous anterior surface of fibula and medially to the anterior border of tibia above the medial malleolus.

Superficial Relations

Its superficial relations (from medial to lateral side) are the saphenous nerve, great saphenous vein and the medial and lateral terminal branches of superficial peroneal nerve.
Deep Relations

Its deep relations (from medial-to-lateral) are the tibialis anterior, extensor hallucis longus, anterior tibial vessels, deep peroneal nerve, extensor digitorum longus and peroneus tertius.

Synovial Sheaths

The extensor tendons acquire synovial sheaths as they pass deep to the superior extensor retinaculum. The function of the synovial sheaths is to permit frictionless movements of the tendons.

Inferior Extensor Retinaculum

The inferior extensor retinaculum is Y-shaped (the stem of the Y pointing laterally and the two limbs medially). It is present on the dorsum of foot. Laterally, it is attached to the upper surface of the anterior part of calcaneus. Medially its upper band is attached to the medial malleolus and the lower band passes to the medial side of the foot to fuse with the deep fascia of the sole.

Peroneal Retinacula (Fig.97.9)

The peroneal retinacula are the thickened bands of deep fascia on the lateral side of the ankle. The tendons of peroneus longus and brevis muscles pass deep to them. The small saphenous vein and sural nerve pass superficial to the superior peroneal retinaculum.

i. The superior peroneal retinaculum is attached to the back of lateral malleolus above and to the lateral surface of calcaneus below.

ii. The inferior peroneal retinaculum is attached to the lateral surface of calcaneus posteriorly and to the stem of the inferior extensor retinaculum anteriorly. Some of the fibers of the retinaculum are attached to the periosteum of peroneal trochlea as it crosses the trochlea. This gives rise to two osteofascial canals for the tendons of peroneal muscles. This explains why the proximal common synovial sheath of the peroneal tendons becomes double distally.

Flexor Retinaculum (Fig.97.10)

It is a thick band of deep fascia on the medial aspect of ankle. From its upper attachment it is directed inferiorly, posteriorly and laterally. Medially or above, it is attached to the medial malleolus and laterally or below to the medial process of the tubercle of calcaneus. Its distal border gives origin to the abductor hallucis muscle. The medial calcaneal nerve (a branch of tibial nerve) and the medial calcaneal artery (a branch of posterior tibial artery) pierce the retinaculum.
Deep Relations

Its deep relations from above downwards (or medially) are tibialis posterior tendon, flexor digitorum longus tendon, posterior tibial artery, tibial nerve and flexor hallucis longus tendon.

Clinical insight ...

**Tarsal Tunnel Syndrome**

In tarsal tunnel syndrome, the tibial nerve is compressed in the osseofibrous tunnel deep to flexor retinaculum. The symptoms are: burning, tingling and pain in the sole of the foot. Surgical division of the flexor retinaculum relieves the severe and persistent pain.
There are three joints between the tibia and the fibula. The proximal (superior) tibiofibular joint is of synovial type. The middle tibiofibular joint is of the fibrous type. The distal (inferior) tibiofibular joint belongs to syndesmosis type of fibrous joint.

**Proximal Tibiofibular Joint**

It is plane type of synovial joint between the facet on the posterolateral aspect of lateral condyle of tibia and the medial aspect of the head of the fibula. The joint capsule is thick anteriorly and posteriorly. The fibular collateral ligament and the tendon of biceps femoris are related to the superolateral aspect of the joint. The tendon of the popliteus enclosed in the synovial sheath passes across the posteromedial aspect of the joint. In 10% of people, the synovial sheath of the popliteus tendon may communicate with the synovial cavity of this joint. The proximal tibiofibular joint allows a slight amount of gliding movement. The nerve to popliteus and the recurrent genicular nerve supply the joint.

**Interosseous Membrane of Leg**

This is a fibrous membrane that stretches between the interosseous borders of tibia and fibula, thus intervening between the anterior and the posterior compartments of the leg. The direction of fibers in the membrane is downward and laterally from the tibia to fibula. At the lower end, the interosseous membrane is in continuity with the interosseous ligament of distal tibiofibular joint. The anterior tibial artery enters the anterior compartment of leg through a large oval opening above the superior margin of the membrane. The perforating branch of peroneal artery pierces the membrane near its lower margin to enter the anterior compartment. The nerve to popliteus supplies the membrane.

**Relations of Interosseous Membrane**

i. The anterior surface is related to the anterior tibial vessels and deep peroneal nerve. The anterior surface of the membrane provides partial origin to tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius.

ii. The posterior surface of the membrane gives partial origin to the tibialis posterior and the flexor hallucis longus.

**Distal Tibiofibular Joint**

The interosseous ligament is the connecting bond between the medial convex surface of the distal end of fibula and the rough fibular notch of the lateral surface of tibia. The anterior tibiofibular ligament lies in front of the joint between the adjacent margins of tibia and fibula. The stronger posterior tibiofibular ligament strengthens the joint on the posterior aspect. The inferior margin of this ligament forms a separate ligament called inferior transverse tibiofibular ligament, which is yellow in color due to rich content of elastic fibers. The inferior transverse tibiofibular ligament extends beyond the lower limits of tibia and fibula as it stretches from the proximal end of lateral malleolar fossa to the posterior border of tibial articular surface. It forms the posterior lip of the socket of
ankle joint and makes contact with the posterolateral part of the body of talus. The distal tibiofibular joint receives twigs from the nerve to popliteus, deep peroneal nerve and saphenous nerve.

**ANKLE OR TALOCRURAL JOINT**

The ankle joint is a strong weight-bearing joint of the lower limb. The ankle joint belongs to the uniaxial hinge variety of synovial joint.

**Articulating Bones**
The bones, which take part in this articulation are, the lower end of tibia, lower end of fibula and the talus (Fig. 98.1). The radiographic appearance of the ankle joint is shown in Figure 98.2.

**Articular Surfaces**
i. Proximally, the articular facets of the lower end of tibia, fibula and inferior transverse tibiofibular ligament form the tibiofibular socket. The tibial articular surface covers the lower end of tibia and lateral surface of medial malleolus. The fibular articular surface is a triangular facet on the medial aspect of lateral malleolus.

ii. Distally, the articular facets are present on the superior, lateral and medial surfaces of the talus. These facets form a continuous articular area. The comma-shaped facet on the medial aspect of the talus articulates with the facet on the medial malleolus. The triangular facet on the lateral aspect of talus articulates with the facet on lateral malleolus. The trochlear surface on the superior aspect of talus is wider in front than behind. During dorsiflexion of the ankle, the grip of the malleoli on the talus is strongest because this movement forces the anterior wider part of trochlea posteriorly between the malleoli. The ankle joint is relatively unstable during plantarflexion because the narrower posterior part of the trochlear surface does not fill the tibiofibular socket.

**Fibrous Capsule**
The capsule is attached superiorly to the margins of articular surfaces of the tibia and the malleoli. It is attached inferiorly to the margins of articular surfaces of talus.

**Ligaments**

1. Medial collateral ligament (deltoid ligament) is very strong. It is triangular in shape hence the name deltoid ligament (Fig. 98.3).

**Parts**
i. Superficial part is composed of tibionavicular ligament (extending from medial malleolus to tuberosity of navicular bone and the spring ligament), tibiocanean ligament (extending from medial malleolus to the margin of sustentaculum tali of calcaneus) and posterior tibiotalar ligament (extending from medial malleolus to posterior part of medial surface of talus).

ii. Deep part is composed of anterior tibiotalar ligament (extending from medial malleolus to anterior part of medial surface of talus).
The lateral ligament of the ankle joint is thick and divided in three discrete parts, namely, anterior talofibular, posterior talofibular and calcaneofibular (Fig. 98.4). The anterior talofibular ligament extends from the anterior border of lateral malleolus to the lateral aspect of the neck of talus. The posterior talofibular ligament runs from the distal part of malleolar fossa of lower end of fibula to the posterior tubercle of talus. The calcaneofibular ligament is cord-like and extends from the distal end of lateral malleolus to the lateral surface of calcaneus.

Synovial Membrane
The synovial membrane lines the fibrous capsule except the anterior and posterior aspects of the capsule where adipose tissue intervenes between the capsule and the synovial membrane. There is an extension of synovial membrane between the tibia and fibula just below the interosseous ligament of the distal tibiofibular joint.

Relations (Fig. 98.5)
i. The anterior relations of the ankle joint are the structures that pass deep to the extensor retinaculum (tibialis anterior, extensor hallucis longus, anterior tibial artery, deep peroneal nerve, extensor digitorum longus and peroneus tertius).

2. The lateral ligament of the ankle joint is thick and divided in three discrete parts, namely, anterior talofibular, posterior talofibular and calcaneofibular (Fig. 98.4). The anterior talofibular ligament extends from the anterior border of lateral malleolus to the lateral aspect of the neck of talus. The posterior talofibular ligament runs from the distal part of malleolar fossa of lower end of fibula to the posterior tubercle of talus. The calcaneofibular ligament is cord-like and extends from the distal end of lateral malleolus to the lateral surface of calcaneus.

ii. The posteromedial relations are the structures that pass deep to flexor retinaculum (tibialis posterior, flexor digitorum longus, posterior tibial artery, tibial nerve and flexor hallucis longus).

iii. The posterolateral relations are the tendons of peroneus longus and brevis lying deep to the peroneal retinacula.

iv. The direct posterior relation is tendocalcaneus separated from the joint by fibrofatty tissue.

Arterial Supply
The joint receives blood through the rich arterial anastomoses around the ankle, which consists of vascular networks around the malleoli. A large number of arteries take part in the formation of the medial and lateral malleolar networks.

Nerve Supply
The articular branches of deep peroneal and tibial nerves supply the joint.
Section Movements

The movements permitted at the ankle joint are dorsiflexion and plantarflexion.

i. In dorsiflexion, the dorsum of the foot moves toward the anterior surface of the leg and thus the angle between the foot and the leg is reduced. This enables one to strike the ground with the heel during walking.

ii. In plantarflexion, the dorsum moves away from the anterior surface of the leg. This enables one to raise the heel from the ground and touch the toes to the ground as in running.

Muscles producing Dorsiflexion

The tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius are the dorsiflexors.

Muscles producing Plantarflexion

The gastrocnemius with soleus is the main plantarflexor. The other muscles that help in the movement are the tibialis posterior, flexor hallucis longus and flexor digitorum longus.

Clinical insight ...

i. The ankle joint is the most frequently injured joint. The ankle injuries occur in plantarflexed position of the foot. The lateral ligament is more often injured compared to the medial. A sprained ankle results due to tear of anterior talofibular and calcaneofibular ligaments when the foot is twisted in lateral direction (inversion injury). In forcible eversion of foot, the deltoid ligament may be torn. At times the deltoid ligament pulls the medial malleolus thereby causing avulsion fracture of the malleolus.

ii. Pott’s Fracture (fracture-dislocation of the ankle) occurs when the foot is caught in the rabbit hole in the ground and the foot is forcibly everted. In this condition at first, there is an oblique fracture of the shaft and lateral malleolus of fibula. The strong eversion pull on the deltoid ligament causes transverse fracture of the medial malleolus. If the tibia is carried anteriorly the posterior margin of the distal end of tibia is also broken by the talus producing trimalleolar fracture (because here the distal end of tibia is regarded as a third malleolus).
The foot consists of upper surface or dorsum and lower surface or sole.

**Dorsum of Foot**

The dorsum contains the dorsal venous arch, tendons, extensor digitorum brevis muscle, nerves and the dorsalis pedis artery.

**Sensory Nerve Supply (Fig. 99.1)**

i. The saphenous nerve supplies along the medial margin of dorsum up to the base of big toe.

ii. The sural nerve supplies along the lateral side of the dorsum and lateral side of little toe.

iii. The superficial peroneal nerve supplies the larger intermediate area. The superficial peroneal nerve also supplies the medial side of the big toe and all the other toes (except the first interdigital cleft and the lateral side of fifth toe).

iv. The deep peroneal nerve supplies first interdigital cleft (adjacent sides of big toe and second toe).

v. The medial plantar nerve supplies the nail beds of the medial three and half digits and the lateral plantar nerve supplies those of lateral one and half digits.

**Dorsal Venous Arch**

The dorsal venous arch drains the dorsum of the foot and toes via the dorsal metatarsal veins. The small saphenous vein begins at the lateral end of dorsal venous arch and the great saphenous vein on the medial end.

**Tendons on Dorsum (Fig. 97.8)**

The tendons of the four muscles of the anterior compartment pass on the dorsum to reach their respective distal attachments. If the foot is dorsiflexed the tendon of tibialis anterior becomes visible and can be felt on the medial side of foot. The tendon of extensor hallucis longus can be felt just lateral to tibialis anterior tendon, when the big toe is dorsiflexed. The four tendons of extensor digitorum longus are visible in the distal part of dorsum on
dorsiflexion of lateral four toes. The tendon of peroneus tertius is not distinctly visible.

**Extensor Digitorum Brevis (Fig.99.2)**

The extensor digitorum brevis is felt on dorsiflexion of medial four toes as a small elevation just in front of the lateral malleolus. It originates from the anterior part of the dorsal surface of calcaneus and from the stem of the inferior extensor retinaculum. It slants distally and medially across the dorsum of foot and ends into four tendons. The medial part of the muscle with its tendon forms an independent muscle called extensor hallucis brevis, which crosses the dorsalis pedis artery superficially. This tendon is inserted into the base of the proximal phalanx of big toe. The other three tendons join the tendons of extensor digitorum longus of the second to fourth toes.

**Action**

The lateral three tendons extend the metatarsophalangeal and interphalangeal joints of the second to fourth toes. In the big toe, the extensor hallucis brevis acts only on proximal phalanx.

**Nerve Supply**

It is supplied by lateral terminal branch of deep peroneal nerve through pseudoganglion.

**Dorsalis Pedis Artery**

The dorsalis pedis artery (dorsal artery of foot) is the direct continuation of anterior tibial artery midway between the malleoli. It courses downwards and medially on the dorsum of the foot to reach the proximal end of the first intermetatarsal space (Fig.97.8), where it turns downwards between the two heads of the first dorsal interosseous muscle. It enters the sole and ends by completing the plantar arch medially.

**Clinical insight ...**

**Dorsalis Pedis Pulse (Fig.99.3A)**

The palpation of dorsalis pedis artery is very easy because of its superficial location. It is felt just lateral to the extensor hallucis longus tendon against the tarsal bones. A diminished or absent dorsalis pedis pulse indicates arterial insufficiency of the lower limb caused by block in any one of the proximal arteries of the lower limb (cause may be thrombosis, embolism or arteriosclerosis in femoral, popliteal or anterior tibial arteries). Figure 99.3B shows the gangrene of the foot due to vascular insufficiency.

**Surface Marking**

A line starting from the midpoint between the malleoli to the proximal end of first intermetatarsal space represents the dorsalis pedis artery.

**Relations**

On the deep (inferior) aspect the artery lies successively on the capsule of ankle joint, talus, navicular and intermediate cuneiform bones. On the superficial or superior aspect the skin, fasciae, and inferior extensor retinaculum and extensor hallucis brevis cover it distally. Medially it is related to the tendon of extensor hallucis longus and...
laterally to the medial tendon of extensor digitorum longus and medial terminal branch of deep peroneal nerve.

Branches
There are three named branches of dorsalis pedis on the dorsum, arcuate artery, lateral and medial tarsal arteries and the first dorsal metatarsal artery.

Arcuate Artery
The arcuate artery (a branch of dorsalis pedis) passes laterally across the bases of metatarsal bones deep to the extensor tendons. It terminates by taking part in the lateral malleolar network. The arcuate artery has the shape of the arch with forward convexity.

Dorsal Metatarsal Arteries
From the convexity of the arcuate artery, three dorsal metatarsal arteries originate for the second to fourth intermetatarsal spaces (the first dorsal metatarsal artery is the direct branch of dorsalis pedis artery, at the point where it dips into the first intermetatarsal space). Each dorsal metatarsal artery receives two sets of perforating arteries. The proximal set consists of perforating arteries for the second to fourth spaces, which connect the dorsal metacarpal arteries to the plantar arch. The distal set of perforating arteries connects each dorsal metatarsal artery to the corresponding plantar metatarsal artery. At the interdigital cleft each dorsal metatarsal artery divides in two dorsal digital arteries for the adjacent sides of first and second, second and third, third and fourth, and fourth and fifth digits. The first dorsal metatarsal artery (a direct branch of dorsalis pedis artery) gives a twig to the medial side of the big toe while the fourth artery gives a twig to the lateral side of little toe.

Sole of Foot
The sole of the foot bears, the weight of the body and is subjected to the maximum wear and tear. Hence it is covered by thick skin with keratinized layer of epidermis. The subcutaneous fat is divided into small loculi by fibrous septa, which anchor the skin to the deep fascia. The fibrofatty tissue is particularly well developed at three sites, which come in contact with the ground, namely, the heel and heads of the metatarsals and pulp of terminal digits.

Fig. 99.3B: Gangrene of foot and toes due to arterial insufficiency

Fig. 99.4: Sensory nerve supply of sole
Sensory Nerve Supply (Fig. 99.4)

i. The medial calcanean branches of tibial nerve supply the skin over the heel.

ii. The cutaneous branches of medial plantar nerve supply the skin of the medial half of the sole and the plantar digital branches of the same nerve supply the plantar aspect of the great, second, third and medial half of fourth toes.

iii. The cutaneous branches of lateral plantar nerve supply, the lateral half of sole and the plantar digital branches of the same nerve supply, the plantar aspect of lateral half of fourth toe and the entire fifth toe.

Arterial Supply of Heel

The heel receives blood from two sources, the medial aspect from the medial calcanean branches of the posterior tibial artery and the lateral aspect from the lateral calcanean branch of peroneal artery. If the posterior tibial artery is blocked above the origin of its medial calcanean branch or if the medial calcanean artery is injured it is likely to cause necrosis of the skin covering the skin.

Deep Fascia of Sole

The deep fascia of sole is called plantar fascia. The central part of the plantar fascia is much thicker than its lateral and medial parts.

Plantar Aponeurosis (Fig.99.5)

The thick central part of the plantar fascia is triangular in shape. It is known as the plantar aponeurosis. It is regarded as the degenerated tendon of plantaris muscle.

Attachments

i. The apex of plantar aponeurosis is directed posteriorly and is attached to the medial process of the calcaneal tubercle.

ii. Its base splits into five slips (one for each toe) proximal to the metatarsal heads. Each slip divides into a superficial and a deep stratum. The superficial stratum is connected to the superficial transverse metatarsal ligament. The deep stratum of each slip divides into two slips, which pass on either side of flexor tendons to get attached to the deep transverse metatarsal ligaments, plantar ligaments of metatarsophalangeal joints and fibrous flexor sheath at the base of each proximal phalanx.

iii. Laterally the plantar aponeurosis is continuous with the plantar fascia covering the abductor digiti minimi.

iv. Medially the plantar aponeurosis is continuous with the plantar fascia covering the abductor hallucis.

v. A lateral intermuscular septum projects from the lateral margin of plantar aponeurosis. It is attached to the fibrous sheath of peroneus longus tendon and the fifth metatarsal bone.

vi. A medial intermuscular septum projects from the medial margin of the plantar aponeurosis. It is attached to a large number of ligaments, tarsal bones and fascia over the muscles and tendons.

Function

The plantar aponeurosis gives protection to the plantar nerves and blood vessels. It also provides support to the arches of foot.

Clinical Conditions of Plantar Aponeurosis

i. The chronic inflammation of the posterior bony attachment of the plantar aponeurosis (at its apex) is called plantar fasciitis. This gives rise to pain in the heel. This condition is common in people, who have to stand for long periods of time.

ii. The plantar fascia may tear at its apex. This condition is more common in policemen hence called policeman’s heel.

iii. Ossification at the apex of the aponeurosis leads to formation of calcaneal spur.

Fibrous Flexor Sheath

The deep fascia over the toes is modified to form a fibrous flexor sheath, which along with the phalanx gives rise...
to an osseofibrous tunnel for the flexor tendons in each digit.

i. Proximally the fibrous sheath is continuous with the fibrous slips of plantar aponeurosis.
ii. It is attached to the margins of the phalanges and to the base of terminal phalanx.
iii. The sheath contains long and short flexor tendons surrounded by synovial sheath in each of the lateral four toes.
iv. In the sheath of great toe there is only one tendon of flexor hallucis longus lined by synovial sheath.
v. The function of the fibrous sheath is to restrain the flexor tendons during movements of the toes.

**Muscles of Sole**

The intrinsic muscles of the sole and the tendons passing through the sole are arranged in four layers from superficial to the deep aspect of the sole. There are total eighteen intrinsic muscles of the sole and tendons of four extrinsic muscles. These tendons pass through the sole for reaching their sites of insertion. The nerves and vessels travel through two neurovascular planes. The first neurovascular plane lies between the first and second layers of muscles while the second neurovascular plane lies between the third and fourth layers.

**Muscles in First Layer (Fig. 99.6)**

There are three muscles in the first layer.

**Abductor Hallucis**

i. The abductor hallucis muscle takes origin from the medial tubercle of calcaneus and the flexor retinaculum. The plantar nerves and vessels enter the sole deep to this muscle. The muscle runs forwards along the medial margin of the foot.
ii. It is inserted mainly into the plantar surface and partly into the medial surface of the base of the proximal phalanx of big toe.
iii. The muscle produces abduction of big toe (to move it away from second toe) and flexion of big toe.
iv. The trunk of the medial plantar nerve supplies a branch to abductor hallucis.

**Flexor Digitorum Brevis**

The flexor digitorum brevis lies immediately deep to the plantar aponeurosis.

i. It arises by a narrow tendon from the medial tubercle of calcaneus and from plantar aponeurosis.
ii. Distally, it divides into four tendons for the lateral four toes. Each tendon enters the fibrous flexor sheath along with the tendon of flexor digitorum longus. At the base of proximal phalanx, the tendon of flexor digitorum longus perforates the tendon of flexor digitorum brevis, which divides again to get inserted into both sides of the plantar surface of the middle phalanx.
(Note: The mode of insertion of the flexor digitorum brevis is similar to that of flexor digitorum superficialis of upper limb).
iii. The flexor digitorum brevis is supplied by a twig from the trunk of the medial plantar nerve.

**Abductor Digiti Minimi**

This muscle lies along the lateral margin of the foot.

i. It takes origin from the lateral and medial tubercles of calcaneus and from the deep aspect of plantar aponeurosis.
ii. It ends in a tendon, which is inserted into the lateral side of the proximal phalanx of little toe.
iii. The muscle is supplied by a branch from the lateral plantar nerve.

**Tendons and Muscles in Second Layer**

i. The tendons of flexor hallucis longus and of flexor digitorum longus.
ii. Lumbrical muscles and flexor digitorum accessorius (Fig. 99.7).

**Long Flexor Tendons**

i. There is a crossing of the tendons of flexor digitorum longus and flexor hallucis longus in the second layer, during which the long flexor tendon of the great toe
gives few fibers through the William Turner’s slip to the common tendon of flexor digitorum longus.
ii. The common tendon of the muscle receives insertion of the flexor digitorum accessorius.
iii. The tendons of the flexor digitorum longus give origin to the four lumbral muscles.

**Flexor Digitorum Accessorius**
1. It takes origin by two heads. The fleshy medial head arises from medial surface of calcaneus. The tendinous lateral head arises from the lateral tubercle of calcaneus.
2. The two heads unite and are inserted into the lateral side of the tendons of the flexor digitorum longus.
3. A branch from the trunk of lateral plantar nerve supplies this muscle.
4. The flexor digitorum accessorius straightens the oblique pull of action of the flexor digitorum longus on the lateral four toes. It assists in the plantarflexion of the same toes.

**Muscles in Third Layer (Fig. 99.8)**
The third layer consists of three muscles namely, flexor hallucis brevis, adductor hallucis, and flexor digit minimi brevis.

**Flexor Hallucis Brevis**
1. This muscle has double origin from the medial part of the plantar surface of cuboid bone and from the lateral cuneiform bone.
2. Distally the common muscle belly divides into medial and lateral parts, which end in two tendons. These tendons are inserted into the respective side of the base of proximal phalanx of big toe. A well-developed sesamoid bone occurs in each tendon near its insertion. (Note: This muscle has two heads of origin and two tendons of insertion with two sesamoid bones).
3. A branch of medial plantar nerve supplies the muscle.
4. Its action is to flex the proximal phalanx. However, its main function is to stabilize the toe in walking by preventing extension.
**Adductor Hallucis**

i. This muscle has two heads of origin.

ii. The transverse head takes origin from the ligaments on the plantar aspect of the metatarsophalangeal joints of third, fourth and fifth toes.

iii. The oblique head arises from the plantar aspect of the bases of second, third and fourth metatarsal bones.

iv. The common tendon is inserted into the lateral part of the base of proximal phalanx of big toe along with lateral tendon of flexor hallucis brevis.

v. A branch from the deep branch of lateral plantar nerve supplies the muscle.

vi. It is the adductor of big toe.

**Flexor Digiti Minimi Brevis**

i. This muscle arises from the medial part of the plantar aspect of the base of fifth metatarsal bone and from the sheath around the peroneus longus tendon.

ii. It is inserted into the lateral side of the base of the proximal phalanx of little toe.

iii. The superficial branch of the lateral plantar nerve supplies the muscle.

**Muscles and Tendons in Fourth Layer**

The fourth layer contains four dorsal interossei and three plantar interossei in addition to the tendons of peroneus longus and tibialis posterior muscles.

**Interossei Muscles of Foot**

The interossei muscles are located between the metatarsal bones. The interossei are numbered from medial to lateral side.

*Plantar Interossei (Fig. 99.9A)*

There are three plantar interossei, which are unipennate.

i. The first plantar interosseous muscle arises from the plantar aspect of the shaft of the third metatarsal bone. The second arises from the fourth metatarsal and the third from the fifth metatarsal bone.

ii. Each plantar interosseous muscle is inserted into the medial side of the base of the proximal phalanx of its own digit and partly in the extensor expansion.

*Fig. 99.9A: Plantar interossei muscles (unipennate)*

*Dorsal Interossei (Fig. 99.9B)*

There are four dorsal interossei, which are the bipennate muscles.

i. They arise from the shafts of the adjacent metatarsal bones.

ii. Each dorsal interosseous muscle ends in a tendon, which is inserted into the base of the proximal phalanx and the extensor expansion as follows. The first muscle is inserted into the medial side of second toe. The second muscle is inserted into the lateral side of second toe. The third muscle is inserted into the lateral side of third toe and the fourth muscle is attached to the lateral side of the fourth toe.

*Nerve Supply of Interossei*

i. The lateral plantar nerve supplies both plantar and dorsal interossei as follows. The superficial branch of lateral plantar nerve supplies the interossei of the fourth space (third plantar and fourth dorsal). The other interossei are supplied by deep branch of the lateral plantar nerve.
The dorsal interossei of first and second spaces receive additional twigs from the deep peroneal nerve.

**Actions**

i. The action of the interossei takes place around an axis passing through the second toe.

ii. The plantar interossei adduct the toes toward the second toe.

iii. The dorsal interossei abduct the toes away from the second toe.

iv. In the case of the second toe either the lateral or medial movement is abduction.

v. Besides this, the interossei and the lumbricals bring about the dorsiflexion of the interphalangeal joints and the plantarflexion of the metatarsophalangeal joints.

**Tendons in the Deep Layer of Sole**

i. The peroneus longus tendon crosses the sole from lateral to medial side to reach its insertion in the medial cuneiform bone and the base of first metatarsal bone.

ii. The tibialis posterior tendon is mainly inserted into the tuberosity of navicular bone. From here, it sends slips to all the tarsal bones (except the talus) and to the middle three metatarsal bones.

**Arteries of Sole (Fig. 99.10)**

Branches of medial plantar artery, branches of lateral plantar artery and branches of plantar arch supply the structures in the sole.

**Medial Plantar Artery**

i. This is the smaller terminal branch of the posterior tibial artery. It begins deep to the flexor retinaculum and enters the sole under cover of the abductor hallucis along with the medial plantar nerve.

ii. It courses forward lying in the interval between the abductor hallucis and flexor digitorum brevis.

iii. Its branches include the cutaneous branches to the skin of the medial side of sole, muscular branches and three digital branches, which are often small or absent and end by joining the first, second and third plantar metatarsal arteries.

iv. The terminal part of medial plantar artery anastomoses with the branch of first plantar metatarsal artery to the medial side of big toe.

**Lateral Plantar Artery**

This is the larger terminal branch of the posterior tibial artery (deep to the flexor retinaculum).

**Subdivisions**

The lateral plantar artery is subdivided into two parts as follows.

i. The first part is the lateral plantar artery proper coursing between first and second layers of sole.

ii. The second part takes major part in the formation of plantar arch, coursing between the third and fourth layers of sole.

**Course and Relations of First Part**

The lateral plantar artery enters the sole under cover of the abductor hallucis muscle along with the lateral plantar nerve. The neurovascular bundle runs in lateral and oblique direction lying between the flexor digitorum brevis (the muscle of first layer of sole) and the flexor accessorius (the muscle of the second layer of sole). It reaches the base of the fifth metatarsal bone on the lateral margin of the foot, where the first part ends.

**Branches of First Part**

i. Muscular branches

ii. Cutaneous branches to the lateral half of the sole

iii. Anastomotic branches, which join the lateral malleolar network.

**Plantar Arch (Second Part of Lateral Plantar Artery)**

i. The lateral plantar artery turns deep (superior) and runs in the medial direction across the sole lying plantar to the bases of the metatarsal bones. This part of the artery is called the plantar arch. It ends by joining the termination of dorsalis pedis artery (in the first intermetatarsal space).

ii. The plantar arch thus, extends from the fifth metatarsal base to the proximal end of the first intermetatarsal space located between the muscles of the third and fourth layers. The arch presents a concavity proximally and convexity distally. The deep branch of the lateral plantar artery lies in the concavity of the plantar arch.
Branches of Plantar Arch

i. Three proximal perforating arteries pass upward through the second, third and fourth intermetatarsal spaces to communicate with the dorsal metatarsal branches of the arcuate artery.

ii. Four plantar metatarsal arteries run forward in corresponding intermetatarsal spaces and end by dividing into two plantar digital branches for adjacent sides of the toes. The first plantar metatarsal artery arises exactly at the anastomotic junction of the dorsalis pedis and the lateral plantar artery and it sends a proper plantar digital branch to the medial side of big toe. The lateral side of the little toe receives a proper plantar digital branch directly from the lateral end of the plantar arch. The plantar metatarsal arteries are called the common plantar digital arteries after uniting with the digital branches of medial plantar artery. The distal part of each plantar metatarsal artery gives rise to a distal perforating artery, which joins the distal part of the dorsal metatarsal artery. The common arteries divide in two proper plantar digital arteries for the adjacent sides of the two toes.

Veins of Sole

The veins in the sole accompany the arterial trunks and their branches. The venae comitantes accompanying the lateral and medial plantar arteries unite deep to the flexor retinaculum to form the venae comitantes accompanying the posterior tibial artery.

Nerves of Sole

The sole of the foot contains the lateral and medial plantar nerves, which are the terminal branches of the tibial nerve (arising deep to the flexor retinaculum). They enter the sole with the corresponding branches of the posterior tibial artery under cover of the abductor hallucis.

Medial Plantar Nerve (Fig. 99.11)

This is the larger terminal branch of the tibial nerve. At first it passes deep to the abductor hallucis and then appears between it and the flexor digitorum brevis. It gives the medial proper digital nerve for the big toe and then divides at the bases of the metatarsal bones in three common plantar digital nerves.

Branches

i. Cutaneous branches to the skin of medial half of sole.

ii. The branches to abductor hallucis and flexor digitorum brevis arise from the trunk of the nerve.

iii. The branch to flexor hallucis brevis originates from the medial proper digital nerve to the big toe.

iv. The branch for the first lumbrical arises from the first common plantar digital nerve.

v. The articular branches supply the joints of the foot.

vi. The proper digital branches supply the skin of the plantar aspect of the toes and also the nail bed on the dorsal aspect of the toes.

vii. The three common plantar digital nerves supply the adjacent sides of the first and second toes, second and third toes, and third and fourth toes.

Bleeding Wounds of Plantar Arch

It is difficult to control the bleeding from the plantar arch by direct ligature due to its deep location. The immediate treatment consists of compression of the femoral artery. The compression of anterior tibial alone or posterior tibial alone or of both the tibial arteries may not be effective due to presence of anastomoses around the ankle, in which the peroneal artery also takes part.

Morton’s Metatarsalgia

This is a condition in which a neurofibroma occurs on the digital nerve supplying the adjacent sides of third and fourth toes. There is usually a communication between the most lateral digital branch of medial plantar nerve and the medial branch of lateral plantar nerve. The neurofibroma may arise in this communication. The pressure of the tight fitting shoe may be the cause of this condition, which results in severe pain in the third and fourth toes.

Clinical insight ...

Fig. 99.11: Course and distribution of medial plantar nerve
Section

(Note: The distribution of common digital branches of medial plantar nerve is similar to that of median nerve in the hand).

Lateral Plantar Nerve (Fig. 99.12)
This nerve is one of the terminal branches of the tibial nerve deep to the flexor retinaculum. It enters the sole under cover of abductor hallucis and then passes forward and laterally across the sole in oblique direction to reach the tuberosity of the fifth metatarsal bone, where it divides into superficial and deep branches. During its oblique course, it lies between the flexor accessorius muscle of the second layer and the flexor digitorum brevis muscle of the first layer. At its termination the lateral plantar nerve lies between the flexor digitorum brevis and the abductor digiti minimi.

Branches of the Trunk
The trunk of the lateral plantar nerve supplies the flexor digitorum accessorius and the abductor digiti minimi. It gives sensory branches to the skin of lateral part of the sole.

Superficial Branch of Lateral Plantar Nerve
The superficial branch runs distally along the lateral border of sole and divides into two common plantar digital nerves.

i. The lateral common plantar digital nerve supplies three muscles, namely, flexor digiti minimi brevis, fourth dorsal intersosseous and third plantar intersosseous muscles (both in the fourth intermetatarsal space).

ii. The medial common plantar digital nerve becomes the proper plantar digital nerve for the lateral side of the little toe. The medial common plantar digital nerve often connects with the third common plantar digital branch of the medial plantar nerve. It divides into proper plantar digital nerves for the adjacent sides of the fourth and fifth toes.

Deep Branch of Lateral Plantar Nerve
i. The deep branch turns medially from the base of fifth metatarsal bone and travels across the sole between the muscles of the third and fourth layers to terminate into the adductor hallucis muscle.

ii. It carries only motor fibers, which supply the lateral three lumbricals, first, second and third dorsal intersossei, first and second plantar intersossei and adductor hallucis.

(Note: The distribution of lateral plantar nerve is similar to that of ulnar nerve in the hand).

Joints of Foot
There are numerous joints between the tarsal, metatarsal and phalangeal bones of the foot (Fig. 99.13). They include interphalangeal, metatarsophalangeal, tarsometatarsal, intermetatarsal and intertarsal joints.

Intertarsal Joints
The intertarsal joints are divided into two subtypes.

Fig. 99.12: Course and distribution of lateral plantar nerve

Fig. 99.13: Bones and major joints of the foot
Major Intertarsal Joints
i. Subtalar or posterior talocalcanean joint
ii. Talocalcaneonavicular joint
iii. Calcaneocuboid joint.
The talocalcaneonavicular and calcaneocuboid joints form midtarsal or transverse tarsal joint.
These major intertarsal joints allow movements of inversion and eversion of foot.
The smaller intertarsal joints include the cuneonavicular joint, cuboideonavicular joint, cuneocuboid joint and intercuneiform joints. The articular surfaces of all the small joints are flat, and all have dorsal and plantar ligaments. These joints give certain amount of resilience to the tarsus but the amount of movement in each is very small.

Subtalar Joint
i. This is the posterior talocalcanean joint belonging to the plane variety of synovial joint.
ii. This articulation is between the concave posterior facet on the inferior surface of the body of talus and the convex posterior facet on the superior surface of calcaneus.
iii. The joint is surrounded by fibrous capsule.
iv. The lateral and medial talocalcanean ligaments strengthen the joint on each side. The interosseous talocalcanean ligament is a bilaminar band, which occupies the sinus tarsi (tarsal canal). It descends obliquely from the sulcus tali to sulcus calcanei. The ligament separates the talocalcaneonavicular and posterior talocalcanean joints. The cervical ligament is lateral to the sinus tarsi and extends from the upper surface of calcaneus to the inferolateral tubercle of the neck of talus.

Talocalcaneonavicular Joint
i. This is a compound articulation consisting of anterior talocalcanean and talonavicular articulations. It belongs to the ball and socket type of synovial joint.
ii. The articular surface of the rounded head of the talus fits into the socket formed by the posterior surface of navicular, middle and anterior talar facets on the calcaneus and the superior surface of the spring ligament.
iii. A fibrous capsule surrounds the articulating bones. The synovial cavity of this joint is separate from the other joints.
iv. The plantar calcaneonavicular ligament and the calcaneonavicular part of bifurcate ligament connect the calcaneus to the navicular bone (there being no direct articulation between them).

Calcaneocuboid Joint
i. This is a saddle variety of synovial joint having independent synovial cavity. The bones taking part in this joint are the anterior surface of calcaneus and the posterior surface of cuboid. The joint lies along the lateral side of foot.
ii. The long plantar ligament is the longest ligament, which extends from the plantar surface of calcaneus to the plantar surface of cuboid and beyond it to the bases of the three metatarsal bones (second to fourth). It converts the groove on the plantar surface of cuboid in a tunnel for the tendon of peroneus longus.
iii. The short plantar ligament is called the plantar calcaneocuboid ligament. It lies superior to the long plantar ligament. It stretches from the anterior tubercle of the calcaneus to the adjoining part of cuboid.
iv. The calcaneocuboid part of bifurcate ligament extends from the stem of the bifurcate ligament to the dorsal aspect of cuboid.

Movements of foot
Inversion and Eversion
The inversion and eversion are the movements of the foot, which take place at the subtalar and midtarsal joints. These movements occur along an oblique axis and are basically rotation movements of the foot on the talus.
Definition

i. The inversion is defined as a movement in which the medial border of the foot is raised so that the sole faces medially.

ii. Eversion is defined as a movement in which the lateral border of the foot is raised so that the sole faces laterally.

There is difference in the rotation movements when the foot is off the ground and on the ground.

Functional Importance

The movements of inversion and eversion are necessary while walking on uneven and sloping ground. They enable the body to move sideways over the foot while the foot is fixed. It is not possible to reproduce the movements of inversion and eversion in an artificial limb. Therefore, an amputee wearing an artificial limb finds difficulty in walking on uneven ground.

Muscles Producing Inversion and Eversion

Tibialis anterior and tibialis posterior are the main invertors of the foot. Both the muscles pass medial to the axis of rotation. The peroneus longus, brevis and tertius are the evertors of the foot. These muscles pass lateral to the axis of rotation.

Arches of Foot

The human foot is aptly described as an architectural marvel. Its construction is the best example of the structural adaptation to function. The foot has two major functions. It supports the body weight during standing and progression and it acts as a lever to propel the body forwards during walking, running and jumping. To fulfill the first function, the foot must be pliable to withstand the stresses and to fulfill its second function it must be transformable into a lever. A segmented arched lever converts the foot into a spring to make it ideally suited for its functions.

Types of Arches (Figs 99.14A and B)

The bones of the foot are arranged in the form of longitudinal and transverse arches. The longitudinal arches are medial and lateral. The transverse arch is present as half arch per foot. Only when the two feet are held close to each other the transverse arch becomes complete.

The arches of the foot are present from birth. Due to the presence of subcutaneous fat the arching is not apparent during infancy and childhood. Gradually, the plantar surface acquires the concave appearance and the characteristic footprint is evolved.

Parts of Longitudinal Arches

The longitudinal arches have anterior and posterior pillars, summit and joints. The supports of the arches are more or less similar to the mechanical supports of the overhead bridges.

Medial Longitudinal Arch

The bones of the medial longitudinal arch from behind forward are calcaneus, talus, navicular, cuneiforms and medial three metatarsal bones including the two sesamoid bones under the head of the first metatarsal bone. The short and sturdy calcaneus forms the posterior pillar of the medial longitudinal arch. The head of the talus lies at the summit of the arch. Therefore, the talus is the keystone of
Supports of Medial Longitudinal Arch (Fig. 99.15)

i. The summit of the arch (head of the talus) transfers the body weight to the other bones of the foot. Therefore, support to the talus is very important. The head of the talus is held in a socket provided by the navicular, sustentaculum tali and the spring ligament. The combination of the spring ligament and the underlying tibialis posterior tendon forms a dynamic support to the head of talus. In addition the flexor hallucis longus and flexor digitorum longus assist.

ii. The anterior and posterior pillars of the medial arch are held together by the plantar aponeurosis, abductor hallucis and flexor hallucis brevis. These structures act as tie beams of the arch.

iii. The combined action of the tendon of tibialis anterior and deltoid ligament of the ankle joint is to exert a sling action from above. The slips of insertion of the tibialis posterior in all the tarsal bones (except the talus) provide the support from below.

Lateral Longitudinal Arch

The bones forming the lateral longitudinal arch from behind forwards are calcaneus, cuboid and lateral two metatarsals. This arch being very short it almost touches the ground. The heads of lateral two metatarsal bones form the anterior pillar while the posterior pillar is the calcaneus. The calcaneocuboid joint is the important joint in this arch. The lateral arch being lower and less mobile than the medial is adapted to transmit weight and thrusts.

Supports of Lateral Longitudinal Arch (Fig. 99.16)
The long plantar and short plantar (plantar calcaneocuboid) ligaments are the main ligamentous supports of this arch. The plantar aponeurosis and the intrinsic muscles of little toe function as tie beam of this arch. The tendons of peroneus brevis and tertius, which are inserted in the base of the fifth metatarsal bone act as slings from above. The tendon of peroneus longus, which grooves the cuboid and courses transversely across the sole, provides the support to the cuboid bone (and the calcaneocuboid joint) from above, through its pulley like action.

Transverse Arch

Each foot is composed of a series of transverse arches. The bony components of the transverse arch are the bases of the metatarsals and the cuboid and the three cuneiform bones. The factors that maintain the transverse arch are the interosseous ligaments and the dorsal interossei muscles. The tendon of peroneus longus and the adductor hallucis muscle play a major role in support to this arch.

Functions of Arches

The medial longitudinal arch functions as a propulsive force during locomotion being more elastic and dynamic. The lateral longitudinal arch functions as a static organ of support and weight transmission. Besides this the arches act as shock absorbers. The concavity of the arches provides protection to the deeply located nerves and vessels of the sole.
Deformities of Foot

i. Pes planus or flat foot is due to collapse of medial longitudinal arch. The support to the head of the talus is lost hence it is pushed downward between the calcaneus and navicular bones. During long periods of standing, the plantar aponeurosis and other plantar ligaments including the spring ligament are overstretched, which may gradually result in flattening of the medial longitudinal arch with lateral deviation of foot. A person with flat foot has clumsy gait with susceptibility to trauma. The nerves and vessels of sole are compressed, which produces pain and swelling of foot.

ii. Pes cavus means highly arched foot. It is associated with claw foot in which there is dorsiflexion of metatarsophalangeal joints and plantarflexion of interphalangeal joints.

iii. Rocker bottom feet are the ones in which there is plantar convexity. This is found in babies born with trisomy 18 (Edward syndrome).

iv. The hallux valgus refers to the deformity in which the big toe passes transversely under the second toe due to hyperadduction and there is abnormal prominence of the head of first metatarsal bone on the medial side of the foot, just behind the big toe (Fig. 99.17). There is collapse of the transverse arch due to varus position of first metatarsal bone. The exposed and prominent head of first metatarsal tends to rub on the shoe, giving rise to an adventitious (adventitial) bursa called bunion. Constant wearing of pointed shoes with high heel predisposes to bunion formation and inflammation. The patient experiences pain and fatigue in the foot during routine walking.

v. Talipes is a Latin word meaning clubfoot. There are different types of talipes. In talipes equinus, the foot is plantarflexed and the person walks on toes (like a horse). In talipes calcaneus, the foot is dorsiflexed and the person walks on heel. In talipes varus the foot is inverted and the person walks on lateral margin of foot. In talipes valgus, the foot is everted and the person walks on medial margin of foot.

vi. In talipes equinovarus deformity, the foot is held in plantarflexed and inverted position due to paralysis of dorsiflexors and evertors (for example due to injury to common peroneal nerve). Congenital talipes equinovarus (CTEV) deformity or club foot deformity is a common birth defect. The patient walks on the lateral margin of plantarflexed foot.

vii. The hammertoe deformity is produced due to paralysis of lumbricals and interossei. There is hyperextension at the metatarsophalangeal joints, hyperflexion of proximal interphalangeal joints and extension at the distal interphalangeal joints in lateral four toes.
A patient with 4 gm hemoglobin was given intramuscular injections of iron in the gluteal region. After a few weeks, the patient complained of difficulty while stepping on the right foot. The examination revealed sensory loss in the intermediate area of the dorsum of right foot and dorsum of all toes except lateral side of little. The patient experienced difficulty in dorsiflexing and everting the right foot.

Questions and Solutions

1. Name the nerve that is injured by the injection needle in the gluteal region.
   Sciatic nerve is injured due to injection in the wrong place.

2. What is the safe site of injection in gluteal region?
   Anterosuperior quadrant is the safe site.

3. How does the above nerve enter the gluteal region?
   The sciatic nerve enters the gluteal region via greater sciatic foramen.

4. Enumerate from above downwards the anterior relations of the above nerve in the gluteal region.
   Dorsal surface of upper part of ischium, superior gemellus, tendon of obturator internus, inferior gemellus, quadratus femoris and upper horizontal fibers of adductor magnus are the anterior relations.

5. Comment on the artery supplying this nerve.
   The artery of sciatic nerve (companion artery of sciatic nerve) is a branch of inferior gluteal nerve. It enters the interior of the sciatic nerve and hence may be a source of bleeding during above knee amputation of lower limb. The morphological importance of this artery is that it is one of the remnants of the axis artery of lower limb.

6. Name the two parts of this nerve giving the root value of each.
   i. Tibial or medial part—root value—L4, L5, S1, S2, S3.
   ii. Common peroneal or lateral part—root value—L4, L5, S1, S2.

7. Which part of this nerve is specifically injured in the above patient based on the signs?
   Common peroneal part is injured as is evident from the loss of sensation in the areas supplied through branches of common peroneal nerve and weakness of peroneal and extensor muscles of the leg.

8. Explain sensory and motor loss in the above patient.
   When the common peroneal part of sciatic nerve is injured, it amounts to loss of function of its terminal branches (deep peroneal nerve and superficial peroneal nerve).
   Loss of sensation in the first interdigital cleft is characteristic of injury to deep peroneal nerve. Loss of sensation on dorsum of foot and dorsum of toes except the lateral side of little toe and first interdigital cleft is typical of injury to superficial peroneal nerve.
   Difficulty in eversion of foot is due to loss of motor supply to peroneus longus and brevis (supplied by superficial peroneal nerve). Difficulty in dorsiflexion of foot is due to loss of motor supply to tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius muscles in the extensor compartment of leg (supplied by deep peroneal nerve).
9. Which nerve is sensory to the lateral side of little toe and what is it a branch of?

Sural nerve is sensory to lateral side of little toe. It arises from tibial nerve in the popliteal fossa.

CASE 2

A 50-year-old policeman with a history of chronic dull ache in both legs came to the hospital, when he noticed dilated and tortuous veins on the medial side of his both legs. The skin on the medial malleolus was found to be discolored, dry and scaly.

Questions and Solutions

1. Name the clinical condition mentioning the vein involved.

Bilateral varicose veins of lower limb due to dilatation of long (great) saphenous vein.

2. What is the relation of this vein to medial malleolus?

It ascends 2.5 cm in front of medial malleolus.

3. Name the closely related cutaneous nerve at this location mentioning its origin.

Saphenous nerve is closely related to long saphenous vein near medial malleolus. It is a branch of femoral nerve arising in femoral triangle.

4. Name the veins that connect it to the deep veins of lower limb.

Perforating veins connect the superficial and deep veins in the leg and thigh.

5. What is the direction of flow of blood in the connecting veins?

The blood flows from superficial veins to deep veins.

6. Name the connecting veins according to the position.

i. Adductor canal perforator or Hunter’s perforator in thigh.
   
   ii. Boyd’s perforator near knee.

   iii. Three ankle perforators in leg.

7. Write briefly on saphenous opening.

Saphenous opening is a deficiency in fascia lata. Its center is situated 3.5-4 cm below and lateral to the pubic tubercle. It is 3 cm long and 1.5 cm wide. It is covered with a thin cribiform fascia. Except on its medial side it is bounded by a sharp falciform margin. The long saphenous vein passes through the cribiform fascia and saphenous opening. The surface marking of this opening is important to the surgeon while testing for patency of saphenofemoral valve. Since, the saphenous opening lies in front of femoral sheath, the femoral hernia enters it from the femoral canal and then the hernia turns upwards around the falciform margin.

8. Name the terminal tributaries of this vein before it pierces cribiform fascia.

Terminal tributaries of long saphenous vein are superficial epigastric vein, superficial circumflex iliac vein and superficial external pudendal vein.

9. Write a note on the usefulness of this vein in cardiac bypass surgery.

The long saphenous vein is a muscular vein. Hence, it is used for coronary artery graft. The blocked segment of the coronary artery is replaced by a segment of patient’s own saphenous vein in the thigh. While suturing the venous graft, the venous segment is reversed so that its valves do not impede the arterial blood flow.

CASE 3

A 55-year-old woman underwent hysterectomy operation. On third postoperative day, she developed sudden pain in her left calf. On examination, the calf was found to be swollen, tender and warm. Doppler ultrasound examination revealed Deep Vein Thrombosis (DVT) in calf. She was immediately started on IV anticoagulants.

Questions and Solutions

1. Name the deep veins of lower limb starting from leg to thigh.

Deep veins of leg

i. Veins accompanying anterior tibial artery in anterior compartment of leg.

   ii. Veins accompanying posterior tibial artery in posterior compartment of leg.

   iii. Veins accompanying peroneal artery in posterior compartment of leg.

Deep vein of popliteal fossa

Popliteal vein

Deep veins of thigh

i. Femoral vein (in subsartorial canal and femoral triangle).
2. Which veins are usually involved in deep vein thrombosis (DVT)?
Calf veins or deep veins of leg are usually involved in DVT.

3. Describe the venous pump in the calf.
The deep veins of the leg are located in the tight fascial compartment along with the arteries. When the muscles of the calf contract, there is rise in the pressure inside the posterior compartment, which results in compression of the deep veins. The valves of deep veins open up and the blood is propelled in upward direction. The soleus contains venous sinuses filled with blood and on contraction it squeezes the blood out into the deep veins. For this reason, the soleus is regarded as the peripheral heart and the calf muscles collectively work as a venous pump. During relaxed state of the muscles of calf, the blood is sucked from the superficial to the deep veins through the perforators.

4. Describe the formation course and termination of popliteal vein.
The popliteal vein is located superficial (posterior) to the popliteal artery in the popliteal fossa.

Formation
The popliteal vein begins at the distal border of the popliteus muscle by the union of the veins accompanying the anterior and posterior tibial arteries.

Relations
The popliteal vein has triple relation to the popliteal artery. The vein lies medially in the lower part, it crosses superficially (posteriorly) in the middle part (between the two heads of gastrocnemius) and lies laterally at the upper part.

Termination
The popliteal vein continues as the femoral vein at the adductor opening in adductor magnus.

Tributaries
i. Small saphenous vein
ii. Veins accompanying the branches of the popliteal artery

5. What is the fatal complication of DVT?
Pulmonary embolism is the fatal complication of DVT. The detached clot or the embolus blocks the pulmonary circulation thereby causing respiratory distress.

6. Trace the path of embolus from calf vein thrombosis to the pulmonary circulation.
The embolus starting from deep veins of the posterior compartment of leg travels in succession through popliteal vein, femoral vein, external iliac vein, common iliac vein, IVC, right atrium, right ventricle, pulmonary trunk and pulmonary arteries.

CASE 4
A football player, on receiving a blow on the lateral side of the left knee, felt a sharp pain in the knee. The left knee was swollen. The drawer signs were negative. Radiological examination did not show any fracture.

Questions and Solutions
1. Which intra-articular structure is torn in this patient?
Medial meniscus is torn (since negative drawer signs rule out injury to cruciate ligaments).

2. Name the type of tear that usually occurs in this structure in sports injury.
Bucket handle tear

3. Give a brief account of the relations of this structure.
The medial meniscus is C-shaped. It is related to the superior surface of the medial condyle of tibia. Its two ends represent the two horns of the meniscus. Its anterior horn is attached to the anterior part of intercondylar area of tibia and the posterior horn to the posterior part of intercondylar area between the attachment of posterior horn of lateral meniscus and posterior cruciate ligament. The periphery of medial meniscus is fused with the fibrous capsule and tibial collateral ligament. This fixity of medial meniscus makes it less mobile and more prone to ruptures.

4. What are ligaments of Humphrey and Wrisberg?
These ligaments are called anterior and posterior meniscofemoral ligaments. They arise from the posterior horn of lateral meniscus and pass in front (Humphrey) and behind (Wrisberg) of posterior cruciate ligament to gain attachment to medial femoral condyle just in front and behind the attachment of posterior cruciate ligament.

5. How is the integrity of cruciate ligaments tested?
The drawer tests are performed to assess the integrity of cruciate ligaments. If there is excessive anterior
movement of tibia on the femur with the knee and hip joints kept flexed in supine position of the body, it is called anterior drawer sign. This sign indicates injury to anterior cruciate ligament. If there is excessive posterior movement of tibia on the femur with the knee and hip joints kept flexed in supine position of the body, it is called posterior drawer sign. This sign is indicative of injury to posterior cruciate ligament.

6. Write a short note on the muscle that has origin inside the capsule of knee joint.

   The popliteus muscle has intracapsular and extrasynovial tendinous origin from the anterior part of the groove on the lateral condyle of femur. A few fibers are attached to the lateral meniscus. The tendon of popliteus intervenes between the lateral meniscus and fibular collateral ligament. The tendon pierces the posterior part of the capsule and expands into a triangular fleshy part, which is inserted into the posterior surface of tibia above the soleal line. The popliteus is covered with fascia, which is an extension from semimembranosus insertion. The fascia and the muscle form the lower part of the floor of the popliteal fossa. The muscle receives nerve supply from tibial nerve in the popliteal fossa. This nerve pursues unusual course to pierce the muscle. First it travels on the posterior surface of the popliteus and then it winds round the inferior margin of the muscle to reach its anterior surface for supplying (this nerve also supplies motor branch to tibialis posterior, tibiofibular joints and interosseous membrane). The action of the popliteus is to unlock the locked knee joint (key muscle of knee joint) at the beginning of flexion.

CASE 5

A few days following the removal of plaster cast for fracture of the upper end of left fibula, the patient complained of loss of sensation on the intermediate area of the dorsum of foot including toes except the lateral side of little toe. On examination, it was noticed that the patient was unable to dorsiflex and evert the left foot.

Questions and Solutions

1. Name the nerve that is injured (by pressure of plaster cast) in this patient.
   Common peroneal nerve

2. Name the site where this nerve is palpated.
   The lateral side of neck of fibula is the site where the nerve is rolled.

3. Name the deformity in which the foot cannot be dorsiflexed.
   Foot drop

4. Inability to dorsiflex the foot is due to loss of function of which nerve in the leg?
   Deep peroneal nerve

5. Describe the course and distribution of this nerve.
   For course and distribution of deep peroneal nerve, refer to anterior compartment of leg (chapter 97).

6. Describe the muscles that are the chief evertors of foot.
   Peroneus longus and peroneus brevis are the chief evertors of foot. For description of these muscles refer to lateral compartment of leg (chapter 97).

CASE 6

A candidate for recruitment in the army was rejected because he was found to have pes planus (flat foot) in the medical checkup.

Questions and Solutions

1. Define pes planus and explain the anatomical factors that are responsible for it.
   Pes planus means flat foot. In this condition, there is collapse of medial longitudinal arch. There are two reasons for it. The head of the talus is pushed downwards between navicular bone and calcaneus. The ligaments supporting the medial longitudinal arch (spring ligament, long and short plantar ligaments) and the plantar aponeurosis are overstretched due to strain.

2. Name the bones forming the medial longitudinal arch of foot.
   Calcaneus, talus, navicular, three cuneiforms and medial three metatarsal bones.

3. Which bone is the keystone of this arch?
   Talus

4. Describe the main ligament that supports the head of the talus.
   Spring ligament or plantar calcaneonavicular ligament supports the head of the talus from below. It is a thick
Clinicoanatomical Problems and Solutions

Chapter 7

band that extends from anterior margin of sustentaculum tali to the plantar surface of navicular bone. Its upper surface presents fibrocartilaginous facet for the head of talus. Its lower surface is in contact with tendons of tibialis posterior and flexor hallucis longus. Its medial margin gives attachment to deltoid ligament of ankle joint. The spring ligament not only supports the keystone of the medial arch but also provides resilience to it needed for propulsion.

5. What are the consequences of the flat foot?
The flat foot leads to loss of elasticity in the foot, which makes it liable to trauma and arthritic changes. Loss of concavity of the plantar aspect of foot leads to compression of nerves and vessels in the sole.

6. Define inversion and eversion.
Inversion is the movement in which the medial margin of foot is raised and the sole faces medially. Eversion is the movement in which lateral margin of foot is raised and the sole faces laterally.

7. Name the joints where these movements take place.
Subtalar joint and midtarsal joints (calcaneocuboid and talocalcaneonavicular).

CASE 7
A 50-year-old woman came to the hospital, when she noticed a lemon-sized swelling in the upper thigh. On examination, the swelling was found to be inferior and lateral to the pubic tubercle and it was seen to push into the saphenous opening.

Questions and Solutions

1. Which hernia gives rise to swelling below and lateral to pubic tubercle?
Femoral hernia

2. Describe the formation of femoral sheath.
The femoral sheath is a funnel-shaped fascial envelope around the femoral vessels as they descend behind the medial half of inguinal ligament in the thigh.
Formation
The fascia transversalis forms the anterior wall and fascia iliaca forms the posterior wall of the femoral sheath. The lateral wall is straight while its medial wall is sloping. The femoral sheath closes inferiorly because of the blending of its anterior and posterior walls with the tunica adventitia of femoral vessels.

Compartments
The femoral sheath is divided into three compartments by two anteroposterior septa.
   i. The medial compartment is called the femoral canal.
   ii. The intermediate compartment contains the femoral vein.
   iii. The lateral compartment contains the femoral artery and femoral branch of genitofemoral nerve.

3. Name the passage through which the hernia enters the thigh.
Femoral canal

4. Give the name and the boundaries of the upper opening of the passage.
The femoral ring is the name of the upper opening of the passage. Its boundaries are, in front-inguinal ligament, medially-lacunar ligament, laterally-femoral vein the middle compartment of femoral sheath, posteriorly-pectineus and fascia.

5. Describe the direction of the hernia and the importance of this knowledge to the surgeon.
The femoral hernia at first comes downwards in the femoral canal then it goes anteriorly into the saphenous opening and finally turns upwards against the falciform margin of the saphenous opening. In manual reduction of the hernia, the surgeon reverses the order by pushing the hernia, downwards, posteriorly and upwards.

6. In case of strangulation of this hernia, what is done to enlarge the upper opening of the passage?
To enlarge the femoral ring, its medial boundary (lacunar ligament) is surgically cut.

CASE 8
A policeman sustained a bullet injury in his left gluteal region in a street encounter. After convalescence, he developed a characteristic limp during walking. There was sagging of right hip while taking a step on left foot. On examination, Trendelenburg sign was positive.
Questions and Solutions

1. Which nerve of the gluteal region is injured?
   Left superior gluteal nerve (L4, L5, S1).

2. Describe the course and branches of the above nerve.
   The superior gluteal nerve is a branch of sacral plexus inside the pelvic cavity. It enters the gluteal region above the piriformis, through the greater sciatic foramen. It is accompanied by superior gluteal artery, which is a branch of posterior division of internal iliac artery. It runs between the glutei medius and minimus muscles and supplies them and the tensor fasciae latae.

3. Explain positive Trendelenburg sign.
   When the left foot is raised from the ground, the right hip sags due to the failure of gluteus medius and minimus of left side to contract and support the pelvis of the right side.

4. Describe the attachments and actions of the muscles supplied by this nerve.
   Refer to chapter 94.

CASE 9

A 20-year-old tennis player twisted his right foot during a practice session. He could not move his foot due to severe pain. On examination, there was swelling of right ankle, black and blue discoloration on lateral side of ankle and restricted and painful foot movements. Radiographs of the right ankle showed no fracture of lower end of tibia, fibula and talus. The doctor advised RICE.

1. Which ligament of ankle joint is sprained?
   The lateral collateral ligament of ankle joint is sprained.

2. What are the parts of this ligament?
   It consists of anterior tibiofibular, posterior tibiofibular and calcaneofibular parts.

3. Explain RICE.
   It is combination of measures to be taken immediately (first aid measures) in cases of ankle sprain. It consists of rest (R), ice pack (I) to reduce inflammation, compression (C) by elastic bandage and elevation (E) to reduce collection of tissue fluid at the site of injury.

4. Name the bones taking part in the ankle joint and describe their articular surfaces.
   The ankle joint is a strong weight-bearing joint of the lower limb. It is a uniaxial hinge variety of synovial joint. The bones, which take part in this articulation are, the lower end of tibia, lower end of fibula and the talus.
   i. Proximally, the articular facets of the lower end of tibia, fibula and inferior transverse tibiofibular ligament form tibiofibular socket. The tibial articular surface covers the lower end of tibia and lateral surface of medial malleolus. The fibular articular surface is a triangular facet on the medial aspect of lateral malleolus.
   ii. Distally, the articular facets are present on the superior, lateral and medial surfaces of the talus. These facets form a continuous articular area. The comma-shaped facet on the medial aspect of the talus articulates with the facet on the medial malleolus. The triangular facet on the lateral aspect of talus articulates with the facet on lateral malleolus. The trochlea on the superior aspect of talus is wider in front than behind. During dorsiflexion of the ankle, the grip of the malleoli on the talus is strongest because this movement forces the anterior wider part of trochlea posteriorly between the malleoli. The ankle joint is relatively unstable during plantarflexion because the narrower posterior part of the trochlea does not fill the tibiofibular socket.

5. Describe the attachments of the ligaments of ankle joint
   i. The medial ligament of the ankle joint (deltoid ligament) is very strong. It is triangular in shape. It is attached to the medial malleolus above. Inferiorly, it is attached to the medial margin of plantar calcaneonavicular ligament, navicular tuberosity, neck of talus, sustentaculum tali and medial aspect of body of talus, from before backwards.
   ii. The lateral ligament of the ankle joint is thick and divided into three discrete parts, namely, anterior talofibular, posterior talofibular and calcaneofibular. The anterior talofibular ligament extends from the anterior border of lateral malleolus to the lateral aspect of the neck of talus. The posterior talofibular ligament runs from the distal part of malleolar fossa of lower end of fibula to the posterior tubercle of talus. The calcaneofibular ligament is cord like and extends from the distal end of lateral malleolus to the lateral surface of calcaneus.
6. **Name the movements of ankle joint mentioning the muscles producing them.**

The movements permitted at the ankle joint are dorsiflexion and plantarflexion. In dorsiflexion the dorsum of the foot moves toward the anterior surface of leg and thus the angle between the foot and the leg is reduced. This enables one to strike the ground with the heel during walking. In plantarflexion the dorsum moves away from the anterior surface of leg. This enables one to raise the heel from the ground and touch the toes to the ground as in running.

**Muscles of Dorsiflexion**
The tibialis anterior, extensor digitorum longus, extensor hallucis longus and peroneus tertius are the dorsiflexors.

**Muscles of Plantarflexion**
The gastrocnemius and soleus are the main plantarflexors. The other muscles that help in this movement are the tibialis posterior, flexor hallucis longus and flexor digitorum longus.

7. **Explain foot drop.**

Foot drop or drop foot is the deformity of foot in which the foot looks floppy (drooping downwards) causing difficulty in walking. There is loss of ability to raise the foot at the ankle joint (loss of dorsiflexion). The muscles in the anterior (extensor) compartment of leg (tibialis anterior, extensor digitorum longus and extensor hallucis longus) are paralyzed due to injury to deep peroneal nerve (the nerve of anterior compartment of leg). Foot drop can also occur if common peroneal nerve is damaged at fibular neck or if sciatic nerve is injured in gluteal region.

**Case 10**

A 70-year-old man tripped while descending steps of the staircase in his house. His left lower limb hit against the wall. He complained of pain on movement of the limb and difficulty in walking when putting pressure on the left foot. Examination by orthopedic surgeon revealed shortening of left lower limb and pain on moving the thigh. Plain X-ray of hip did not reveal any fracture. CT scan of pelvis revealed multiple fractures in the floor of acetabulum.

**Questions and Solutions**

1. **What is the reason for shortening of left lower limb?**

The impact of fall on the left lower limb had forced the head of femur upwards and hit the floor of acetabulum (causing its fracture). The upward shift of femur is the reason for shortening of left lower limb.

2. **Describe the articular surfaces of hip joint.**

The bones taking part in hip joint are the head of femur and the acetabulum of hip bone.

i. The acetabulum (in Latin means cup) is a cup-shaped cavity formed by the union of ilium, ischium and pubis. The rim of the acetabulum presents a notch in its lower part. This notch gives attachment to the transverse acetabular ligament and to the ligament of head of femur. The fibrocartilaginous labrum acetabulare deepens the acetabulum. The horseshoe, shaped articular surface (lunate surface) of acetabulum is covered with articular cartilage. It is thickest and widest superiorly, where the maximum body weight is transmitted to the femur. The nonarticular part of acetabulum is known as acetabular fossa. It is filled with Haversian pad of fat.

ii. The spherical head of the femur is covered by articular cartilage, except for a rough pit where the ligament of the head of femur is attached. The articular cartilage is thickest in the center and thins out towards the periphery.

3. **Describe the special parts of the fibrous capsule of hip joint.**

i. Zona orbicularis is the inner part of the capsule consisting of circularly arranged fibers. It forms a tight collar for the neck of the femur.

ii. Retinacula are the longitudinal fibers on the anterior surface of the neck. These fibers originate from the capsular attachment to intertrochanteric line and proceed towards the femoral head in close contact with the anterior surface of the femoral neck and produce grooves on the femoral neck. Their main function is to support the retinacular arteries running towards the head.

4. **Name the three major ligaments of the hip joint and describe the strongest of the three.**

There are three major ligaments namely, iliofemoral, pubofemoral and ischiofemoral. The iliofemoral is the strongest ligament. It is the thickest and a very powerful ligament. Its shape is like inverted Y. It stretches from the anterior inferior iliac spine to the intertrochanteric line of femur. Since the line passing through the center of gravity lies slightly behind the hip joints, there is a tendency for the body to fall backward. The iliofemoral ligament prevents this tendency. It also prevents hyperextension.
5. Name the vessels and the nerve related anteriorly to the joint.

The femoral artery, femoral vein and femoral nerve are the anterior relations of the hip joint.

6. Mention the major nerve in posterior relation to the joint giving its root value.

The sciatic nerve is related to the hip joint posteriorly. Its root value is L4, L5, S1, S2, S3.

7. Enumerate the movements of the hip joint and the muscles producing them.

- Flexion—Produced by iliopsoas and aided by pectineus, sartorius and rectus femoris.
- Extension—Produced by gluteus maximus and aided by hamstring muscles.
- Adduction—Produced by adductor longus, brevis and magnus and assisted by pectineus and gracilis.
- Abduction—Produced by gluteus medius and minimus and assisted by tensor fasciae latae.
- Medial rotation—Produced by gluteus medius and minimus and assisted by adductor muscles.
- Lateral rotation—Produced by obturator externus and obturator internus with gemelli and assisted by piriformis, quadratus femoris, gluteus maximus and sartorius.

8. If a patient comes with avascular necrosis of femur (which results in nonfunctional hip joint) which surgical procedure will restore the function in the joint?

The hip replacement by prosthetic or artificial hip joint restores the function of the hip joint.
1. Which of the following is not attached to fibula?
   a. Tibialis anterior
   b. Extensor hallucis longus
   c. Extensor digitorum longus
   d. Peroneus tertius

2. The number of ossification centers in the lower limb (on one side) in full-term newborn are:
   a. Six
   b. Five
   c. Two
   d. One

3. Profunda femoris artery leaves the femoral triangle through:
   a. Apex
   b. Behind sartorius
   c. Between psoas major and pectineus
   d. Between pectineus and adductor longus

4. In Clergyman’s knee which bursa is affected?
   a. Prepatellar
   b. Suprapatellar
   c. Subcutaneous infrapatellar
   d. Semimembranosus

5. Which is not a branch of common peroneal nerve?
   a. Lateral inferior genicular
   b. Recurrent genicular
   c. Sural
   d. Sural communicating

6. Femoral branch of genitofemoral nerve is located in:
   a. Femoral canal
   b. Inguinal canal
   c. Middle compartment of femoral sheath
   d. Lateral compartment of femoral sheath

7. When S1 nerve root is irritated, the patient experiences pain in which of the following?
   a. Medial aspect of thigh
   b. Gluteal region
   c. Popliteal fossa
   d. Lateral side of foot

8. What is the name of the deformity if a patient walks on the toes?
   a. Talipes varus
   b. Talipes valgus
   c. Talipes equinus
   d. Talipes calcaneus

9. Which of the following is not a branch of dorsalis pedis artery?
   a. First dorsal metatarsal
   b. Tarsal branches
   c. First plantar metatarsal
   d. Arcuate

10. The structure that comes out of the lesser sciatic foramen is:
    a. Tendon of obturator internus
    b. Pudendal nerve
    c. Internal pudendal artery
    d. Nerve to obturator internus

11. Which of the following is maximally taut while walking downhill?
    a. Medial collateral ligament
    b. Posterior cruciate ligament
    c. Lateral collateral ligament
    d. Anterior cruciate ligament

12. Rider’s bone is found in the tendinous origin of:
    a. Adductor longus
    b. Adductor brevis
    c. Adductor magnus
    d. Gracilis

13. Which is the main joint of the medial longitudinal arch?
    a. Calcaneocuboid
    b. Subtalar
    c. Talocalcaneonavicular
    d. Ankle

14. Pes anserinus is the term used for insertion of the following muscles except:
    a. Semitendinosus
    b. Semimembranosus
    c. Sartorius
    d. Gracilis

15. Which of the following pairs of muscles does not share the nerve supply?
    a. Soleus and popliteus
    b. Gluteus medius and tensor fasciae latae
    c. Quadratus femoris and superior gemellus
    d. Obturator externus and adductor brevis
16. Violent inversion of foot will lead to avulsion of a tendon that is inserted into tuberosity of the fifth metatarsal bone. Identify the tendon.
   a. Peroneus brevis
   b. Peroneus longus
   c. Peroneus tertius
   d. Tibialis posterior

17. Which dermatome is located over the medial border of foot?
   a. S1
   b. S2
   c. L4
   d. L5

18. Which muscle extends the hip joint and flexes the knee joint?
   a. Long head of biceps femoris
   b. Rectus femoris
   c. Sartorius
   d. Short head of biceps femoris

19. What is true about lateral meniscus?
   a. Attached to fibular collateral ligament
   b. Attached to popliteus
   c. Bucket handle tear common
   d. Semicircular shape

20. Which nerve is tested if a physician pinches the skin of a patient between big toe and second toe?
   a. Superficial peroneal
   b. Deep peroneal
   c. Sural
   d. Saphenous

21. Which of the following is not attached to lateral surface of medial condyle of femur?
   a. Posterior cruciate ligament
   b. Anterior cruciate ligament
   c. Ligament of Humphrey
   d. Ligament of Wrisberg

22. Which genicular artery pierces the fibrous capsule of knee joint?
   a. Descending genicular
   b. Middle genicular
   c. Anterior tibial recurrent
   d. Circumflex fibular

23. For surgical access to the femoral neck the greater trochanter is separated. All the following muscles will be removed along with greater trochanter except:
   a. Piriformis
   b. Gluteus medius
   c. Gluteus minimus
   d. Quadratus femoris

24. The lateral cutaneous branches of the following nerves enter the gluteal region.
   a. Subcostal and iliohypogastric
   b. Subcostal, ilioinguinal and iliohypogastric
   c. Subcostal and ilioinguinal
   d. Iliohypogastric and ilioinguinal

25. Gerdy's tubercle is present on:
   a. Lateral condyle of femur
   b. Medial condyle of tibia
   c. Medial condyle of femur
   d. Lateral condyle of tibia

26. Which ligament prevents the forward displacement of femur on tibia at knee joint?
   a. Anterior cruciate ligament
   b. Posterior cruciate ligament
   c. Transverse ligament
   d. Patellar ligament

27. The femoral hernia is manually reduced by pushing the hernia sequentially in following directions.
   a. Upwards, backwards and medially
   b. Forwards, upwards and laterally
   c. Backwards, downwards and medially
   d. Downwards, backwards and upwards

28. Which of the following has same root value as that of tibial nerve?
   a. Sciatic nerve
   b. Common peroneal nerve
   c. Obturator nerve
   d. Accessory obturator nerve

29. Which of the following muscles acts on both knee and ankle joints?
   a. Soleus
   b. Short head of biceps
   c. Gastrocnemius
   d. Long head of biceps femoris
30. Which of the following muscle is not supplied by obturator nerve?
   a. Part of adductor magnus inserted into linea aspera
   b. Obturator internus
   c. Obturator externus
   d. Gracilis

**KEY TO MCQs**

1-a, 2-b, 3-d, 4-c, 5-c, 6-d, 7-d, 8-c, 9-c, 10-a, 11-b, 12-a, 13-c, 14-b, 15-c, 16-a, 17-c, 18-a, 19-b, 20-b, 21-b, 22-b, 23-d, 24-a, 25-d, 26-b, 27-d, 28-a, 29-c, 30-b.
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