Dedication
To my parents, grandparents, beautiful wife Kristen, and daughters Labrini and new addition to our family Ioanna Zgonis.
With love
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Contemporary medical management of diabetic patients has become increasingly dependent on the expertise of clinicians from multiple disciplines. Education and prevention remain the foundation of care; however millions of people in this country, and round the world live with diabetes every day. While we pray for a cure, as clinicians we will continue to face the many sequelae of this terrible disease. In this text Dr. Zgonis and his distinguished panel of contributing authors have eloquently articulated a detailed, logical, and pragmatic methodology for evaluating and treating diabetic pathology of the foot and ankle. The title, *Surgical Reconstruction of the Diabetic Foot and Ankle* may lead the reader to infer that this is purely a surgical text. My primary goal in penning this foreword is to accurately convey the truly comprehensive nature of this tome.

It is important to understand the background that inspired Dr. Zgonis to embark on this project. Through the leadership of Dr. Zgonis, our institution has assembled dozens of faculty from over 14 disciplines to form a center of excellence for the treatment of diabetic foot and ankle disease. This text is a natural progression of his efforts to raise awareness and educate both patients and clinicians about a patient centric, integrated multi-disciplinary approach to the clinical and surgical care of the diabetic patient. The authors cover a broad foundation of topics including: pre/perioperative care, use of diagnostic imaging, negative pressure wound therapy, management of post operative complications, and a stepwise approach to foot and ankle amputations and infections. The evaluation and treatment of the diabetic neuropathic foot is extensively covered, particularly the surgical reconstruction of acute and chronic neuroarthropathy, nonunions, malunions, and management of acute trauma in the neuropathic extremity.

Equal attention is given to the ischemic extremity with in depth discussion of vascular insufficiency, vascular reconstruction, and the entire range of treatment options for soft tissue coverage. Advances in surgical techniques and fixation have improved limb salvage rates for diabetic patients. The contributing authors provide a compelling overview of revisional and reconstructive surgery for the foot and ankle with an emphasis on external fixation.

For students and experienced clinicians alike, *Surgical Reconstruction of the Diabetic Foot and Ankle* will improve the quality of care and patient outcomes by providing a comprehensive stepwise approach for managing even the most complicated diabetic patients.

Daniel W. Carlisle, MD  
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It is with a certain respect, appreciation, and honor to write this preface for my first edition of the Surgical Reconstruction of the Diabetic Foot and Ankle. I feel obligated to thank many individuals throughout my academic journey that have helped me achieve my goals and also publish this unique textbook. I also want to thank my family for their continuous support and share with you my personal background and heritage.

Being raised in a Greek-American family, I had the opportunity to spend most of my childhood in a very small village in the northern part of Greece called Rodia, a suburb of Grevena, Greece. During that time, my parents remained mostly in the United States while my sister and I started school in Greece. My grandfather was the most influential person in my life since he taught me so many things through an era of poverty, hard work, and lack of education. Growing up in a village with a little more than 500 people and with the influence of my grandparents, I learned the three most important values in life that were taught to me by my grandfather: faith, family, and education. Up to this date, I always remember and sometimes still hear his voice about the meaning of life.

After high school, I eagerly returned back to where I was born in the United States and joined my family in Boston, Massachusetts. I can still vividly remember the difficulty of adjusting to a new environment and most importantly the challenges that I had to face with the language barrier and education. Throughout all these years, I tried to accomplish all of my degrees and training and also portray to my grandfather that I was still working very hard and was very appreciative of his daily teachings and wisdom that created and shaped my personality and work ethic.

Accepting a position as an Assistant Professor within the Department of Orthopaedics, Division of Podiatric Medicine and Surgery at the University of Texas Health Science Center (UTHSC) in San Antonio, Texas, was one of my biggest turning points in my academic career. My podiatric surgical residency director (Dr. Clinton Lowery) at the University of Pittsburgh Medical Center in Pittsburgh, Pennsylvania and reconstructive foot and ankle fellowship directors (Drs Jolly and Blume) at the New Britain General Hospital, New Britain, Connecticut and Yale New Haven Hospital, New Haven, Connecticut were some of my colleagues that encouraged me to return to academics and focus on teaching, research and service to the public and the profession. This move was made possible with the help and leadership of Dr. Lawrence Harkless who personally guided me throughout my tenure at UTHSC – San Antonio, Texas which is now led by the chairman of the department of orthopaedics Dr. Daniel W. Carlisle.

I am also obligated and honored to mention Dr. Polyzois’ family and their contribution to my academic journey. Dr. Demetrios Polyzois who is the current president of the Hellenic College of Orthopaedic Surgeons and his son Dr. Vasilios Polyzois who serves as the chief of orthopaedic traumatology at KAT General Hospital in Athens, Greece are two individuals who have taught me so much in diabetic limb salvage through the use of external fixation methods. Their friendship, professionalism, and astute experience in the use of external fixation have made me return to Greece on a yearly basis and also take time to visit the small village where I grew up in memory of my grandparents.

My goal in an academic environment with a very large diabetic population in need of diabetic foot treatment was to establish a Center of Excellence where all patients were seen and treated by all specialties. As diabetes mellitus has now been described by many as an epidemic and with more lower extremity amputations being performed as a result of diabetes related complications, the need of awareness and patient and health care education were my goals through the first edition of this reconstructive book.

A multidisciplinary team of authors has been gathered to share their expertise and approach to some of the most difficult case scenarios in dealing with the diabetic foot and ankle. The importance of a major health care system or academic institution is also emphasized throughout the textbook. Topics that address the diabetic patient’s vascular status, infection, medical management, trauma, soft tissue coverage, and reconstruction are presented by many specialists in the field of their expertise. Being in an academic institution, I always teach the students, residents, and fellows that the diabetic foot represents a direct image of the patient’s overall health status.

In conclusion, I hope that this textbook will raise awareness to the public and health care professionals and to also help guide you through the most challenging reconstructive cases in patients with diabetes mellitus. Education, prevention, and continuous teamwork by all specialties will only bring promising results to this devastating disease and its related complications.

TZ
I would like to thank the Acquisitions Editor, Robert Hurley; Managing Editor, Dave Murphy; Director of Marketing, Sharon Zinner; Production Editor, John Larkin; Design Manager, Teresa Mallon; and all the members of the Production Services group involved with this text for their great support and guidance throughout the project.

TZ
INTRODUCTION

Over the past two decades, a gradual trend toward an increasing aggressiveness in diabetic limb salvage has been seen worldwide. The reasons for this are at a minimum twofold. The first is the improved technology and surgical techniques available to treat diabetic foot complications. These have allowed for earlier and more accurate diagnosis of pathology, as well as more alternatives in wound healing and definitive surgical care. The other likely reason is the increased awareness of the problem at hand. It is now known that as late as 2005, 7% of the U.S. population was estimated to have diabetes, a total of nearly 20.8 million people. Of this number, almost 6.2 million were not aware that they had diabetes, and it is estimated that an additional 1.5 million people will be diagnosed with diabetes yearly (1,2). More specific to limb salvage, it is known that following lower extremity amputation in the diabetic patient, there is a 1-year mortality rate between 11% and 41%; the 5-year rate is between 39% and 68% (3). Most and Sinnock (4) found in 1983 that amputation occurred at an age-adjusted rate of 15 times higher in the diabetic population. The overall estimated rate was 59.7 per 10,000 in the diabetic population, with this rate increasing to 101.4 per 10,000 in diabetic patients 65 years and older (4–6). Also, even for healed diabetic foot ulcers, there is a recurrence rate of 34%. The recurrence rate increases to 61% at 3 years and up to 70% at 5 years (7).

Possibly the most challenging aspect of limb salvage in the diabetic foot is the multifactorial causation of the presenting pathology. Indeed, it has been shown that for patients admitted to the hospital for diabetic foot complications, less than 14% received adequate lower extremity evaluations (8). Some form of structured organization or system is best suited to address the multiple factors involved, which include a compromised immune system, peripheral vascular disease, peripheral neuropathy, and numerous other medical conditions that may be present (9). A “micro system of care” has been described by Nelson et al (10). This is defined as a “system of policies, staff, and technology within the overall healthcare system or medical center that focuses on a specific patient population with a narrow need or condition” (9,10). Within this “system” exists the multidisciplinary approach to limb salvage in the diabetic patient. In the multidisciplinary setting, the various risk factors can all be addressed, including neuropathy, ischemia, and infection. Local factors such as high pressures producing ulceration can be addressed and the “basics” of limb salvage can be accomplished, including patient assessment, medical management/stabilization, wound care, treatment of infection and ischemia, foot-sparing surgery, and prevention (11). Acute problems can also be more efficiently managed and coordinated by providing the medical center with a link to a multidisciplinary team of specialists, with subsequent reduction in hospital length of stay, morbidity, and loss of limb (11,12). This allows standardization of the management approach in a more efficient manner. When done in the setting of an academic medical center, this approach also provides for the utilization of the existing infrastructure to design and implement clinical research trials and more coordinated educational venues (12).

A careful review of the literature reveals that the multidisciplinary approach to the diabetic foot, especially in the academic setting, is not new. This method has proven to be very effective in a variety of ways. Improved outcomes and decreased rates of lower extremity amputation as well as reduced lengths of hospital stay have been shown to occur with a multispecialist approach (11). The utilization of the best available professional expertise has been shown to be a cost-effective delivery of care and also reduces amputation rates and hospital length of stay (13–15). This approach is especially beneficial in the inpatient setting, in which one study showed that at any given time approximately 25% of inpatients have diabetes and of these approximately 20% have some form of foot pathology that required acute care or
follow-up management upon discharge (16). Ziran et al (17) reported improved outcomes when patients with osteomyelitis were followed by a team, including an orthopaedic surgeon and a musculoskeletal infectious disease specialist. Wrobel et al (18) showed that patients within the Veterans Administration (VA) system receiving care at facilities with high levels of feedback coordination and programming had significantly lower rates of amputation. Robbins et al (9) found that after implementing a team approach protocol, the rate of major amputations decreased from 2.15 in 2001 to 1.42 in 2004. DeNamur et al (19) reported on 19 diabetic patients undergoing limb salvage in cases of varying complexity. All patients studied were either scheduled for, or at risk for, a major amputation. Eighteen of the 19 patients avoided major amputation after undergoing intervention via a multidisciplinary team approach at a teaching institution. Limb salvage rates of 65%, 72%, and 81% with multidisciplinary treatment strategies have been reported in three separate studies with 3-year follow-up (7,20,21).

A multidisciplinary setting is also beneficial in the outpatient setting in the treatment of diabetic foot pathology and the follow-up of the limb salvage patient. Utilizing this approach, Keyser (22) reported an 88% rate of healing of initial diabetic foot ulcers in an outpatient wound care program and a 93% salvage rate of the contralateral limb after unilateral major lower extremity amputation. There is some evidence to suggest that outpatient screening may result in more distal amputation by discovering foot pathology earlier (9). Holstein et al (23) found that with the establishment of a multidisciplinary diabetic foot clinic, there resulted a 75% reduction in the incidence of major amputations.

The multidisciplinary team approach has also been shown to be significantly effective regarding the cost of healthcare provided when treating diabetic foot pathology and pursuing limb salvage. Ortegon et al (24) showed that the combination of effective diabetic foot care and intensive glycemic control reduced the rate of amputation by approximately 58%. Their study also revealed a cost per quality-adjusted life year gained of $12,165. Other studies have also shown limb salvage to be cost-effective as the more proximal an amputation is performed, the higher the respective rehabilitation and prosthetic costs (25,26). When these data are combined with reduced length of stay figures, the economic impact is obvious. Clinical practice guidelines (CPGs) for treating diabetic foot pathology can also contribute significantly to effective management and cost containment by promoting timely consults and referrals by the appropriate specialty (27,28). Secondary to the wide range of specialty care and ancillary services available in a major academic healthcare environment, CPGs are ideally suited to provide efficient management of the limb salvage patient and can be easily implemented and followed.

The multidisciplinary approach to diabetic limb salvage is the most critical step in providing comprehensive, efficient, and cost-effective treatment in the diabetic limb salvage effort. The following list is the core group of specialists and personnel used in the academic healthcare medical center setting that are necessary to provide a coordinated process of care that is patient-centered: podiatrist, orthopedist, internist, endocrinologist (diabetologist), infectious disease specialist, cardiologist, nephrologist, vascular surgeon, ophthalmologist, plastic surgeon, nursing staff, nutritionist, interventional and noninterventional radiologist, and pedorthist/orthotist. This list certainly can be modified or expanded on, depending on the respective healthcare center setting in which the multidisciplinary approach is being used. In addition, psychiatry and a pain medicine specialist can be very beneficial. A number of ancillary services are also critical to complete the multidisciplinary approach. The following is a compact summarized breakdown of the respective areas that can be covered by the individual specialties and services.

1. **Podiatrist**: A podiatric surgeon can often function as the “gatekeeper” of the team (Fig. 1.1). This role can also be accomplished by the internist or orthopedist with a dedicated foot and ankle practice. The gatekeeper role is extremely important in assuring that proper and timely consults and referrals are accomplished. The podiatrist can function in a number of areas, such as patient education, as well as prevention and offloading and care of ulcerations, including meticulous wound care, debridement of necrotic tissue, and prompt abscess drainage (13). The podiatric surgeon may also engage in the definitive surgical management in the limb salvage pathway, including major reconstructive procedures, various plastic surgical techniques, and even prophylactic diabetic foot surgery in some cases.

2. **Orthopedist**: An orthopaedic surgeon with a dedicated foot and ankle practice may function in a similar role as the podiatric surgeon, including both preventative care and definitive surgical care for limb salvage.

3. **Internist**: Many times the internal medicine specialist is the initial provider to the diabetic patient undergoing limb salvage. They are essential in the control of hyper-
Introduction

3.

Noninterventional management of lower extremity ischemia at times may be undertaken by the internist, including the use of anticoagulants or thrombolytic therapy (12). Pharmacologic agents such as bisphosphonates may also be used in the setting of the Charcot foot.

4. Endocrinologist: Subspecialty care by the endocrinologist can prove very beneficial, especially in the difficult to control hyperglycemic limb salvage patient.

5. Infectious disease specialist: The role of the infectious disease specialist has evolved and expanded in the treatment of diabetic lower extremity infections, especially with the emergence of many antibiotic-resistant organisms and the potential for multiorganism involvement in the diabetic patient. Appropriate antibiotic selection and dosage is crucial in the operative and nonoperative treatment of osteomyelitis as well as soft tissue infections, especially in patients with immunopathy or those who are on immunosuppressive medications.

6. Cardiologist: Cardiovascular risk factor management must be undertaken for successful limb salvage. Patients with valvular disease or those who have undergone valve replacement present unique problems in the surgical management of the limb salvage patient.

7. Nephrologist: End-stage renal disease is not uncommon in this patient population. Management of the patient on renal dialysis or the post–renal transplant patient can be complicated, including the adjustment of pharmacologic agent dosing (in particular, antibiotics) and the management of immunosuppressive agents.

8. Vascular surgeon: Since insufficient vascular perfusion almost always results in a nonhealing wound, the vascular specialist assumes a critical management role in diabetic limb salvage (12). The incidence of peripheral arterial occlusive disease in diabetic patients is fourfold that of nondiabetic patients and is obviously noted to be a key component in the causal pathway to amputation (28). Sumpio et al (12) showed that when a multidisciplinary approach to limb salvage was used, the number of surgical procedures for aorto-iliac occlusive disease, including aorto-bifemoral, axilla-femoral, iliofemoral, or femoral-femoral bypasses more than doubled. A significant increase in infrainguinal reconstructions also occurred, as well as a relative decline in numbers of major amputations. The vascular specialist may not only be

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Figure 1.1 The important role of the multidisciplinary team approach to diabetic limb salvage. (From Frykberg RG, Zgonis T, Armstrong DG, et al. Diabetic foot disorders. A clinical practice guideline [2006 revision]. J Foot Ankle Surg 2006;45(5):S-17, Fig. 5, with permission.)
involved in the perfusion of an ischemic limb, but may also address the less common scenario of venous insufficiency and its impact on limb salvage.

9. Ophthalmologist: Retinopathy and disturbances of visual acuity can have a negative impact on balance and gait.

10. Plastic surgeon: Wound coverage is an integral part of limb salvage. Besides providing wound coverage, plastic surgical repair may help avoid inelastic scar tissue over wounds, which is many times the result of secondary wound healing. In particular, different forms of local flaps result in greater exposure and visualization and may eliminate the need for additional incisions (12). This role also may be performed by the orthopaedic or podiatric surgeon with the proper training and experience in this area.

11. Nursing staff: Nursing input is invaluable in the limb salvage effort. Important areas of contribution range from wound care and patient and family education to discharge planning and home healthcare.

12. Nutritionist: Achievement of adequate dietary demands must be met not only to achieve strict glycemic control, but also to accomplish expedient wound healing (protein level, sufficient vitamin intake, etc.).

13. Interventional and noninterventional radiologists: Expert diagnostic imaging for osteomyelitis and in the ischemic extremity is absolutely necessary. A dedicated musculoskeletal radiologist is usually available in the academic healthcare medical center setting and may add invaluable information with a variety of imaging techniques. Timely angiographic studies and other interventional techniques are of obvious necessity to assure a successful limb salvage procedure when vascular perfusion is compromised.

14. Pedorthist/Orthotist: Pedorthic/orthotic care is not only paramount in the postoperative treatment of the limb salvage patient, but is also extremely important when employed as a preventative tool. Significant decrease in plantar foot pressures are known to occur with the use of various types of insoles (custom total contact, accommodative, etc.) as well as by shoe modifications such as rocker bottom soles. Therapeutic shoe wear may often help in accommodating foot deformity from Charcot neuroarthropathic changes.

Additional specialty areas of psychiatry, pain management and geriatric medicine may complement the multidisciplinary team when dealing with issues of depression, fear, anger, and intractable neuropathic pain and in the ever-growing numbers of geriatric diabetic patients.

15. Ancillary services: Important services that complement the preceding specialists are a vital part of the team approach. These include, but are not limited to, clinical laboratory services, vascular laboratory services, physical therapy, transplant service, intensive care units and well-trained and experienced cast technicians for applying total contact casts, etc. Although not always found in the academic healthcare setting, hyperbaric oxygen units may also be beneficial.

All of these specialties and services are integral in the multidisciplinary approach to limb salvage. As mentioned, at times there may be overlap in services or one role may be able to be filled by more than one specialty. Regardless, the individual healthcare provider must be qualified and the team approach must always be patient centered.

To this end, dedicated diabetic foot clinics in academic centers have a number of advantages. One such benefit, true of any dedicated center, is a devoted focus and awareness given to the problem. This typically results in an ability to coordinate the expertise required for comprehensive treatment. In an academic setting, most relevant services are under one roof. In theory, this should result in improved efficiency not only in delivering care but also in limiting the number of return visits required by patients, which in turn, improves compliance. Generally, the culture of an academic setting fosters a greater emphasis on research. Such centers have established institutional review boards (IRB) overseeing safety and ethical research practice. Also, other helpful resources such as patient recruitment, advertising, and biostatistics tend to be more available. This ethos combined with a system that sees large volumes of patients with similar pathology provides an ideal environment for promoting clinical studies. Finally, academic centers are the preferred referral centers in most regions when care of the medically complex patient is required. Managing the multisystemic effects of diabetes is labor intensive. In major academic centers, often, the day-to-day management of inpatient care for this difficult population falls on residents and fellows and their efforts cannot be overstated.

Daily wound inspections, dressing changes, débridements, lab data gathering, performing timely blood cultures, and routine medication management are examples of the tasks typically performed by the house staff.

CASE REPORT

A 65-year-old diabetic woman presented to clinic with a 2-year history of a progressive varus deformity of the left foot and ankle secondary to diabetic Charcot neuroarthropathy. The patient ambulated with weight bearing to the lateral malleolus and had been treated with extensive wound care and bracing for a chronic nonhealing ulcer over the distal lateral malleolus for 13 months (Fig. 1.2). Previous diagnostic imaging and bone biopsy confirmed osteomyelitis of the distal fibula. Bone cultures showed multiple organisms, including methicillin-resistant *Staphylococcus aureus*. Besides diabetes mellitus, this patient’s past medical history included peripheral vascular disease now status post–femoral-popliteal bypass of the left side, status post-aortic valve replacement, hypertension, end-stage renal failure now on renal dialysis, and coronary artery disease. Secondary to her chronic infection, nonhealing ulcer, and nonbraceable deformity, amputation had been recommended to her by other surgeons.

After proper clinical evaluation, it was determined that this patient would be a potential limb salvage candidate and she was co-admitted to the podiatry and internal medicine service secondary to her coexisting medical problems. Preoperative work-up was accomplished including the input of vascular surgery (to assure patency of her graft), nephrology (to manage her renal disease and provide inpatient dialysis), cardiology (to manage her anticoagulant therapy secondary to her valve replacement and associated risk factors), radiology (to review old and new imaging studies), and infectious disease (to assist with antibiotic choice and dosage). Clinical, cardiac, and vascular laboratory services were used. After surgical clearance was achieved, limb salvage was undertaken. Talectomy was performed along with tibiocalcaneal arthrodesis and distal lateral malleolus and ulcer...
Conclusion

Resection (Fig. 1.3). Fixation was achieved with an external ring fixator, which provided good stability and allowed the arthrodesis to heal with a plantigrade foot (Fig. 1.4). Postoperative care included extensive patient and family education by nursing team members and follow-up pedorthic and orthotic care.

CONCLUSION

Foot ulcers are a major cause of morbidity and cost in the diabetic population. Therefore, prevention should be of paramount importance. If an ulcer develops, then treatment must be initiated at the earliest possible stage and implemented with a comprehensive understanding of the risk factors that preceded its development. We believe, and the literature supports, that a multidisciplinary approach is the most effective method of prevention and healing of diabetic foot ulcers with regard to both outcomes and cost. Education, prophylactic measures, and early intervention are the principles driving this effort. To this end, the expertise of a multitude of specialists is coordinated to provide care in both the outpatient and inpatient settings.

REFERENCES

INTRODUCTION

In the year 2000, it was estimated that the prevalence of diabetes would rise from 2.8% to 4.4% by 2030 (1). This is an alarming prediction in light of the high number of complications that are associated with this disease. The US Health and Nutrition Survey further demonstrated that 28.5% of those with diabetes develop peripheral neuropathy, 9.5% develop signs of peripheral arterial disease, and 7.7% develop foot ulcers; approximately three times the frequency observed in non-diabetic individuals (2). As a result of these complications, there were approximately 29,000 diabetics admitted to U.S. hospitals with a diagnosis of cellulitis or infected ulcers, 84,000 admitted for other cellulitis or abscesses of the foot, 217,000 admitted for ulcers of the lower extremity, 66,000 admitted for osteomyelitis, 134,000 admitted for chronic non-healing ulcers, and 79,000 admitted for lower limb atherosclerosis with ulcers or gangrene in 2002 (3). A staggering percentage of these individuals undergo surgical intervention while in the hospital. Even more are treated as outpatients for less complex problems as well as elective procedures. These numbers do not include the thousands of patients with diabetes admitted for Charcot reconstructions, and other conditions not included in the preceding statistics.

Among patients who develop ulcerations, Apeleqvist et al (4) found that 24% required surgery in the form of an amputation at some level, costing an average of $44,790 (for surgery and hospitalization). Other studies have also demonstrated surgical amputation rates in 16% of the cases where ulcers developed (5). Ultimately, when you combine all of the different diabetes-specific complications as well as the nondiabetes-related reasons that people with diabetes may need surgery, it represents millions of cases in the United States alone.

When surgical reconstruction is necessary for diabetic patients, the inherent risks of surgery may be increased if their diabetes is not managed both preoperatively and perioperatively. There are many risks associated with surgery, and these are magnified in patients with diabetes, particularly if they are poorly controlled, and have a history of cardiovascular, renal or other systemic comorbidities. The situation becomes even more complex in the presence of infections or gangrene, and/or when complex reconstructive surgery is needed.

High-risk diabetic patients fall into two broad categories; those who are acutely high risk, and those who are chronically high risk. However, before the specific steps necessary to prepare a high-risk patient for surgery are considered, it is worthwhile to review the optimally prepared patient, along with the barriers in achieving that state.

PREOPERATIVE MANAGEMENT

Many patients with diabetes who are undergoing surgery may have multiple co-morbidities, such as infection or gangrene, that can lead to even greater surgical risks, but may also heighten the need for surgery. In fact, unstable hemodynamics or severe infection may be an indication for surgical intervention, such as when a patient requires an incision and drainage, along with resection of infected tissues. Therefore, the presence of infection is an unavoidable preoperative problem in many cases.

It is obvious that optimal glycemic control is desired in the period leading up to surgery. However, there are many points of view regarding what constitutes optimal control. The American Diabetes Association (ADA) (6) and the American Association of Clinical Endocrinology (AACE) (7) have recommended a target HbA1c of <7.0% and <6.5%, respectively. Although this number is not likely to change to any significant degree in the relatively short period leading up to surgery, it is a good indicator of the challenges that lie ahead in preparing the patient for surgery, as well as optimizing the chances of recovery.

More commonly, the preoperative condition of the patient is assessed by measuring the fasting blood plasma glucose levels. The ADA glycemic target is 90 to 130 mg/dL, while the AACE target is <110 mg/dL. Deviations from these goals can increase the risks associated with surgery. One of the most comprehensive studies, the DCCT (The Diabetes Control and
Complications Trial Research Group) (8) demonstrated that euglycemia resulted in decreased complications of all kinds. Kassas et al (9) showed that neutrophilic chemotaxis is impaired when glucose concentrations exceed 240 mg/dL. It has also been shown that elevated plasma glucose levels in the postoperative period will also increase the risk of infections (10–12).

Chronic hyperglycemia has also been shown to diminish a patient’s capacity to heal wounds after surgery. Although the precise mechanism remains unknown, hyperglycemia is known to increase the presence of microvascular and macrovascular disease, as well as decrease phagocytosis, chemotaxis, and polymorphonuclear leukocyte mobilization (13,14). Growth factors such as VEGF, PDGF, and KGF may also be produced at lower levels or in less effective forms (15–17). Skin fibroblast proliferation has also been shown to decrease in the presence of hyperglycemia (18,19).

PREOPERATIVE EVALUATION

A comprehensive evaluation is always necessary prior to surgery, especially when examining a patient with diabetes. This preoperative evaluation should take into account their level of glucose control, and cardiovascular and renal function. Patients with diabetes have a high risk for cardiovascular disease. Frequently, patients with peripheral vascular disease also suffer from significant coronary artery disease and left ventricular dysfunction. Similarly, patients with diabetic retinopathy are more likely to have microvascular disease in other parts of their body, including the cardiovascular system. Evaluation of patients at risk for cardiac complications become even more complicated in the presence of peripheral neuropathy, because the associated sensory deficits may also mask the symptoms of more serious cardiac issues, such as angina. Therefore, it is essential to have an objective preoperative evaluation of cardiac function and myocardial ischemia prior to surgery when possible.

Patients who suffer from sympathetic neuropathy may also have signs of parasympathetic neuropathy, resulting in tachycardia from diminished vagal innervation to the heart. This condition can make the patient less responsive to medications designed to control heart rate (i.e., β-blockers). Therefore, it is essential that excessive fluid volume not be administered prior to surgery (20).

Prior myocardial infarction also places the patient in a higher risk category. Those without a prior history of myocardial infarctions have only a 0.6% risk of developing one perioperatively, whereas those who have had a prior myocardial infarction have a 6% risk (tenfold increase). Although any intraoperative myocardial infarction is a serious matter, the damage associated with second infarctions is dramatically worse, and is believed to result in mortality in 50% to 75% of patients, as compared with 15% of patients who have not had a prior myocardial infarct (21–23).

When planning for surgery in a patient who has had a prior myocardial infarct, a study by Tarhan et al (23) demonstrated that the risk of a second infarct during surgery was 30% during the first 3 months, with an accompanying mortality rate of 54% to 70%. After 6 months of cardiac stability, the risk drops dramatically, with a mortality rate of approximately 5%. Therefore, it is clear that surgery should be delayed at least 6 months, whenever possible, for patients with an acute myocardial infarction history to assure cardiac stability, and some level of recovery from the myocardial infarction.

Congestive heart failure is also more prevalent in patients with diabetes, and it can result in diminished left ventricular function, with associated mortality during or following surgery in the 15% to 20% range (24,25). Diabetic patients are especially susceptible to not have optimal fluid balance because of their diminished renal function. Fluid balance can be achieved through various techniques, including diuretics, vasodilators, and bed rest. Whenever possible, the surgeon should allow 1 to 2 weeks for treatment prior to surgery, to restore fluid balance and to reduce the risks associated with congestive heart failure.

Diminished renal function is another common complication associated with diabetes, and it may range from chronic renal failure requiring dialysis to mild proteinuria. Renal deficiencies in conjunction with cardiac abnormalities are especially significant in light of the potential hemodynamic issues. Patients who are undergoing dialysis should have adequate preoperative dialysis, as well as normalization of their clotting mechanisms prior to surgery.

Although preoperative measurement and control of blood glucose levels is a routine among diabetic patients, the dangers associated with hyperglycemia have a direct influence on cardiac and renal function. Hyperglycemia can reduce cardiac performance by causing intravascular volume expansion, for example. Similarly, marked elevation in blood glucose has been shown to impair white blood cell function, resulting in a higher risk of infections. Fortunately, rapid adjustments to glucose levels can be made just prior to surgery, to optimize these levels. Most hospitals adhere to a sliding scale to reduce glucose levels with insulin, or elevate them by administering fluids containing dextrose.

PREOPERATIVE PREPARATION OF PATIENTS WITH DIABETES: ASSESSING THE RISKS

There are several factors to consider when determining the risks of performing surgery on patients with diabetes. Certainly, the extent of the procedure and the duration and type of anesthesia necessary to perform the procedure must be considered. In addition, some procedures cannot wait for optimal patient preparation, such as in the case of serious infections or peripheral vascular disease, in which delays may result in progression of gangrene with systemic manifestations. There may also be cases in which substantial pain is involved, and may preclude the surgeon from further optimization of the patient’s condition.

Preoperative evaluation begins with a thorough history and physical examination to ascertain the patient’s recent and chronic conditions, particularly those that affect the cardiovascular system. Patients on dialysis or with diminished lung capacity have additional risks related to fundamental fluid hemodynamics and oxygenation. Because neuropathy associated with diabetes may mask many painful sensations, a purely symptomatic assessment may be insufficient. Therefore, in patients in whom extensive neuropathic changes are present, a thorough assessment of the electrocardiogram (EKG) is essential. When possible, patients in higher-risk categories may even require cardiac stress tests prior to surgery. Patients who will undergo low-risk procedures (i.e., a short procedure under local anesthesia) typically do not require this type of extensive workup.
Table 2.1 demonstrates one strategy for stratification based on patient risk factors. As the level of risk increases, so does the need for a more comprehensive preoperative assessment. Since the primary dangers associated with surgery in the higher-risk patient relate to cardiovascular concerns, this is when a more expanded assessment becomes necessary. Patient risk levels are also reflective of the more recent cardiovascular events. Patients having acute problems are almost always at a higher level of risk for intraoperative and postoperative morbidity than patients who are able to safely delay surgery while cardiac issues are stabilized and optimized.

As part of the preoperative assessment of diabetic patients, laboratory values and vital signs are monitored. A typical preoperative assessment should include the following tests:

<table>
<thead>
<tr>
<th>Test</th>
<th>Typical Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemoglobin A1c</td>
<td>A/C ratio</td>
</tr>
<tr>
<td>Glucose (fasting)</td>
<td>Creatinine clearance</td>
</tr>
<tr>
<td>Glucose (peak postprandial)</td>
<td>Lipids: LDL-chol (fasting)</td>
</tr>
<tr>
<td>WBC</td>
<td>Lipids: HDL-chol (fasting)</td>
</tr>
<tr>
<td>Differential (%)</td>
<td>Triglycerides (fasting)</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>Adult vitals: heart rate</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>Adult vitals: respiratory rate</td>
</tr>
<tr>
<td>Platelets</td>
<td>INR Adult vitals: blood pressure</td>
</tr>
</tbody>
</table>

Table 2.2 summarizes the normal ranges for these tests, and the concerns that one may have when out-of-range values are discovered. Table 2.2 demonstrates the optimal values, levels of deviation in which variations become critical, and a brief explanation of why these critical variations pose a significant surgical risk.

Although it is highly desirable to prepare and optimize a patient prior to surgery, this is not always possible. The acute high-risk patient is an individual who is undergoing an emergency procedure, commonly because of an infection, trauma, embolism, or some other sudden change in health. With this type of patient, there is the added challenge of preparing them for surgery in a relatively short period of time. Depending on the circumstances, there may be several issues to consider in preparation for surgery. Comorbidities, such as impaired renal function or cardiovascular disease, are a separate consideration altogether, and must be evaluated in preparation for surgery.

**MANAGEMENT OF DIABETIC PATIENTS ON THE DAY OF SURGERY**

On the day of surgery, it is important for the diabetic patient to have sufficient glycogen stores to avoid the hypoglycemia associated with surgical stress. For this reason, the diabetic patient should undergo surgery early in the day, whenever possible, so that their insulin regimen can be minimally adjusted following an overnight fast in preparation for surgery. Glycogen stores can be further maintained intravenously by administering 5% dextrose prior to surgery (and should be followed up with postoperative administration in cases in which the diabetic patient cannot resume eating after surgery). In cases where the patient is having surgery later in the day, blood glucose levels can be checked prior to surgery and can be adjusted with insulin or glucose infusion as needed.

One of the more common regimens for insulin adjustment on the day of surgery is to administer one half of the normal insulin dose prior to surgery, and another one half following surgery. This alteration in dosing may apply to both intermediate- and long-acting insulins, to provide insulin during surgery as well. In addition, rapid and short-acting insulins are also withheld prior to surgery and after prolonged periods of preoperative fasting.

Diabetic patients who take oral hypoglycemics should have their medication withheld on the day of surgery. Prior to surgery, patients who take oral antihyperglycemics should:

- Diabetic patients who take oral hypoglycemics should have their medication withheld on the day of surgery. Diabetic patients should be treated according to American Diabetes Association guidelines.

**TABLE 2.1 Assessing the Level of Surgical Risk**

<table>
<thead>
<tr>
<th>Risk Category</th>
<th>Typical Procedures</th>
<th>Preoperative Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LOW RISK</strong></td>
<td>Toe or forefoot amputations, incision and drainage distal to the ankle, minimal to moderate reconstruction (i.e., exostectomy, soft tissue repairs and transfers)</td>
<td>EKG, appropriate laboratory work</td>
</tr>
<tr>
<td><strong>MODERATE RISK</strong></td>
<td>Comprehensive reconstructive cases including single or multiple foot and ankle joint fusions, plastic reconstructive cases, extensive incision and drainage procedures, possible ankle and/or trans-tibial amputation.</td>
<td>Preoperative assessment based on individual history; may include EKG, appropriate laboratory studies, possible cardiac stress test, blood type and cross-match</td>
</tr>
<tr>
<td><strong>HIGH RISK</strong></td>
<td>Emergency surgery involving limb or life threatening infection with systemic manifestations</td>
<td>May require intervention surgery prior to initiating surgery to the limb; preoperative assessment based on individual history; may include EKG, appropriate laboratory studies, possible cardiac stress test, blood type and cross-match</td>
</tr>
</tbody>
</table>
### Table 2.2: Optimal Lab Values and Significance

<table>
<thead>
<tr>
<th>Lab Test</th>
<th>Optimal Values</th>
<th>Critical Values</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemoglobin A1C</td>
<td>&lt;7% (4.8%–5.9% in non-DM)</td>
<td>&gt;8% requires therapeutic action</td>
<td>Controlled values may decrease vascular and neuropathic complications</td>
</tr>
<tr>
<td>Glucose (fasting)</td>
<td>90–139 mg/dL</td>
<td>&lt;50 or &gt;450 mg/dL</td>
<td>Decreases diabetes complications</td>
</tr>
<tr>
<td>Glucose (peak postprandial)</td>
<td>&lt;180 mg/dL</td>
<td>&lt;50 or &gt;450 mg/dL</td>
<td>Decreases diabetes complications</td>
</tr>
<tr>
<td>WBC</td>
<td>4–11 K/uL</td>
<td>&lt;2 or &gt;30 K/uL</td>
<td>May indicate infection or immunosuppression</td>
</tr>
<tr>
<td>Differential (%)</td>
<td>Neutrophils: 50–70, Lymphocytes: 18–42, Bands: 0–5, Monocytes: 2–11, Eosinophils: 1–4, Basophils: 0–2</td>
<td>Above or below reference range</td>
<td>May indicate infection, malignancy, or immunosuppression</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>Female: 12–16 g/dL, Male: 14–18 g/dL</td>
<td>Above or below reference range</td>
<td>May indicate anemia or blood loss</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>Female: 36%–48%, Male: 40%–52%</td>
<td>&lt;25% or &gt;60%</td>
<td>May indicate anemia or blood loss</td>
</tr>
<tr>
<td>Platelets</td>
<td>150–440 K/uL</td>
<td>&lt;50 or &gt;999 K/uL</td>
<td>May indicate bleeding, autoimmune disease, malignancy, splenectomy, inflammatory conditions, or chronic infection</td>
</tr>
<tr>
<td>INR</td>
<td>0.9–1.1 unless the following: 2–3: ppx and tx of VTE, tissue heart valve, valvular heart dz, atrial fibrillation</td>
<td>&gt;5.0 or below reference range</td>
<td>May be subtherapeutic or increased risk for internal bleeding</td>
</tr>
<tr>
<td>PTT</td>
<td>2.5–3.5: mechanical heart valves 22–35.0: Reference for heparin: 60–100 seconds</td>
<td>&gt;50 seconds or below reference range</td>
<td>May be subtherapeutic or increased risk for internal bleeding</td>
</tr>
<tr>
<td>A/C Ratio</td>
<td>&lt;30 mcg/mg</td>
<td>&gt;30 mcg/mg</td>
<td>May indicate microalbuminuria, an independent risk factor for CAD if DM</td>
</tr>
<tr>
<td>Creatinine Clearance</td>
<td>Female: 75–115 mL/min, Male: 85–125 mL/min</td>
<td>Above or below reference range</td>
<td>May require therapeutic medication, diet changes</td>
</tr>
<tr>
<td>Lipids: LDL-chol (fasting)</td>
<td>&lt;100 if no CVD, &lt;70 if CVD</td>
<td>Above reference range</td>
<td>May require therapeutic medication, diet changes</td>
</tr>
<tr>
<td>Lipids: HDL-chol (fasting)</td>
<td>Female: &gt;50, Male: &gt;40</td>
<td>Above reference range</td>
<td>May require therapeutic medication, diet changes</td>
</tr>
<tr>
<td>Triglycerides (fasting)</td>
<td>&lt;150</td>
<td>Above reference range</td>
<td>May require therapeutic medication, diet changes</td>
</tr>
<tr>
<td>Adult vitals: Heart rate</td>
<td>60–100 beats per minute</td>
<td>Above or below reference range</td>
<td>May indicate a number of systemic conditions or secondary to medication, pain or infection</td>
</tr>
<tr>
<td>Adult vitals: Respiratory rate</td>
<td>12–20 breaths per minute</td>
<td>Above or below reference range</td>
<td>May indicate a number of systemic conditions or secondary to medication, pain or infection</td>
</tr>
<tr>
<td>Adult vitals: Blood pressure</td>
<td>90–130 mm Hg systolic, 60–90 mm Hg diastolic</td>
<td>&gt;180/110 mm Hg needs immediate attention</td>
<td>Increased BP associated with increased CV events and mortality</td>
</tr>
</tbody>
</table>

A/C ratio, urine albumin/urine creatinine; BP, blood pressure; CAD, coronary arterial disease; CV, cardiovascular; CVD, cardiovascular disease; DM, diabetes mellitus; dz, disease; ppx, prophylaxis; PTT, partial thromboplastin time; tx, treatment; VTE, venous thromboembolism; WBC, white blood cell count.

surgery, the blood glucose levels can be adjusted with administration of dextrose or insulin as needed. Similarly, diet of diabetics can also be monitored prior to surgery, and their blood glucose levels can be adjusted as necessary.

In general, the focus of perioperative glucose management is toward avoidance of hypoglycemia because of the restriction of oral intake to avoid aspiration or emesis. However, the stress of surgery often leads to an increased demand for insulin (26) because of increases in counterregulatory hormones such as growth hormone, glucagon, epinephrine, norepinephrine, and cortisol. Gluconeogenic precursors such as amino acids, free fatty acids, and lactate also increase in response to surgical stress. Normally, this would trigger increased insulin secretion, thereby preventing catabolism and protein breakdown. Because the diabetic patient usually lacks insulin during surgery, he/she may take longer to heal wounds, and may experience a more extended period of protein breakdown.

PERIOPERATIVE MANAGEMENT OF THE DIABETIC PATIENT

There is a tendency for surgeons to believe that once the patient is anesthetized, there is a relatively stable state that is sustained until the case is over. However, surgery involves an acute injury to the body, which requires the patient to respond through a series of ongoing physiologic changes that they must be prepared for prior to surgery. Despite the presence of anesthesia, the body responds to surgery as it would to trauma, through a series of neural and endocrine alterations evolved to promote survival.

Blood loss requires shunting of fluid between intravascular and extravascular spaces to sustain the heart and blood pressure. This is an active process that requires energy stored within the body. During surgery and in the postsurgical period, glucose obtained from glycogenolysis in muscles and the liver may become depleted, resulting in the breakdown of muscle tissue to supply both glucose and proteins necessary for healing of tissues. Once surgical recovery begins, the wasting of muscle will stop, and the tissues can be replenished.

In diabetic patients, the shifting of biologic resources can be initiated by surgery, particularly when there is substantial fluid loss. The energy expelled to combat circulatory impairment is followed by catabolic events that provide substrates for wound healing but deplete muscle tissues in the process. Ultimately, once the wound heals, the catabolic effect will be replaced by an anabolic one. As discussed in the previous section, a lack of insulin during surgery may trigger this catabolic effect; therefore, it is advantageous for blood glucose to be monitored intraoperatively to prevent protein breakdown during periods of high stress.

Hypoxia, hypotension, and pain are strong stimulators of the hypothalamus. Thus, intraoperative complications can trigger a neuroendocrine event in diabetic patients, resulting in severe hypotension. Once a surgical incision is made, additional hypothalamic stimulation may occur, resulting in activation of the autonomic nervous system and hormonal release from the pituitary gland. As a result, norepinephrine reaches the circulatory system, resulting in release of catecholamines that reduce insulin and increase glucagon. During surgery, insulin levels drop, and the nondiabetic patient responds by gradually raising the level. However, diabetic patients may have an impaired ability to raise insulin levels, resulting in extended periods of hyperglycemia and all of the associated effects discussed previously (29-25).

Wound healing is also affected by low oxygen tension, resulting from macrovascular and microvascular disease associated with diabetes. One study demonstrated that breathing 80% oxygen during surgery and 60% oxygen for 2 hours after surgery resulted in decreased abdominal surgical wound infections (27). However, there are no prospective data that support this approach for diabetic patients to reduce the risk of postoperative infections.

Finally, cardiac risks associated with surgery can also be mitigated. With increasing frequency, high-risk patients with abnormal thallium perfusion imaging can be treated with β-blockers such as bisoprolol or atenolol perioperatively. This has been shown to greatly reduce the risk of death and myocardial infarction during surgery (28,29). Furthermore, this effect persisted for as long as 6 months after surgery.

CONCLUSION

On a percentage basis, patients with diabetes require surgery more frequently than nondiabetic patients because of the multitude of complications associated with their disease. Preoperative preparation of these patients involves optimization of blood glucose levels to ensure energy throughout the procedure. Furthermore, cardiovascular risks must be properly assessed to minimize the risk of morbidity and mortality during surgery. Ideally, surgical patients with diabetes mellitus will be properly prepared in advance, so that their risks can be minimized. Surgery in this population of patients can become a difficult balancing act because of the need for glycemic control. In addition, the surgeon must keep in mind that getting the patient through surgery is just the beginning because of the persistent nature of diminished wound healing, increased risk of infection, and prolonged tissue catabolism following surgery. With careful planning and perioperative monitoring, it is possible to reduce the risks associated with diabetic patients requiring surgery.

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REFERENCES

Chapter 2 Preoperative and Perioperative Management of the High-Risk Patient with Diabetes Mellitus

INTRODUCTION

Given the fact that patients with longstanding diabetes are often fraught with coincident neuropathy and an impaired immune system, they prove challenging in all facets of medical management and imaging is no exception. In the face of clinically significant neuropathy with or without autonomic dysfunction, the patient with diabetes is at high risk for occult trauma. Given this fact, it is not unusual for these patients to suffer from injury that results in infection or wound healing complications that increases their morbidity and mortality rate. When nuclear medicine imaging (NMI) is used early in the diagnostic workup, significant clinical and physiologic information can be verified. With the most commonly used techniques, important physical details can be documented, such as blood flow to an organ or limb, bone reactions such as arthropathy, contusion, or fracture, as well as the discrete white blood cell accumulations seen in infection. Although the science behind NMI is the same regardless of the patient type, it is particularly useful in patient populations that present with combinations of structural abnormalities, acute arthropathy, and infections.

HISTORICAL REVIEW

The discovery of radioactivity is attributed to Henri Becquerel in 1896. His findings inspired his assistant, Madame Curie, to pursue research and analyses of uranium and its by-products leading to the isolation of polonium and radium. The Nobel Prize for physics in this research was shared by Becquerel and Marie and Pierre Curie in 1903. In 1911, Marie Curie received a second Nobel Prize in chemistry for her work in the radioactivity associated with uranium and its decay products. Therapeutic properties were discovered from the study of radium, and this remains the basis for the host of NMI used in clinical medicine and therapeutics today.

Although the imaging technology behind nuclear medicine dates back to the early 1900s, the first scanner used for isotope imaging, the rectilinear scanner, was developed in 1951 by Benedict Cassen. In 1952, Hal Anger developed the first scintillation camera, the Anger camera, which has served as the prototype for present day camera systems. Over time, its use in musculoskeletal imaging has been researched and developed for specific categories of pathology. By the 1980s, computed tomography advanced nuclear medicine into the world of cross-sectional imaging and single photon emission computed tomography (SPECT) systems moved to the forefront of NMI. This sectional imaging technique was first used for research in cerebral and cardiac imaging, although today SPECT can be applied to all organ systems. Examples of this imaging technique are provided later in this chapter.

Although any organ system can be studied with the benefit of nuclear medicine techniques, perhaps one of its greatest strengths is in musculoskeletal imaging. Nuclear medicine imaging has facilitated the study of lower extremity neoplasms (soft tissue and bone), hypercoagulable states such as sickle-cell anemia and deep vein thrombosis, fractures, contusions, and the spectrum of arthropathy to include bone and joint infections. Nuclear medicine technology includes radiolabeled leukocyte and antibody imaging, which has become a very powerful tool for diagnosing infection and is particularly useful in imaging acute and chronic inflammatory conditions of the lower extremities. Repeating NMI after clinical cure can confirm or refute the absence of indolent or subclinical infection. Complex foot and ankle deformities such as the combination of the Charcot foot with concomitant ulceration and infection pose an arduous challenge to the surgeon and as such ancillary imaging techniques such as NMI help to shed light on these limb-threatening conditions. An academic review of the nature of this imaging modality and illustrations of common radiolabeled imaging techniques will underline the clinical utility of NMI in identifying and discriminating between the various complications of diabetes in the lower extremity, including the Charcot foot and infections of soft tissue or bone.

ACADEMIC FUNDAMENTALS

The clinical value of NMI lies in the visual data it produces. Radiolabeled compounds emit energy from radionuclide (radioisotope) decay, and that is what puts an image on the film. Much like a radiograph exposes film with electron energy, radionuclides expose film using gamma, alpha, or beta ray
or bone will exhibit an increased area of uptake on a technetium metabolic abnormalities. Any region of hyperemia in soft tissue pathology, hypertrophic osteoarthropathy (HOA), neoplasms, and diabetic gangrene, fibrous dysplasia, reflex sympathetic dystrophy of bone (e.g., sickle cell disease and intraosseous tumors), necrosis, avulsion fractures, diseases resulting in marrow expansion (forefoot) are readily identified and can be imaged in multiple orthogonal planes to better separate bone from adjacent soft tissue structures.

BONE AND SOFT TISSUE IMAGING

From a practical perspective, musculoskeletal imaging techniques primarily use technetium. Technetium (99mTc) has a short half-life of 6 hours, and is readily available labeled to chemicals that are physiologic in nature. These compounds are essentially inert and there is virtually no incidence of allergic reaction to them, which is a great advantage over other imaging modalities that use iodine or other contrast materials. Technetium-99m is a metastable isotope; therefore, it has a short physical half-life. (The m in 99mTc indicates that the isotope is metastable and therefore decays quickly, resulting in a short physical half-life.) It emits a low-energy gamma ray emission of 140 kV that imposes a minimum of radiation exposure to the patient. These properties make technetium a readily available isotope with excellent imaging characteristics. Technetium imaging in particular is performed for the identification of arthritic changes, avascular necrosis, avulsion fractures, diseases resulting in marrow expansion of bone (e.g., sickle cell disease and intraosseous tumors), diabetic gangrene, fibrous dysplasia, reflex sympathetic dystrophy, hypertrophic osteoarthropathy (HOA), neoplasms, and metabolic abnormalities. Any region of hyperemia in soft tissue or bone will exhibit an increased area of uptake on a technetium scan. Osseous injury resulting from bone fracture (surgically induced or traumatic), hypertrophic nonunion of bone, or osteomyelitis treated to cure will continue to reveal hyperemia from continued bone remodeling for more than 1 year after the initial insult (Fig. 3.1). Therefore, a thorough history is integral to appropriate interpretation of these studies. Technetium-99m alone localizes in multiple organ systems of the body; therefore, to achieve specific target localization, the isotope is labeled to a chemical. The chemical action determines what tissue or organ system is visualized. In short, the chemical localizes the isotope in the target tissue/organ and the isotope emits the radiation energy that produces the image. Remember that these chemical compounds are distributed via the intravascular compartment and many are eliminated by the renal system (tubular filtration or glomerular filtration). For this reason, a bone scan using technetium requires increased hydration to clear background activity and improve the target-to-background ratio. To accomplish this, the patient is instructed to drink 32 oz of fluid after the injection and returns in approximately 2 hours for third phase scanning. In cases of severe peripheral vascular disease or renal vascular impairment, the delivery of the radiochemical will be delayed and may compromise the target to background ratio seen upon imaging. Figure 3.1 illustrates a healthy 38-year-old patient with normal renal vascular status. Contrast that to images seen in Figures 3.2B and 3.5B, in which diabetic patients with multisystem compromise (including chronic renal failure) increase the background radiation and reduce image resolution in third phase bone scan imaging.

The triphasic bone scan, using 99mTc-MDP, is helpful in discriminating among cellulitis, abscess, and osteomyelitis by comparing their respective imaging patterns. Cellulitis shows an increased intensity in the initial phase and then diminishes throughout the second and third phases of the study. A soft tissue abscess will reveal intense localized uptake throughout the first two phases of the study, but will wash out in the third phase if there is no bone involvement in the pathology. The third phase of a triphasic scan reveals bone uptake of the isotope and facilitates the differentiation between soft tissue and bone pathology. Oblique positioning during the second and third
Historical Review

phases is usually sufficient to provide separation of the soft tissue structures from bone delineating abscess formation that exists tangential to bone structures. In contrast, osteomyelitis shows an increased localized uptake in all three phases of imaging. It is important to note that the diagnosis of osteomyelitis cannot be made from a third phase 99mTc-MDP bone scan as it illuminates areas of hyperemia without clarifying its etiology. Definitive diagnosis of infection requires further imaging to identify an appropriate location for bone biopsy when it is warranted. Although the bone scan is sensitive for many processes associated with hyperemia, this study lacks specificity; as a consequence, it is only to be used as a screening tool.

The differentiation in appearance between osteomyelitis and septic arthritis in routine bone scanning is not commonly discussed. However, it is understood that these two conditions are distinct clinical entities and demonstrate different behavior patterns in NMI. In the face of septic arthritis, it is possible to identify the articulations involved as being separate and distinct from soft tissue structures outside or even adjacent to the joint periphery. Although the initial pattern of uptake on these images is identical to that seen in osteomyelitis, follow-up imaging patterns for these two entities are decidedly different. In the case of osteomyelitis, the affected bone will yield an increased uptake on a 99mTc-MDP scan long after clinical cure. Experience has shown that this uptake can be demonstrated a year or more after clinical cure because of ongoing remodeling of bone (MSJ). In contrast, once clinical cure has been achieved for a septic joint, long-term follow-up studies will return to baseline without third phase isotope uptake as there is no residual hyperemia in either soft tissue or bone once a septic joint is resolved (Fig. 3.2A–D).

The triphasic bone scan is also useful in studying the spectrum of bone healing. Any condition that includes remodeling of bone will produce an increased region of uptake on all three phases of the triphase scan. Injury to bone such as fracture (iatrogenic, pathologic, or traumatic), contusion, or dislocation will elicit three phases of uptake because of associated hyperemia. The 99mTc-MDP scan in particular is helpful in sorting out conditions such as delayed union and nonunion of bone and will reveal distinct patterns of uptake in cases of hypertrophic or atrophic nonunions.

INFECTION IMAGING

It is important to gain a general understanding of the physical properties of the more commonly used isotopes in nuclear medicine leukocyte imaging as they determine the imaging characteristics of each radiolabeled compound. An overview of the most commonly used isotopes in infection imaging is provided in Table 3.1. The following is an academic review of commonly used isotopes and their respective roles in infection imaging.

Nuclear medicine imaging techniques for the identification and isolation of infection have been in use since the 1950s. Volume 3: Imaging in the Orthopaedic Patient (third edition) by Armin Von Knoch 2009

Figure 3.2  This case represents a diabetic patient with longstanding ulceration and acute onset of redness, warmth, swelling, and tenderness in a bunion deformity. The side-by-side comparison of the Tc-MDP third phase and Tc-HMPAO imaging depicts septic arthritis. A. A positive Tc-MDP third phase scan in the region of the first metatarsal phalangeal joint (MTPJ) shows increased activity in the region of the proximal phalanx base and the first metatarsal head before surgical débridement and antibiotic therapy. The obliquity of this view throws the first MTPJ away from that of the second MTPJ ruling out associated joint involvement. The “photogenic” character of 99mTc-MDP allows resolution sufficient to separate out the small bones of the lesser tarseus here. B. 99mTc-MDP after treatment confirming that there is no residual bone remodeling supporting the clinical cure of septic arthritis. C. 99mTc-HMPAO before surgical débridement and antibiotic therapy. The region of interest is outlined to delineate a smaller focus of activity versus that identified on the 99mTc-MDP scan suggesting only localized medial eminence involvement. This illustrates the lower target-to-background ratio of Tc-HMPAO as compared with Tc-MDP. D. 99mTc-HMPAO 3 weeks after completion of 4 weeks of oral antibiotic therapy. Cultures obtained before a delayed primary closure confirmed the absence of infection in the first metatarsal head.
Gallium is one of the first isotopes used to localize infections and other pathologic processes. This agent binds with transferrin, which is an iron bound protein found within the cytoplasm of white blood cells (WBCs). An intravenous injection of gallium citrate provides an in vivo labeling of leukocytes and bacterial organisms allowing for the identification of inflammatory processes (Fig. 3.3A,B) (2). Notice from Figure 3.3 that this agent has a normal distribution within soft tissue structures of the entire body and includes delineation of glandular structures within the head and neck region. It has been primarily used in the study of fever of unknown origin and is still used today.

Since the introduction of gallium imaging for infection, research has brought about the development of alternate radiolabeled WBC studies to enhance the specificity and imaging quality of these exams. In 1976, indium-oxine-leukocyte imaging (\(^{111}\)In-oxine-WBC imaging) came to the forefront and since that time has enjoyed a large degree of clinical usage. Indium delineates leukocyte accumulation, providing a faithful mirror of WBC activity within 24 hours. Over time, this imaging technique has earned its place in the study of both acute and chronic infectious processes (3–18). Indium imaging, like gallium, suffers from inherently poor imaging characteristics, as it emits dual high-energy alpha rays to produce its images. This results in poor spatial resolution and a low target-to-background ratio. This technique often requires a minimum of 24 hours to localize within an area of WBC accumulation. Depending on the differential diagnosis, imaging may be obtained in series at 6, 24, 48, and 72 hours. In cases of positive uptake, the region of isotope localization becomes more discrete as time progresses because of the combined effect of the physical and biologic half-life of the compound. Improved localization occurs over time as a result of lowered background radiation and an improvement in target-to-background ratio. At the time this was the best imaging agent available for the noninvasive investigation of infection. Indium leukocyte imaging has remained a primary imaging agent for the localization of infectious processes despite its poor imaging characteristics and low spatial resolution (Fig. 3.4).

**TABLE 3.1**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>T(_{1/2})</th>
<th>Energya</th>
<th>Doseb</th>
<th>Productionc</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technetium ((^{99m})Tc)</td>
<td>6.0 hr</td>
<td>Gamma 140</td>
<td>5.0–10.0</td>
<td>Generator</td>
<td>Abundant</td>
</tr>
<tr>
<td>Indium ((^{111})In)</td>
<td>2.8 d</td>
<td>Gamma 173–247</td>
<td>0.5–1.0</td>
<td>Cyclotron</td>
<td>Limited</td>
</tr>
<tr>
<td>Gallium ((^{67})Ga)</td>
<td>3.25 d</td>
<td>Gamma 100–400</td>
<td>0.5</td>
<td>Generator</td>
<td>Abundant</td>
</tr>
<tr>
<td>Flourine ((^{18})F)</td>
<td>109 min</td>
<td>Photon 511</td>
<td>10.0</td>
<td>Cyclotron</td>
<td>Limited</td>
</tr>
</tbody>
</table>

*Energy of emissions in kilo electron volts (kV).

Dosages reported in millcuries of radioactivity.

Method of production directly impacts isotope availability.

![Figure 3.3](image1.png)

**Figure 3.3** Total body image of a gallium citrate scan for ruling out occult infection. Notice that this is primarily a soft tissue imaging agent with normal areas of uptake, including the lacrimal and salivary glands. It is commonly used in the search for occult infection in cases of fever of unknown origin. Gallium can isolate and differentiate among a spectrum of pathologies, including inflammatory bowel disease, cyst, and abscess and tumor formation.

![Figure 3.4](image2.png)

**Figure 3.4** Positive indium leukocyte studies appear very grainy, with localized white cell accumulation demonstrated as clusters of small, black, often pinpoint regions of intensity. In this image the “T” indicates the direction of the toes, and the reader’s right and left correspond to the medial and lateral aspect of the foot, respectively. Notice that there is no anatomic information to specifically identify the location of the leukocyte accumulation in this image, which is an inherent pitfall of the indium-leukocyte technique.
In the late 1980s interest would be rejuvenated in NMI as a new and improved radiolabeled white cell technique came to the forefront. In 1986 technetium—99m-cI hexamethyl propylene amine oxime aka Tc-HMPAO (CERETEC) would be developed for cerebral perfusion imaging using the isotope technetium, hence the trade name CERETEC. The excellent imaging characteristics of the isotope 99mTc enhanced nuclear medicine tomography in cerebral imaging immensely. Since HMPAO has a high affinity and avidity in labeling to WBCs, it was later suggested for imaging in cases of infection. Technetium is a very “photogenic” isotope because of its low energy of emission and short half-life. That is to say, technetium has favorable imaging characteristics providing improved spatial resolution in imaging that is not achievable using either indium or gallium. By combining technetium with HMPAO, the resulting compound has both high affinity and avidity to leukocytes (because of the HMPAO) and produces images with improved structural resolution (because of the technetium) (Fig. 3.5C). Improvement in spatial resolution is best appreciated when compared directly with other infection imaging agents such as gallium citrate and indium-oxine-leukocyte compounds. The benefit of improved imaging resolution using technetium increased the specificity of radiolabeled WBC imaging and therefore improved the technique. Tc-HMPAO imaging has proved to have great utility in some of the most complicated and challenging of infectious conditions (19–47). This includes both the evaluation and management of postoperative infection and differentiating osteomyelitis from adjacent soft tissue infection (1). Like indium-leukocyte imaging, phlebotomy is required and a physical labeling of WBCs is performed in vitro. This compound is then reinfused into the patient and imaging with 99mTc-HMPAO leukocytes is generally performed at 6, 18, and 24 hours after injection, which may vary with the institution performing the study. This technique is used for the evaluation of clinical conditions suspicious for infection and the management of postoperative infection, and for differentiating osteomyelitis from adjacent soft tissue infection. Although a bone scan in the third phase is helpful in identifying regions of hyperemia, the HMPAO study elucidates well-localized areas of white cell accumulation or infection and can be very helpful when determining discrete sights for bone débridement or bone biopsy procurement (Fig 3.5A,B). It is important to understand that a diagnosis of osteomyelitis cannot be made from a routine bone scan using any NMI agent. Definitive diagnosis of osteomyelitis requires the gold standard of bone biopsy.

The current literature suggests using 99mTc-sulfur colloid as an imaging alternative for the diagnosis of osteomyelitis (7,15). Sulfur colloid is an albumin of sufficient particle size to permeate the reticuloendothelial system (RES), which includes the liver, spleen, and bone marrow. When combined with the isotope 99mTc, the colloid can localize within the RES organs and illuminate the target of interest. 99mTc-sulfur colloid deposition in bone marrow provides information about the intrasosseous compartment by identifying space-occupying lesions, as it is truly a marrow-imaging agent. The colloid will not permeate a nidus of infection, malignancy or other neoplastic entity rather it delineates the pathology as a dead space or void, resulting in an area of photopenia (lack of isotope uptake). In the author’s experience using this technique in the lower extremity, the small bones of the tarsus have been poorly demonstrated. It is likely that larger bones with a greater cubic content of marrow will be more easily visualized using this technique (Fig. 3.6D). This image illustrates the lack of structural detail and failure to delineate skeletal contours when using 99mTc-sulfur colloid in the small bones of the foot and ankle. This case underscores the complexity of diabetic foot ulceration in an amputee. Despite the fact that a transmetatarsal amputation was performed 1 year ago, the region of bone resections remain intense on the 99mTc-MDP bone scan. Even in the absence of infection, these regions should exhibit intensity on the routine bone scan because of continued bone remodeling, but the question remains as to whether there is an infection associated with the bone underlying a region of nonhealing ulceration. One can consider MRI in this event; however, there are likely to be postsurgical changes in bone and soft tissue changes because of active ulceration that confound its interpretation (Fig. 3.6A–E). Hypertrophic bone formation shows local radiotracer uptake the same as any other remodeling bone, which is well illustrated in Figure 3.6B,C. All imaging techniques used for the identification of infection are judged based on their respective sensitivity and specificity. Depending on the author and the research protocol used, these data vary dramatically for NMI in the current literature (48). Many argue that magnetic resonance imaging (MRI) is the best modality for the diagnostic challenge of identifying osteomyelitis as it will predictably show a decreased signal in T1 images and increased signal on T2 images in the face of a degenerative inflammatory process in bone (49–57). The sensitivity and specificity of MRI for infection is commonly reported as 94% to 100% and 69% to 96%, respectively. Unfortunately, other conditions that distort normal anatomy will confound the reading of an MRI; such as the case of postsurgical changes or the coincidence of Charcot neuroarthropathy and infection.
A. Clinical photo 1 year post–left transmetatarsal amputation. Ulceration develops in the distal stump and is persistent despite 6 weeks of local wound care and offloading. B. The left DP radiograph reveals evidence of hypertrophic bone formation about the lesser metatarsal stumps as well as penciling of the fifth metatarsal. C. The third phase bone scan in the presence of a well-healed transmetatarsal amputation continues to show evidence of bone remodeling even at 1 year after surgery. This study is interpreted as suggestive of infection and clinical correlation is suggested. D. This marrow scan using $^{99m}$Tc-sulfur colloid illustrates a lack of structural detail and failure to delineate skeletal contours in foot and ankle imaging. Sulfur colloid fails to provide meaningful structural detail given the small cubic content of the marrow cavities in residual metatarsal shafts. E. The indium leukocyte study reveals accumulation of radiotracer within the distal soft tissue structures without evidence of discrete bone infection. F. Surgical débridement and bone recontouring is required to achieve healing. This clinical photo is taken 8 months postoperatively.
It is extremely important to note that, in its active state, Charcot neuroarthropathy will show a very similar MRI pattern to osteomyelitis. The mixed lytic and resorptive destruction that occurs in bone because of infection is indistinguishable from the destruction that is seen in actively progressive neuropathic disease demonstrated on MRI (11,49,50,58). Differentiating between Charcot joint and infection is among the most important diagnostic challenges in lower extremity pathology and NMI is often a helpful tool in discerning the two conditions as separate and distinct (Fig. 3.7B,E).

COMBINATION IMAGING TECHNIQUES (111In-WBC/99mTc-MDP)

When an 111indium-oxine-WBC study identifies a focus of infection, it becomes apparent that there is no structural detail to these images. As seen in Figure 3.4, an accumulation of WBCs is easily appreciated; however, the specific location of the accumulation cannot be determined using this image alone. The combination of an indium-WBC image and a routine bone scan (99mTc-MDP) provides more specific identification of leukocyte accumulation. The combination imaging technique uses the structural information provided by 99mTc-MDP for plotting out regions of leukocyte accumulation as identified by the 111In-oxine-WBC scan (1,11,12–15,48,59–62) (Fig. 3.8A–D). An overlay or side-to-side comparison of these studies optimizes interpretation of the data set. In general, the 99mTc MDP bone scan, specifically the third phase bone image, is used to provide structural information that allows mapping of the precise location of WBC accumulation when compared with an 111In-oxine-WBC scan. It is felt that correlation in two or more orthogonal planes is important when attempting to differentiate infectious processes that occur in or adjacent to areas of sterile inflammation as occurs in active arthropathy or acute neuropathic disease states (10). Using grid markings, it is possible to express the location of isotope uptake via X-Y coordinates. By using the same field of view without moving the patient, the technetium and indium images are obtained and the anatomic landmarks can be cross-correlated for comparison. This outline of the foot makes it easy to compare foot positioning between these two studies. Multiple orthogonal planes of imaging are helpful in clarifying the localization of infection when it exists. To obtain markings and orthogonal views such as these, specific communications between the ordering physician and nuclear medicine technologist are required and in the author’s (MSJ) opinion are well worth the additional effort.

Combination imaging to differentiate soft tissue infection from osteomyelitis has been repeatedly suggested in the liter-
ature to enhance the specificity and sensitivity of nuclear medicine leukocyte studies. The overall sensitivity and specificity of NMI has been reported ranging from 75% to 100% and 70% to 100%, respectively (11,15,48,63). These statistics vary from author to author as their protocols often compare numerous nuclear medicine techniques of differing sensitivities and specificities.

**INTERPRETATION OF RADIONUCLIDE LEUKOCYTE IMAGING**

The interpretation of NMI studies is chiefly the responsibility of the radiologist; however, the ordering physician should have a good working knowledge of the goals of the study and how images are to be interpreted and clinically correlated. This should include a thorough understanding of conditions that are associated with an increased leukocyte accumulation and those that are not. With this understanding, the clinician can better predict when a false-positive or -negative result is possible. This allows better prognostication for the patient and an improved clinical approach to the pathology.

Specific recommendations regarding how to interpret the combination of $^{99m}$Tc-MDP and $^{111}$In-oxine or $^{99m}$Tc leukocyte images include grading the intensity of uptake, congruence of intensity, and congruence of the size of the region of leukocyte uptake in comparison with that of the unaffected contralateral limb. Combination imaging allows for cross-comparison that further delineates the specific location of pathology and progression of disease.

**Figure 3.8** This illustrates the combination imaging technique using $^{99m}$Tc-MDP and indium-WBC. A. This clinical photo demonstrates an area of ulceration with localized erythema, warmth, and edema 3 years after an acute Charcot breakdown. B. This lateral radiograph shows the end result of neuropathic breakdown; a rocker bottom foot with a planter flexed cuboid bone creating a pressure point and ulceration. C. This $^{99m}$Tc-MDP study illustrates the study’s high sensitivity for areas of hyperemia as is seen in a Charcot foot. Hyperemia suggests an inflammatory and or infectious process exists; therefore, this study alone does not reconcile the issue of Charcot versus osteomyelitis. D. This indium leukocyte study has the outline of the extremity drawn on the image using the indium syringe. This outline of the foot makes it easy to compare foot positioning between these two studies. To obtain markings such as these, specific communications between the ordering physician and the nuclear medicine technologist are required. The combination of indium leukocyte imaging and $^{99m}$Tc-MDP delineates the region of an infectious process within the cuboid bone while at the same time ruling out the existence of infection elsewhere within the degenerated Chopart joint. Using a grid coordinate system, seen here as a large dotted line, discrete areas of infection on the indium scan can be cross-correlated with the anatomic outline on the MDP scan in preparing for bone biopsy and débridement.

**Figure 3.9** A. Clinical photo of a recurrent right posterior heel decubitus in the face of diabetes and end stage peripheral vascular disease. The longstanding nature of this wound, periodic over 1.25 year, prompts the investigation for underlying osteomyelitis. B. Third phase Tc-MDP fails to identify localized radionuclide uptake in the heel bone. C. Combination imaging here is effective in identifying soft tissue infection using $^{111}$Indium-WBC. These images identify leukocyte accumulation in the posterior aspect of the heel consistent with soft tissue infection and support the pursuit of soft tissue débridement. A core biopsy of the posterior heel is guided by the findings in this image and fails to identify organisms of infection or histologic change in bone suggestive of infection.
vides skeletal mapping of white cell accumulation that is helpful in preparing for bone biopsy procurement (Fig. 3.8C,D) (8,11,15,62).

To appropriately interpret radiolabeled leukocyte studies, it is important to understand disease states other than infection that prompt leukocyte accumulation to predict when a false-positive image may result. Alternately, understanding those conditions that do not prompt leukocyte accumulation will help to further narrow the differential diagnosis in the face of a negative leukocyte scan. The radionuclide leukocyte study will remain negative in the presence of severe degenerative arthritis, migratory polyarthritis, metastatic bone disease, and aseptic necrosis. A mild increased uptake has been reported in the presence of closed fracture, delayed or nonunion of bone, and total joint implant arthroplasty (9,10). Clinical conditions that may prompt sterile inflammatory reactions may result in false-positive studies including heterotopic bone formation, myositis ossificans, and fulminant rheumatoid arthritis or active neuropathic disease.

NUCLEAR MEDICINE IMAGING IN NEUROPATHIC JOINT DISEASE: THE CHARCOT FOOT

INTRODUCTION

The diagnosis of neuropathic joint disease is reliant on a combination of radiographic and clinical findings. The earliest reports of neuroarthropathy, also known as Charcot joint, consisted of isolated case reports and small group studies with little or no long-term follow-up. These reports were of little value in attempting to study the natural history of progression of this condition and consequently did not aid in prognostication. Over time, increasing awareness of the link between some systemic diseases and neuroarthropathy has paved the way for research and follow-up of patients demonstrating signs of neuropathic joint disease and dysfunction. When complex conditions ensue and a combination of lower extremity infection, ulceration, acute edema, and/or neuropathic joint disease and dysfunction. When complex conditions ensue and a combination of lower extremity infection, ulceration, acute edema, and/or neuropathic joint disease and dysfunction, especially in diabetic patients, there should be a high degree of suspicion for an impending Charcot foot.

One of the largest retrospective reviews of Charcot foot to date identified this condition as being associated with a host of systemic diseases with or without associated neuropathy. The epidemiologic data of 101 patients in that study describes patients within their fifth and sixth decades of life with longstanding insulin-dependent diabetes mellitus (>15 year duration) affecting men and women with essentially the same prevalence. Nearly one third of these patients suffered with triopathy—the combination of peripheral neuropathy, nephropathy, and retinopathy—a combination of pathologies that increase the incidence of occult trauma and impaired wound healing capacity. In this series of patients the tarsometatarsal joint, metatarsophalangeal joints, and ankle were affected in descending order of prevalence with >20% demonstrating bilateral disease (64). Typically, patients present because of structural deformity, whereas ulcerations and joint swelling are among the alternate presenting complaints. Bone prominences may exist in any anatomic plane; however, dorsal and plantar prominences with or without keratoses and rocker bottom foot types seem to be discussed most commonly in the literature. It is when these clinical scenarios are compounded by erythema, edema, and calor with or without deep pain that merits a more detailed examination, as they may well be complicated by infection. The presence of an open ulceration further complicates the clinical presentation. In obtaining a definitive diagnosis, the first priority is to eliminate that diagnosis associated with the highest degree of morbidity, while in the interim developing a treatment strategy to ensure that further arthropathy is prevented; that is, the part is immobilized.

In the face of active Charcot neuroarthropathy, an increased area of uptake in the 4-hour 111indium-oxine-WBC image will correlate with plain radiographic changes consistent with the acute Charcot flare (11). A subsequent “washout” phenomenon has been identified in these patients occurring between the 4- and 24-hour images that Schauwecker described (Fig. 3.10) (58). In the absence of infection, this abnormal uptake and subsequent washout phenomenon in active neuroarthropathy is presumably because of the development of hematopoietically active bone marrow that accompanies active Charcot arthropathy (15,48). This active marrow is thought to be the result of the fracture repair process that accompanies the destructive changes and remodeling typified in the Charcot joint. The conversion of fatty marrow to hematopoietically active marrow may be because of increased cytokine activity. When there is a concomitant area of infection, the washout phenomenon is not seen and an area of persistent increased intensity delineates the focus of white cell activity and infection in delayed imaging. This is a scintigraphic finding that helps differentiate active Charcot neuroarthropathy from osteomyelitis (58). The washout phenomenon can be subtle and is important to discern when planning for a bone biopsy procedure. Understanding this phenomenon is integral to an accurate interpretation of

![Figure 3.10](image_url)
leukocyte imaging in clinical conditions that involve Charcot neuroarthropathy and the risk of coincident infection. In the face of a "burned out" Charcot arthropathy affected joints are expected to have an increased area of intensity on $^{99m}$Tc-MDP bone scan but do not prompt leukocyte accumulation on the NMI exam (Figs. 3.7B,E and 3.11D,E). In the case of active Charcot neuroarthropathy and coincident infection, when it exists, will be clearly delineated by a positive leukocyte scan that will persist in serial imaging beyond 24 hours.

Combination imaging is helpful when a chronic nonhealing diabetic ulceration exists with or without concomitant neuropathic joint destruction. Here it is vital to identify whether an underlying infection is present, as a wound will not heal over infected soft tissue or bone. In these cases, it is most important

**Figure 3.11** A. Clinical of decubitus ulceration in a patient with a burned out Charcot foot. B. After 1 month of local wound care the decubitus appears deeper with outward signs of change suggesting infection; redness, warmth, and serosanguineous drainage. Successful treatment via hemi-calcaneotomy and short-term antibiotic therapy was supported by the department of infectious disease. C. One year after surgical resolution a small region of ulceration proves recalcitrant to aggressive offloading and local wound care. D. Tc-MDP third phase scan is most suggestive of postsurgical changes; however, it is not specific enough to rule out indolent infection in bone. The intensity noted here is considered mild and diffuse and is most suggestive of bone remodeling because of previous surgery. This does *not* support or refute the absence of infection. Notice the increased uptake of the right knee on the $^{99m}$Tc-MDP scan due to compensatory biomechanics in a rocker Charcot foot. E. The indium 4- and 24-hour scans fail to reveal localized uptake, suggestive of infection. The slightly increased activity in the left extremity in comparison with the right may reflect increased perfusion because of continued neuropathic activity in the limb.
to discriminate between an infected ulceration and an underlying osteomyelitis (Fig. 3.11A–E) (14,48,63,65).

When performing a radionuclide leukocyte scan in the face of ulceration, it is important to note extravasations of wound exudates into dressing materials containing isotope-labeled leukocytes. This distorts the area of interest, as the radioactivity present in wound drainage can amplify the degree of uptake seen in the region of interest. Avoidance of this technical error can be accomplished by having the patient perform a dressing change immediately prior to imaging. This minimizes the accumulation of radionuclide within dressing materials and avoids misinterpretation of the image data. The negative impact that a draining ulcer has on such imaging has been documented and previously reported in the literature (63). In the case of septic joint, serial NMI should be completed at approximately 2 weeks after the completion of antibiotic therapy, as this will confirm the absence of residual infectious activity. A bone scan performed after treatment of a septic joint becomes negative as there is no residual bone remodeling or hyperemia as opposed to that seen after treatment for bone infection (Fig. 3.2A–D). After treatment for osteomyelitis, bone remodeling and hyperemia can be seen on a bone scan for >1 year in many cases. Therefore, a negative 99mTc-MDP scan after treatment of a septic joint rules out the presence of an indolent inflammatory process, providing a sound basis for prognostication of the patient’s outcome.

Technical errors in performing radionuclide leukocyte labeling procedures may occur at every step of the process; therefore, it is important to understand the methods and statistical strategies involved in such work. In general, a radiolabeled leukocyte compound is considered viable for use when a 90% tag or greater is confirmed by the nuclear pharmacy. This is then logged on the patient’s prescription for the isotope. An insufficient label is apt to provide a poor quality exam, as the target-to-background ratio is severely hindered by an increased background radiation or low percentage label. This increase in background radiation is because of the large amount of unbound isotope circulating free within the vascular compartment. When a negative study is encountered, it is prudent to check the prescription log to ensure that the test was performed properly, that is, >90% labeling efficiency of isotopes and leukocytes for imaging. Another source of error in imaging is infiltration of the isotope at the site of injection (Fig. 3.12). Because extremely small concentrations of isotope are used, even a partial infiltration of an injected dose will compromise the data set, as such imaging of the injection site can be performed to rule out false-negative studies.

**DIFFERENTIATION OF INFECTED VERSUS NONINFECTED NEUROPATHIC (CHARCOT) JOINT DESTRUCTION**

Newman discussed six different noninfective bone and joint conditions that occur in the neuropathic foot of diabetic patients (66). Among the 67 patients reviewed in that study 6 conditions were identified listed here in a descending order of incidence: osteoarthropathy, bone loss, new bone formation, osteoporosis, spontaneous subluxations, and dislocations and pathologic fracture. Of these noninfective conditions, only pathologic fracture would be considered as a possible source of a false-positive on a radiolabeled leukocyte study. That is to say that most noninfectious conditions of the neuropathic foot in patients with diabetes should remain silent (without localized area of uptake) on NMI studies. The hallmark in treatment for these conditions is early identification and stabilization of the affected part; consequently, reliable imaging techniques become a staple in proactive therapies.

Important clinical challenges arise when faced with conditions involving actively progressive neuroarthropathy, the presence of open ulceration and clinical signs of infection in the extremity (calor, edema, erythema with or without pain). Negotiating this “Charcot triad” is perhaps the most daunting of clinical challenges. In the absence of ulceration, the differential diagnosis often includes deep vein thrombosis, cellulitis, gout, active neuroarthropathy, or deep space abscess. When ulceration is present, the suspicion for osteomyelitis or deep space abscess increases. Without frank evidence of abscess formation even MRI is unable to discern between the destruction of progressive neuroarthropathy and osteomyelitis. In some patients, there is history of previous ulceration, infection, surgery, or trauma that may confound the interpretation of some nuclear medicine imaging scan (Fig. 3.13A–C). This clinical scenario merits special attention and becomes a matter of limb salvage in populations that suffer from neuroarthropathy. With the incidence of diabetes at epidemic proportions across the country, the clinical combination of peripheral neuropathy and diabetes is on the rise, further underlining the importance of the Charcot foot in management of patients with diabetes.

Combination imaging with the benefit of 111In-leukocytes and 99mTc-MDP is often helpful in distinguishing between infection and other noninfectious etiologies. Using indium as an imaging agent, it is important to understand noninfectious reasons for its uptake to ensure an accurate interpretation of the imag-
ing set. Table 3.2 lists some of the more common noninfectious conditions that may produce an increased uptake of isotope in an indium scan. In light of the rate of white blood cell migration in the presence of an acute infection, it seems intuitive that any radiolabeled leukocyte agent would rapidly accumulate there. In the case of the diabetic with a foot infection, one must consider that the patient’s baseline hematology profile may include neutropenia, thereby reducing the potential to mount an intense leukocyte response. In fact, in many cases, the foot infection is longstanding and leukocyte margination in that event is predictably slower. This slower cellular response is a chronic process involving monocytes and mast cells rather than acute phase reactants. This is the primary reason that indium is preferred in cases of chronic infection as the use of any 99mTc compound (Tc-WBC, Tc-monoclonal antibody, or Tc-sulfur colloid) is limited by its short half-life (Table 3.1). Indium is available to be imaged

Figure 3.13  A. Patient with a burned out Charcot process in a clinically stable rocker bottom foot free of ulceration for 3 years. The patient presents after a 1-month history of increasing swelling, warmth, and tenderness in the right foot. Systemic signs of infection preclude imaging delays and surgical intervention is pursued emergently. B. This indium scan reveals the superficial nature of a localized abscess. Notice that multiple orthogonal views are required to illustrate the superficial location of this infection in the plantar midfoot. C. Surgical intervention for deep incision and drainage in the patient presenting with signs of foot abscess and septicemia. Necrotic and degenerative changes to the soft tissue structures of the sole are extensive and permeate two layers of the sole of the foot, seen here after irrigation. The aberrant morphology of the soft tissues and bone structures of the Charcot foot further complicate identification of local anatomic structures. Given the complex nature of the sole of the foot, this intraoperative photo illustrates why it is difficult to obtain infection imaging that can discriminate between infectious changes of soft tissue and/or bone. D. Limb salvage is achieved with surgical debridement, complete offloading and custom-molded ankle foot orthosis for long-term therapy. Just 1 month after surgery the entire sole is healed and ready for slow advancement to weight bearing in protective gear. Follow-up NMI was performed to confirm the absence of infection prior to releasing the patient for routine follow-up.
for a longer period of time given its protracted physical half-life (2.8 days). To further complicate the picture, from a clinical perspective, it is all too common for a patient with a Charcot joint to present months after the inciting event. Longstanding or burned out neuroarthropathy often yields deformity that is less flexible or even rigid. These cases are more prone to the development of a rocker bottom foot deformity with planter prominences at high risk for ulceration. Plain radiographs often exhibit profound fractures and dislocations in otherwise sclerotic bone. If neuroarthropathy, acute fracture, and post-traumatic osteoarthropathy can produce a false-positive in an indium-labeled-leukocyte study, what is the value of combination imaging in these complex cases? In 1990, Seabold suggested that this clinical quandary may not be reconcilable using the combination NMI technique or even MRI. Of the 14 cases retrospectively reviewed, two Charcot patients demonstrated true-positive indium leukocyte exams, confirming osteomyelitis. Interestingly, there was no evidence of accumulation in their contralateral limbs despite the presence of chronic Charcot joint destruction. This is an important finding as it confirms that a burned out Charcot joint, despite the presence of what looks like post-traumatic osteoarthrits, does not necessarily accumulate In-WBCs (7,11). This phenomenon is demonstrated in Figure 3.7B,E in which we see a patient who has had a fifth digit amputation and biopsy of the fifth metatarsal head in addition to a chronic, burned out Charcot joint. Despite the active soft tissue and bone inflammation resulting from post-surgical change, the In-WBC scan remains negative. In 1988 and most recently in 1997, Schauwecker published his findings based on his experience as a nuclear medicine radiologist. These articles discuss the use of combination imaging of 99mTc-MDP and 111In-WBC scanning in neuroarthropathy. These articles discuss findings in select cases as he describes leukocyte margination in active Charcot joint disease with a delayed washout. This phenomenon was seen in the 4-hour indium scan in which a generalized area of increased uptake was identified in the area of neuropathic destruction followed by a washout of that activity occurring by the 24-hour scan (58). This documented the leukocyte activity that takes place in the face of active, noninfectious neuroarthropathy. Consequently, the current procedure guidelines for NMI using the combination of In-WBC and 99mTc-MDP scanning suggest imaging at two intervals. Depending on the pathology to be studied, indium-WBC images should be obtained at 4 hours and again at 16 to 30 hours after injection (13). The washout phenomenon seen in the presence of a recent neuropathic fracture in an early stage of Charcot foot is demonstrated in Figure 3.10A,B. This is very different from what we see in the case of Charcot foot with an active infection and ulceration (Fig. 3.8A–D). There are two reasons that the indium-WBC imaging technique performs well in the foot. First, there are more bones in the foot than soft tissue. This means there is less background uptake of indium obscuring the region of interest, that is, the bone to soft tissue ratio is very high. Second, there is no active bone marrow in the appendicular skeleton; therefore, leukocytes do not normally accumulate there. That is to say the test has an increased sensitivity in the extremities as compared with the axial skeleton, which has active bone marrow (7). What is of particular value is being able to identify the zone of transition between an infection front and the benign inflammatory change that precedes an active infection as it migrates in tissue or bone. Nuclear medicine techniques take this challenge head-on and are able to identify the extent of inflammation that represents infection better than any other imaging technique available. This is particularly important when studying pathologic changes associated with a Charcot foot complicated by infection. The NMI scan can also be used as an anatomic guide for biopsy planning. Ultimately, the diagnosis of osteomyelitis should be confirmed by bone biopsy for adequate identification of the offending organism and determination of antibiotic sensitivity.

From a clinical perspective, combination imaging techniques using the technetium/indium protocols are routinely available; however, their use is often discouraged in favor of 99mTc-hexamethylene propylene amine oxime (HMPAO, Ceretec) imaging. This recommendation is often made blindly by technologists and radiologists for two reasons. First, because Tc-HMPAO imaging is a same-day imaging modality, it is favored technique, requiring only a single set of images at a fixed interval after injection depending on the facility’s preferred protocol. Second, imaging with a Technetium compound allows use of a general purpose collimator in contrast to Indium that requires a high energy collimator which requires extra time and effort on the part of the technologist to prepare for. Unfortunately, the Tc-HMPAO study has a much lower target-to-background ratio than indium, and as such the resolution suffers when using the technetium agent. In fact, in the small bones of the foot Tc-HMPAO scan can result in a false-negative purely because of this imaging characteristic. In some cases of acute infection, it is reasonable to choose this agent despite the lower resolution in favor of a more expeditious surgical intervention. Certainly, this is perhaps the most important decision when dealing with a diabetic foot infection. In some instances, if surgical intervention must be performed, obtain the MRI study as soon as possible (28,67–69). This must be done with the understanding that surgical intervention will always be considered a confounding factor in interpreting any ancillary imaging technique performed after the fact. This is an important mistake that is often made when it seems easier to take a look in surgery than to completely document the location and extent of the infectious process in advance. It is not unusual to see a clinical infection evident in the heel that later develops into a process that involves the intrinsic musculature of the foot or even the Achilles tendon (Fig. 3.14A–E).

The differential diagnosis of infection in association with a complicated past medical history is an important clinical challenge commonly encountered by physicians and surgeons specializing in the lower extremity. Often, recurrent infection presents after treatment for cellulitis with ulceration, amputa-
tion, or other bone and joint disease in the face of chronic illness. Plain radiography often shows soft tissue edema without significant evidence of infection until 50% to 75% of the bone mineral density is lost (70). The earliest definitive signs of infection take approximately 7 to 10 days to manifest (71). Although the concept of a stage 0 neuroarthropathy has been described as the harbinger for fractures and dislocations, only increased soft tissue density on x-ray has been correlated with the clinical manifestation of the process (72). The time for such changes to develop on plain radiographs remains undetermined. Commonly, leukocyte counts, erythrocyte sedimentation rate, and blood cultures are of little value in these cases (71). As stated, the current literature clearly illustrates that NMI is clinically useful in identifying and differentiating infections of soft tissue and bone. Through clinical practice, it has been found that NMI is helpful in delineating or differentiat-

Figure 3.14  
A. Clinical photo of posterior right heel decubitus with stable appearing eschar while under the management of a wound care center where ancillary imaging was refused in favor of local care. B. Clinical appearance after surgical débridement and 1 month of negative pressure therapy. C. ⁹⁹ᵐTc-MDP blood pool images reveal increased uptake in the plantar heel consistent with the ulceration present. Notice the outline of the vascular tree of the calf as anticipated in the second phase venous blood pool study. D. ⁹⁹ᵐTc-MDP third phase scan identifies a large well-localized centroid of uptake within the entire calcaneal body. E. Indium-labeled-leukocyte study reveals accumulation within the calcaneus as well as up the length of the Achilles tendon extending beyond the myotendinous junction. Mild erythema within the distal one third of the leg was previously suspected to be cellulitis associated with calcaneal osteomyelitis. This underlines the value of combination NMI techniques, as the Tc-MDP study alone failed to elucidate the gravity of this condition. Ultimately, limb salvage failed despite the team approach (e.g., internal medicine, infectious disease, vascular surgery, and nephrology) and ultimately an above-knee amputation was required.
ing conditions that mimic bone infection, such as septic arthritis, gout, rheumatoid arthritis, certain bone tumors, psoriatic arthritis, and Charcot neuroarthropathy.

NMI has many clinical applications as in the case of vascular disease complicated by the presence of infection. A routine bone scan may reveal only trace or mild hyperemia in this scenario given a reduced perfusion. This is a finding that may be misinterpreted and more importantly undertreated if in fact bone is infected. Another scenario exists when a positive NMI study represents a soft tissue infection (Fig. 3.9A–C) without co-incident bone infection. Here, a negative third phase 99mTc-MDP bone scan can be associated with a positive 111In-oxine-WBC scan, a manifestation of infection in a calcaneal decubitus in the face of severe peripheral vascular disease. In this case, the indium study isolates soft tissue infection and by combination imaging rules out osteomyelitis. Without the benefit of the structural information provided by the 99mTc-MDP bone scan, the positivity of the indium study could easily be misinterpreted as osteomyelitis. Combination imaging in multiple orthogonal planes mapped out the region for bone biopsy and was negative for infection from both a microbiological and histologic standpoint.

The interpretation of NMI studies is chiefly the responsibility of the radiologist; however, the ordering physician should have a good working knowledge of the goals of the study and how images are to be interpreted and clinically correlated. This should include a thorough understanding of conditions that are associated with an increased leukocyte accumulation and those that are not. With this understanding, the clinician can better predict when a false-negative or -positive result is possible. This allows better prognostication for the patient and an improved clinical approach to the pathology.

Systemic diseases often manifest with pathology in the lower extremity. Complicated medical conditions such as diabetes, chronic renal failure, coronary artery disease, peripheral vascular disease, and others are compounded by the threat of infection and are among the most challenging clinical scenarios. When these perplexing cases present, there should be a meeting of minds among the surgical specialist, infectious disease specialists, radiologists, and general practitioners as to an appropriate method for obtaining a definitive diagnosis. In general, we safeguard patients by focusing on ruling out the diagnosis that carries with it the highest risk of morbidity. The consensus is that infection of soft tissue and bone carries a high degree of morbidity and merits prompt identification and treatment. In the event that infection is ruled out, the differential diagnosis can be modified and the differential list prioritized based on the clinical severity. When NMI studies are negative and serologic values remain at or return to normal, an eventful clinical recovery is anticipated.

An obvious weakness in protocols requiring radiotracer labeling of WBCs presents in the face of patients who suffer from generalized neutropenia. Neutropenia directly impacts the total number of cells available for labeling and as such this condition diminishes the overall quality of the exam in a proportion that is consistent with the degree of neutropenia. This physiologic manifestation occurs in various disease states, including diabetes. Antibiotic therapy can be initiated immediately before imaging in these cases without affecting leukocyte labeling or interfering with imaging leukocyte accumulation. However, long-term antibiotic management prior to imaging may compromise the quality and interpretation of the NMI imaging set.

**IN VIVO RADIONUCLIDE LABELING INFECTION IMAGING AGENTS**

Research in nuclear medicine technology has focused on arriving at an ideal infection imaging agent for decades. The ideal infection imaging agent would use a low-energy isotope with a short half-life that would create an in vivo label to leukocytes, allowing for prompt imaging of infection. This would minimize radiation exposure to the patient, facilitate expeditious imaging decreasing technologist time and increase the number of patients that could be imaged in a given day. In short, the ideal agent would provide safe, fast, accurate, and inexpensive imaging of infection. To date this imaging agent does not exist. Developing such an agent is a difficult challenge. Monoclonal antibody imaging studies in animals has been going on for many years attempting to develop a technique that will be readily functional for human study. Although there are a number of in vivo radiolabeled compounds used for infection, imaging most of these techniques remain available for research purposes only (28,35,41,42,67–89,73–77). One such agent, a murine anti-CD 15 IgM monoclonal antibody, was labeled to 99mTc-nitro for infection imaging with successful phase II clinical trials reported in 1998. The CD 15 antigen is expressed at the surface of polymorphonuclear leukocytes (PMNs), monocytes, and eosinophils and so predictably aggregates in regions of infection. The agent was FDA approved in 2004 for use in imaging acute and chronic appendicitis, ischemic bowel, postsurgical infection, and nosocomial infection. The target-to-background ratio using this technique is similar to that seen in other infection imaging studies such as indium (Fig. 3.15A–C). The sensitivity and specificity in extremity imaging are similar between antibody imaging 91% and 69% and indium leukocyte imaging 91% and 62%. When interpreted with bone scans, the sensitivity reached 100% for both antibody and indium, whereas specificity was increased to 85% and 77%, respectively (73). Personal experience using this agent in a number of infection cases was very promising, and the technique has proved beneficial for complex cases such as the development of a Charcot ankle 6 months after treatment for a complex ankle fracture. It was noted that the neuropathic destruction fails to prompt accumulation of monoclonal antibodies known to aggregate in regions of infection. This documents the absence of infection in the ankle and confirms the presence of antibody uptake in a region of prior osteomyelitis resection (Fig. 3.16A–E). Chronic nonhealing ulceration in the face of longstanding diabetes and peripheral vascular disease remains suspicious for osteomyelitis of the posterior tuber until proved otherwise (Fig. 3.17A–C). Charcot ankle and chronic neuropathic fracture dislocation of the entire ankle and rear foot should have documentation that there is no evidence of deep bone infection prior to surgical reconstruction (Fig. 3.18A–H). Of note is that this form of NMI is very useful even in the small bones of the distal foot while this cannot be said of Tc-sulfur colloid. This is easily illustrated in the case of chronic soft tissue infection of a spider bite in the great toe. Ancillary imaging with the benefit of the NMI monoclonal antibody technique elucidated the presence of osteomyelitis in the hallux interphalangeal joint of the great toe (Fig. 3.19A–D). Similarly, chronic sesamoiditis complicated by longstanding ulceration
and infection in the face of peripheral vascular disease and diabetes mellitus can be sorted out. The benefit of NMI provides distinct delineation of radiotracer uptake to confirm a well localized focus of infection despite prolonged treatment with various oral antibiotic agents and remote surgical intervention. This condition proved amenable to surgical débridement and antibiotic therapy without further bone loss (Fig. 3.20A–C). Unfortunately, because of severe adverse reactions in patients with severe underlying cardiopulmonary compromise, sales and distribution of the agent were voluntarily suspended by the end of 2005. As of the time of this printing, it is uncertain whether this agent will return for clinical applications.

**PET/CT IMAGING: TECHNICAL CONSIDERATIONS IN NUCLEAR MEDICINE IMAGING OF INFECTION**

Nuclear medicine imaging illuminates the distribution of radionuclide compounds by using regional, whole body, single emission computed tomography (SPECT), or positron emission tomography (PET). These techniques are all considered noninvasive, are available in area hospitals or outpatient centers, and are performed on an outpatient basis. These studies help in the diagnosis of a wide variety of pathologies beyond osteomyelitis and musculoskeletal pathology. Fungal infection, portal hypertension, appendicitis, Crohn disease, inflammatory bowel disease, and tumor imaging are but a few of the clinical conditions that NMI has been useful for over the past few decades (40–47,66–69).

Advances in nuclear medicine technology include the widespread use of PET (72). Positron emission tomography uses a fluorine compound (F-18) labeled to the chemical fluoro-2-deoxy-d-glucose (FDG) as the basis for imaging. The energy of emission available for imaging is a 511 kV photon that is produced by the annihilation of an electron by a positron; hence, the term positron emission tomography. Original research and development of this technique focused on cerebral and cardiovascular imaging because of its ability to provide perfusion imaging. Although MRI and computed tomography (CT) are excellent tools for studying anatomic details, the PET scan is a physiologic imaging technique that reveals metabolic information about

(text continues on page 34)
Figure 3.16  A. Relaxed calcaneal stance position reveals the right foot is dislocated beneath the ankle mortise.  B. Clinical frontal view reveals the residual swelling in this ankle dislocation despite aggressive offloading and Jones compression dressing. The second digit remains retracted 1 year after partial ray resection (performed elsewhere) for a presumptive diagnosis of osteomyelitis.  C. Plain radiograph ankle mortise 6 months after treatment elsewhere for a complex ankle fracture in a neuropathic diabetic patient.  D. Plain radiograph, dorsal plantar right foot documents the prior ray resection and the residual “sucked candy” appearance of the residual second metatarsal stump. The third metatarsal head deviation and phalangeal base degeneration noted here are consistent with the clinical presentation of chronic swelling within that region.  E. A monoclonal antibody study fails to reveal evidence of uptake in the ankle dislocation. Isolated uptake in the region of the second digit and third metatarsophalangeal joint is suggestive of an indolent inflammatory process.  F. A lateral radiograph 1 year postreconstructive ankle surgery. Follow-up clinical and radiographic correlation failed to reveal evidence of progressive infection in the foot or ankle after 1 year.
Figure 3.17  A. Clinical appearance of a longstanding ulceration in a diabetic patient with a Charcot foot and renal disease. B. $^{99m}$Tc-monoclonal antibody imaging reveals a very discrete small localization of intensity consistent with soft tissue infection. This study in addition to serologic testing confirmed the absence of bone infection and allowed purely medical management of this condition. C. Clinical appearance after 4 months of offloading and local wound care.

Figure 3.18  A. Clinical photo of left Charcot ankle dislocation demonstrating the chronic swelling and increased temperature gradient that is consistent with the Charcot process. B. The Charcot ankle developed subsequent to a poorly treated ankle fracture. This patient continued to walk on the limb despite the foot and ankle dislocation and extreme limb length discrepancy. (continued)
Figure 3.18 (Continued) C–D. Ankle views; anterior-posterior and lateral views revealing the dislocation and profound destruction of the Charcot process. Infection imaging is performed after detailed MRI examination fails to discriminate between the destruction of Charcot joint and osteomyelitis. E. $^{99m}$Tc-MDP SPECT study suggests hyperemia within the bones of the ankle mortise and subtalar joint. Notice that the large ankle joint effusion makes it easier to distinguish the individual bones of the ankle mortise. F. $^{99m}$Tc-monoclonal antibody image reveals diffuse localization within the ankle mortise. This diffuse uptake is felt to represent the florid synovial response to dead and degenerative bone fragments in and about the ankle. Subsequent bone biopsy confirms the absence of infection in the tibial plafond and the calcaneus. Both histology and microbiology were in agreement. G. Clinical condition 1.5 years after surgery. Surgical stabilization was pursued only after sufficient biopsy and serologic testing confirmed the absence of infection. Notice indentation markings along the right limb, indicative of prophylactic bracing. H. Lateral radiograph demonstrating stable consolidated tibiocalcaneal fusion, without evidence of infection 1 year postoperatively.
Chapter 3 Utility of Nuclear Medicine Imaging in the Diabetic Foot

Figure 3.19 This series documents a diabetic patient who sustained a spider bite that was treated with many weeks of oral antibiotic therapy. Because of continued erythema, swelling, and pain infection imaging was pursued. A. Clinical evaluation reveals a tender, warm, swollen, and erythematous great toe. B. X-ray dorsal-plantar hallux reveals a fracture of the distal aspect of the proximal phalanx of the great toe. Arthritic changes in these regions can confound plain film interpretation and these subtle findings were overlooked upon initial presentation in the emergency room. C. $^{99m}$Tc-MDP third phase suggests hyperemia within the hallux extending into the first metatarsal head. D. $^{99m}$Tc-monoclonal antibody imaging performed at 60 minutes and 3 hours reveals the cubic morphology of the proximal phalanx consistent with osteomyelitis. Notice that the region of intensity found in this image set is more localized than that seen in the $^{99m}$Tc-MDP scan. Partial débridement of the hallux proved curative, and indium leukocyte imaging confirmed absence of infection at long-term follow-up.
Figure 3.20  A. This series documents a diabetic suffering from the clinical triad of neuropathy, ulceration, and clinical evidence of infection. The challenge is discerning the extent of infection if it exists and whether this affects the degenerative joints affected by the Charcot process. A. Clinical appearance after long-term treatment for sesamoiditis in a neuropathic patient treated elsewhere. B. Radiograph illustrating previous surgical resection of the phalangeal base and neuropathic destruction at the level of the second metatarsal phalangeal joint (MTPJ). C. ⁹⁹mTc-monoclonal antibody imaging isolates accumulation immediately beneath the first metatarsal head. There is no evidence of uptake in the region of the neuropathic destruction of the second MTPJ or elsewhere in this Charcot foot. D. Clinical photo after conservative surgical débridement that included an isolated sesamoid resection, avoiding further more significant bone loss. Follow-up indium leukocyte imaging failed to identify evidence of indolent infection at the time of this clinical photo 5 months after surgery.
are an exception to this rule, as they do not require insulin for use of regular insulin to 2 hours prior to the exam without ingons, potentially creating a false-positive exam. From a practical standpoint, it is important to grade a tumor’s SUV before beginning therapy to ensure accurate interpretation of subsequent PET-CT images after therapy has been implemented.

The question remains as to whether there is a definite utility of PET-CT imaging in the diabetic foot complicated by infection, neuropathic disease, or both. Given the fundamental behavior of the radioisotope compound 18F-FDG, there may well be a place for identifying areas of increased metabolic activity of active neuropathic disease, active osteomyelitis, and other musculoskeletal indications. To date the literature is scant for PET-CT imaging in the extremities, although it is encouraged in the hunt for metastatic disease as well as follow-up of both benign and malignant neoplasms (84-87). To date, the literature using PET-CT imaging in the diabetic foot in particular is anemic and so requires much more study. Keider reported on 14 diabetic patients suspected of having foot infection (involving 18 sites). Keider used this technique and concluded that PET-CT can clarify soft tissue infection from osteomyelitis in the diabetic foot. Findings of osteomyelitis were based on histopathology and microbiology reports from biopsy specimens. Although increased uptake was seen on PET-CT imaging in both soft tissue infection and bone, this imaging set allowed exclusion of four cases that showed no abnormality, five patients with soft tissue infections only, and another site of mild intensity in osteoarthropathy associated with diabetes. Ultimately, PET-CT identified osteomyelitis in four patients localizing eight sites of infection that were confirmed by microbiology (88). Given the research that has been completed in nuclear medicine infection imaging it is intuitive that the nature of an infection exhibited in NMI scanning is more closely related to the cellular activity of the affected tissue than whether the condition is acute or chronic in nature. Therefore, it stands to reason that PET-CT should be effective in

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identifying both acute and chronic conditions of infection while elucidating important structural information. Mochizuki et al and Paik et al suggested that the cellular uptake of FDG in the presence of inflammation and infection is ultimately because of the activity of various cytokines and growth factors that increase the number of glucose transporters and their affinity to FDG (89,90). As of this date, PET-CT imaging has moved to the forefront in three-dimensional imaging; however, to date it only has FDA approval for indications within the realm of oncology (72,78–91). Although it is understood that physicians have used this technique for off-label indications such as infection imaging, the technique remains a modality to which most clinicians have only limited access.

CONCLUSION

Nuclear medicine leukocyte imaging (NMLI) for the diagnosis of infection has been discussed and used by the medical community for decades. Although these studies have withstood the test of time, this imaging technique has a specificity that is less than desirable. The use of combination imaging, 111In and 99mTc-technetium leukocyte images in combination with a 99mTc-MDP bone scan, can afford greater anatomic information and elucidate discrete areas of infection, thereby increasing the specificity of NMI.

The use of nuclear medicine imaging for infection and combination imaging techniques (111In-WBC and 99mTc-WBC/99mTc-MDP) has tremendous utility for the surgical physician, as it not only identifies the presence of disease but also provides a mechanism for monitoring therapy and ultimately confirming when the disease has been successfully eradicated. This has been demonstrated and discussed in the current literature extensively (2–38,48,49,52–63,65,92–94). Specifically, the leukocyte imaging technique can be repeated weeks or months after treatment, confirming the eradication of infection. Most importantly, in cases of immunocompromise and history of exacerbations and remissions of infection these studies can rule out the presence of indolent infection residual of prior therapy. This allows for better prognostication in patient management and prevents insufficient treatment of infection and recurrence. In addition, serial imaging techniques can be employed in a manner that can help minimize or reduce the duration of antibiotic therapy. This reduces morbidity secondary to the renal toxicity that many antibiotics impose.

Further work in nuclear medicine technology should include improving strategies to delineate regions of interest within the small bones of the foot. This may be possible using combination NMI with tomography and digital subtraction protocols for isolation of individual bones within the tarsus and lesser tarsal bones.

Perhaps the greatest strength in nuclear medicine imaging for the lower extremity is its ability to identify and isolate infectious processes, differentiating them from other more benign clinical conditions.

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Chapter 3 Utility of Nuclear Medicine Imaging in the Diabetic Foot


INTRODUCTION

Historically, diabetic surgery was largely reactionary, operating only in the presence of acute infection or when in need of amputation. Several concerns, founded or unfounded, such as diabetic patients do not heal, or are more prone to infection or amputation, or are more likely to develop medical complications following surgery perpetuated this philosophy.

As our understanding of diabetic foot disease has improved, the medical community has realized that recurrent ulcerations treated with protracted conservative care instead of definitive surgery are actually at higher risk for infections, hospitalizations, patient deconditioning, and amputations. Physicians are beginning to recognize the importance of elective diabetic foot surgery in helping patients to stay active and ulcer free (1–5).

CLASSIFICATION OF DIABETIC FOOT SURGERY

The ability to define what constitutes elective surgery in the diabetic foot has been elusive. Corey subdivided elective procedures into prophylactic, reconstructive, and traumatic (6). Later, Armstrong and Frykberg classified procedures as being ablative, curative, or prophylactic/reconstructive (Table 4.1) (7).

More recently, Armstrong et al developed a classification system that was validated in 2006 and is based on the presence or absence of three characteristics: (a) sensory neuropathy, (b) open wound, and (c) acute or limb-threatening infection. According to this system, vascular status must be adequate for healing prior to surgery unless it is considered emergent, otherwise alternative measures should be used in the interim (8).

It is divided into four classes:

Class I (Elective). Procedures for painful deformities in diabetic patients without neuropathy or open wounds

Class II (Prophylactic). Procedures for prevention of ulceration in diabetic patients with neuropathy but no open wounds

Class III (Curative). Procedures to help heal open ulcerations in neuropathic diabetic patients

Class IV (Emergent). Procedures performed in the setting of acute infection

For the purpose of this chapter, procedures are divided into anatomic subunits and focus mainly on classes II and III. These include forefoot, midfoot, and rearfoot procedures.

PATHOPHYSIOLOGY OF THE NEUROPATHIC DIABETIC FOOT

Neuropathy in the diabetic foot manifests itself in several ways including sensory, motor, and autonomic neuropathy. These three components interact in a way that predisposes the diabetic foot to ulcerations.

Sensory neuropathy is the most significant predisposing factor of the three types seen in the diabetic foot. Loss of protective threshold makes patients unaware of increased plantar foot pressures. The inability to perceive pain allows thickened skin or calluses to ulcerate and irritations from shoes or embedded foreign bodies to go completely unnoticed.

Motor neuropathy causes structural and dynamic foot changes, the most common is intrinsic muscle atrophy. When lumbrical and interossei muscle weakening occurs, their digital stabilizing capabilities are lost. Extrinsic muscles gain mechanical advantage over the intrinsics, resulting in digital contractures. These contractures exert retrograde pressures onto the metatarsal heads, thus creating prominent metatarsal heads with concomitant increased plantar pressures (5,9).

Finally, autonomic neuropathy causes dysregulation of skin temperature and the loss of sweat production. Diabetic feet often become dry and begin to crack and fissure (9).

GOALS OF ELECTIVE SURGERY

The primary goals of elective foot surgery in the neuropathic diabetic patient are to prevent foot ulceration, infection, and amputation by creating one or a combination of the following:

1. Stability
2. Realignment
3. Plantigrade foot amenable to bracing or accommodation
4. Reduction of pressure points or "surgical offloading"
Clinical history will also affect the decision and outcome. Morbidities, previous surgeries, medications, mobility, and so-risk is also very important. Consideration of the patient’s co-another specialist may be necessary prior to surgical intervention.

Approach is vital for success. Further evaluation by the patient’s pri-lactic, or reconstructive-type surgeries, a multidisciplinary ap-medical status and pathology are clearly very important factors-timings of the intervention is patient specific and the overall ASSESSMENT AND SURGICAL TIMING

Conservative measures such as débridements, off-loading, and appropriate wound care are attempted first. The percentage of wound healing achieved over time can serve as a general guide to help physicians decide when an alternative approach is necessary. If there has been less than 50% reduction in the size of an ulcer after 4 weeks of standard care, more aggressive therapies, including surgical intervention, should be entertained (10).

When considering elective or prophylactic surgery, every patient should be evaluated as if he or she is completely new. Assessment of the entire patient, including current medical status and social environment, must be fully understood and taken into consideration. Finally, reevaluation of the lower ex-tremity must confirm the absence of infection and ischemia.

This approach does not apply to every patient and treatment decision making must be adaptive, attentive, and flexible. Deformities that are unstable or severely maligned may warrant more aggressive measures on initial presentation.

Medical Status: History and Physical Exam

Timing of the intervention is patient specific and the overall medical status and pathology are clearly very important factors when considering surgery. When dealing with elective, prophylactic, or reconstructive-type surgeries, a multidisciplinary approach is vital for success. Further evaluation by the patient’s prim-ary care physician, cardiologist, nephrologist, nutritionist, or another specialist may be necessary prior to surgical intervention.

Reassessment of the original etiology of the ulcer or area at risk is also very important. Consideration of the patient’s co-morbidities, previous surgeries, medications, mobility, and so-social history will also affect the decision and outcome.

Infection Control

Prior to elective procedures, acute infection should be controlled. However, a chronic wound without evidence of active infection may be present in the setting of an elective procedure; especially if the procedure will eliminate or aid in closure of the wound.

Vascular Assessment

Evaluation of the lower limb’s vascular status must also be care-fully and thoroughly executed. Risk factors and history may give clues to vascular insufficiency. The absence of a palpable pedal pulse is not normal and warrants further investigation. Noninvasive vascular studies are often a good start and may include ankle-brachial indices, Doppler waveforms, pulse volume recordings, segmental pressures, transcutaneous oxygen tension, or treadmill exercise testing. Relying completely on ankle-brachial indices is not recommended, as they may be falsely elevated because of noncompressible vessels. Segmental pressures can be obtained as distal as the digits if surgery involves the toes.

If there are any concerns with the testing results, patients may require angiograms and vascular consultation. It should also be noted that patients with long-term Charcot deformities may not necessarily have adequate perfusion. For the same rea-sons that patients develop Charcot, they can just as easily de-volve arterial disease over time. Surgery should be postponed in patients with questionable or poor perfusion until they are adequately revascularized.

ANESTHESIA CONSIDERATIONS

Confer with the patient’s primary care provider and anesthesiologist in advance so that consensus can be reached about which anesthesia will provide the greatest level of pain control and comfort while minimizing the risk of serious complica-tions. The presence of profound sensory neuropathy is actually of some benefit here. It allows monitored anesthesia care in tandem with either a local or regional block feasible for all but the most complex cases. When more extensive or longer proce-dures are required, either spinal or general anesthesia may be more appropriate.

FOREFOOT

LESSER DIGITS

Several theories have been advanced about the cause of diabetic digital deformity. Two such theories include hyperglycosylation of collagen, resulting in stiffening of tendons and ligaments, as well as motor neuropathy leading to intrinsic musculature wast- ing (11). The end result of either pathway is digital deformities such as hammertoes, mallet toes, and claw toes.

Clinical Assessment and Surgical Indications

Digital deformities in the presence of sensory neuropathy can lead to ulceration that may rapidly extend to the underlying phalanges. When conservative management fails, simple proce-dures can be very effective at reducing the risk of future ulcera-tion or infection.

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TABLE 4.1

Classification of Diabetic Foot Surgery

<table>
<thead>
<tr>
<th>Class</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ablative</td>
<td>Amputations, débridements, incision, and drainage</td>
</tr>
<tr>
<td>Curative</td>
<td>Partial or complete removal of a bone such as a metatarsal head, sesamoid, accessory bone, exostosis, or calcaneotomy</td>
</tr>
<tr>
<td>Prophylactic/reconstructive</td>
<td>Realignment osteotomies or tendon balancing procedures, arthrodeses, and Charcot reconstructions</td>
</tr>
</tbody>
</table>

This often requires correcting the underlying structural bony deformities and/or tendon imbalances, which leads to skin breakdown. This eliminates increased areas of pressure and thereby reduces callus formation and subsequent diabetic foot ulcer development. If open ulcerations are already present, surgery may be necessary to excise wounds and correct the underlying problem. Elective diabetic foot surgery may also be used in the setting of previous amputations or Charcot neuroarthropathy where the residual deformities and imbalances have created high-risk areas (8).
Location of the ulceration may vary by the deformity type. They can occur at the distal tip, at the apex of a flexed joint dorsally, or on the sides of adjacent toes (Fig. 4.1). An essential characteristic in choosing the appropriate procedure is the degree of rigidity, as determined by the Kelikian push-up test. Other factors also play a role in the surgical decision-making process, including the location of the preulcer or ulcer, etiology, biomechanics, and degree of deformity.

Special care should be taken to preserve the second digit whenever possible. Absence of this digit frequently contributes to the formation or progression of a hallux abducto valgus (HAV) deformity, which may then ulcerate. This elevated risk lowers the threshold for corrective procedures of the second digit relative to the other toes.

**Surgical Options**

Flexible or reducible deformities tend to be supported by soft tissue contractures. These may be corrected by a number of procedures, including but not limited to tenotomies, capsulectomies, or tendon transfers and lengthenings. Distal digital tuft ulcers frequently respond well to simple flexor tenotomies via stab incisions and may be performed in the clinical setting.

Rigid deformities are indicative of severe soft tissue contractures as well as joint adaptation(s). These are best managed with joint destructive procedures such as standard arthroplasty or arthrodesis at the site of maximal deformity.

**Surgical Pearls**

If there are open ulcers or calluses present at the time of the procedure, they can either be left to heal by secondary intention or excised. If the ulcer or callus is located over the dorsal aspect of the proximal interphalangeal joint (PIP), it can often be easily excised by incorporating this into the incision planning. Converging semielliptical incisions are very effective in this situation. Distal tuft ulcers may also be excised and primarily closed via a separate procedure or left to heal by secondary intention, as the deforming forces have now alleviated pressure from this area.

**Postoperative Management**

Weight bearing in a postoperative shoe is generally allowed following digital surgery. The postoperative shoe prevents bending forces from exerting flexion of the digits. Cork or other padding may be built into the surgical shoe to allow the toes to float freely in space, but is generally not necessary.

Stabilization of digits may be maintained via Kirschner wires (K-wires) or dressings throughout the postoperative period. K-wires are often employed to help maintain correction postoperatively, but are deferred if there are open digital ulcers at the time of surgery. If used, K-wires typically remain in place for at least 3 weeks after surgery.

Betadine splints are frequently used in lieu of K-wires if open ulcerations are present. They serve two important roles:

1. Betadine splints are effective for preventing infection in the setting of open ulcerations.
2. When dried, the Betadine forms a stabilizing digital splint.

Following removal of K-wires or Betadine splints, digits can be held into place with taping techniques. Typically, tape is used to apply a planterflexory force on the proximal phalanx and a dorsiflexory force on the middle and distal phalanges. This stirrup technique avoids circumferential placement and is applied for a total of 6 weeks postoperatively.

**HALLUX AND FIRST METATARSOPHALANGEAL JOINT**

Dysfunction, faulty biomechanics, or absence of the hallux may predispose the patient to an altered gait pattern and pressure distribution. Most commonly, pronation increases during midstance, and propulsion creates increased forces and pressures through the hallux. A number of structural deformities, such as pes plano valgus, hallux rigidus, HAV, hallux malleus, pes cavus, and rigid plantarflexed first ray increase the risk of hallux and first metatarsophalangeal joint (MPJ) ulceration (Fig. 4.2).
Preservation of the first ray is critical, and it is imperative to prevent ulceration, subsequent infection, and amputation of this site.

**Clinical Assessment**

Ulceration of the hallux is most frequently seen at the plantar-medial aspect because it is the widest part of the soft tissue envelope (Fig. 4.3A). It is further subjected to increased friction, especially in the presence of HAV, hallux limitus, or pes planus. Other sites such as the medial and plantar first MPJ are prone to break down as well. Hallux malleus deformities can cause calluses or ulcerations around the distal tuft, dorsal interphalangeal joint (IPJ), or plantar MPJ from retrograde pressures (Fig. 4.3B). If joint contracture is absent, plantar interphalangeal ulceration in this area may be from an exostosis or accessory bone (12).

**Surgical Options**

Surgical options for hallux or first MPJ problems may be thought of as either curative or prophylactic/reconstructive-type procedures. When partial or complete resection of bone is performed, it is classified as curative. However, when realignment is achieved, either through soft tissue or bony procedures, it is considered reconstructive. Some of the more common procedures are shown in Table 4.2.

Many procedures have been described for the correction of hallux and first MPJ deformities, so much so that they exceed the scope and goals of this chapter. Therefore, only a select few are addressed here. When encountering these conditions, we advise the use of your own clinical judgment as to the indications for procedure selection and fixation.

*Sesamoidectomy or Exostectomy*

**Indications.** Curative procedures such as simple exostec- tomies, condylectomies, or sesamoid planing or excision may be appropriate for bony prominences or increased focal pressure points. Enlarged plantar condyles or sesamoids may be apparent on radiographs and respond well to a simple condylectomy, planing, or resection procedure.

With regard to the first metatarsal head, one must consider the sesamoids. As the hallux dorsiflexes, the sesamoids move distally and become more prominent. This may result in ulceration plantar to these bones. Chronic wounds in this location may benefit from removal of the associated sesamoid(s). Owing to its size and greater association with musculoskeletal deformity, the tibial sesamoid is more commonly associated with ulceration than its lateral counterpart. The advantages of this procedure include the ability to place incisions on non–weight-bearing surfaces, no hardware is required and there is no osteotomy to heal.

**Surgical Technique.** Incision placement primarily depends on whether an ulceration is present and its size and depth. A direct plantar approach is typically only advocated in the setting of an open ulceration, and absent infection allows for ulcer excision and primary closure. If the fibular and/or tibial sesamoid(s) is to be removed, then incisions can be placed on non–weight-bearing surfaces medially.

Typically, a medial longitudinal incision is made along the plantar-medial junction of the first MPJ to remove one or both

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**Table 4.2 Surgical Options for First Ray Pathology**

<table>
<thead>
<tr>
<th>Curative</th>
<th>Prophylactic/Reconstructive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exostectomy</td>
<td>Phalangeal osteotomies</td>
</tr>
<tr>
<td>Accessory bone excision</td>
<td>First metatarsal osteotomies</td>
</tr>
<tr>
<td>Condylectomy</td>
<td>Hallux IPJ arthrodesis</td>
</tr>
<tr>
<td>Sesamoidectomy or</td>
<td>First MPJ arthrodesis</td>
</tr>
<tr>
<td>sesamoidal planing</td>
<td></td>
</tr>
<tr>
<td>Hallux interphalangeal</td>
<td>MPJ release</td>
</tr>
<tr>
<td>arthroplasty</td>
<td></td>
</tr>
<tr>
<td>First MPJ arthroplasty</td>
<td>Tendon procedures</td>
</tr>
<tr>
<td>(Keller arthroplasty)</td>
<td></td>
</tr>
<tr>
<td>Chellectomy</td>
<td>+ Tenotomies</td>
</tr>
<tr>
<td>Metatarsal head resection</td>
<td>+ Tendon transfers</td>
</tr>
</tbody>
</table>

*Including capsulotomies and capsulorrhaphies.

†Examples include Jones tenosuspension and Peroneal longus lengthenings for plantar first metatarsal head ulcers.
of the sesamoids. The nearby neurovascular elements are retracted plantarly followed by incision of the joint capsule at this location. Soft tissue attachments are carefully released about the plantar surface to facilitate resection. Smaller blades, such as a no. 64 blade, may aid in releasing sesamoidal attachments in more confined areas. Removal of both sesamoids can be facilitated through this medial approach, but care must be taken to preserve the flexor tendons.

**Postoperative Management.** Because this class of procedure does not require bone healing or fixation, the postoperative course is largely dictated by incision placement. Incisions placed in non-weight-bearing areas such as the plantar-medial or dorsal approaches permit immediate partial weight bearing in a postoperative shoe. However, complete non-weight bearing of at least 3 to 4 weeks is required for plantar incisions. Plantar ulcers left to heal via secondary intention can be off-weighted with padding or felted foam dressings.

**Complications and Outcomes.** Whether one or both sesamoids are removed, the biomechanics of the first ray can become altered. Removal of a tibial sesamoid may worsen HAV, whereas fibular sesamoidectomy may cause a hallux varus deformity. Complete removal of both sesamoids, especially in pes cavus deformities, may be considered, but an adjunctive hallux IP arthrodesis should be performed concomitantly to avoid subsequent hallux malleus deformity. This can cause transfer lesions plantar to the lesser metatarsals and first ray.

A 1991 article examined this procedure in 26 feet of 24 diabetic neuropathic patients, with 13 being tibial sesamoidectomies and 13 being total sesamoidectomies. With a mean follow-up of 33 months, a 16% recalculation rate was noted after a mean 22 months postoperatively. None of the study participants developed HAV; however, 8% did develop a hallux hammertoe (15).

**Hallux Interphalangeal Arthroplasty and Arthrodesis**

**Indications.** Plantar and dorsal hallux IP ulcerations in the presence of a normal first MPJ may benefit from an IP arthroplasty. Plantar interphalangeal ulcerations from enlarged condyles or accessory bones often do well with this procedure because the bony prominence can be removed through the arthroplasty site. More common causes of plantar ulceration include interphalangeal hyperextension from hallux limitus or pronation causing a plantar-medial pinch callus or ulceration (12).

Arthrodesis is an important option in elective hallux procedures when stability is in question. An unstable hallux can produce protuberances prone to ulceration or can crowd the second digit. Fusion of the interphalangeal joint is also indicated when osteotomies and osteotomies fail. Active infection or ulceration that extends to bone precludes hardware; therefore, this procedure is contraindicated in this situation (12).

**Surgical Technique.** The interphalangeal joint arthrodesis or arthroplasty is typically approached via either a dorsal longitudinal or a lazy-S incision to allow for joint preparation. The extensor hallucis longus is often tenotomized and repaired later to gain access to the joint. The head of the proximal phalanx is resected with the osteotomy perpendicular to the long axis of this bone. If an arthrodesis is being performed, curettage or an osteotomy parallel to the proximal phalanx cut is then made in the distal phalanx to remove the cartilage.

Stabilization following arthroplasty is discretionary and may require no more than splinting or K-wires. Arthrodesis fixation choices may include single or multiple K-wires or Steinmann pins oriented in parallel or crossing. A single cannulated cancellous lag screw to achieve compression is also an acceptable technique. If the presence of a distal hallux tip ulcer precludes these methods, a cerclage monofilament wire technique or cross K-wires exiting from the sides of the digit for fixation are recommended.

**Postoperative Management.** Arthroplasty of the hallux permits partial weight bearing in a postoperative shoe. However, non–weight bearing or offloading is recommended for arthrodesis until trabeculation across the site is seen. Generally, this takes 4 to 8 weeks for hallux IP arthrodesis.

**Complications and Outcomes.** After arthroplasty, hallux shortening is an expected postoperative finding, but is rarely problematic. Inadequate bone resection may allow ulcer recurrence. If hallux malleus develops as a complication from this procedure, transfer lesions or ulcerations may develop beneath the base of the proximal phalanx or first metatarsal head, necessitating fusion of this joint. A study by Rosenblum et al examined outcomes of this procedure in 39 patients, 91% of whom healed without re-ulceration with a mean follow-up of 23.6 months (14).

Complications associated with arthrodesis may include malunions, nonunions, infection, hardware complications, and wound-healing problems. Shives et al and Johnson compared the single-screw fixation with the crossed K-wire technique and found that the rate of pseudoarthrosis was 10% and 44%, respectively (15).

**First Metatarsophalangeal Joint Arthroplasty (Keller Arthroplasty)**

**Indications.** If structural deformity of the first MPJ exists, then it may be appropriate to perform a Keller-type procedure, which resects a portion of the proximal phalanx base. This is primarily indicated when structural deformities, such as HAV or hallux rigidus, cause ulcerations of the first ray. Other general indications of the Keller arthroplasty include advanced degenerative changes of the first MPJ, elderly patients with deformity, and an elongated hallux (12).

**Surgical Technique.** A linear or curvilinear incision medial to the extensor hallucis longus allows for excellent visualization of the first MPJ. A proximally based U-capsulotomy provides good joint exposure and can be interposed within the joint at the conclusion of the case. The proximal one third of the proximal phalanx is resected. Depending on the primary deformity, additional bone cuts, such as cheilectomies or medial eminence resections, are performed. It is important to tether the long flexor tendon to prevent a floating hallux or poor digital purchase. This can be achieved either by suture routed through drill holes, or attached to phalangeal anchors. Finally, the U-capsulotomy is wrapped over the first metatarsal head and sutured into the soft tissues laterally. The use of K-wires, Betadine splints, or taping techniques may be used to maintain the corrected position and are based on the surgeon’s preference, the presence of ulceration(s), and the use of soft tissue anchors.
Postoperative Management. Because this procedure does not require bone healing and the incision is placed on non-weight-bearing areas, partial weight bearing in a postoperative shoe is permitted. Elevation and compression help to minimize swelling. Sutures generally remain in place for 3 to 4 weeks. The patient may then transition to a tennis shoe based on symptoms and surgeon’s preference.

Complications and Outcomes. Like the hallux arthroplasty, shortening of the digit is expected and usually is asymptomatic. Other potential complications include reulceration, lesser metatarsalgia, poor hallux purchase, deformity recurrence, and flail toe. Many modifications of the Keller arthroplasty have been suggested to prevent these potential complications. One of the most important modifications is tethering or attaching the flexor tendon to the remaining proximal phalanx to improve toe purchase and digital stabilization.

Boulton et al compared this technique with conservative care in 41 diabetic neuropathic patients. The surgical group healed in 24.2 (±9.9) days and reulcerated in 4.8% of subjects. This compared well with the 67.1 (±17.1) days and 35% reulceration rate of the conservative care group (16).

FIRST METATARSAL HEAD RESECTION

Indications. The final option for an ulceration plantar or medial to the first metatarsal head is complete resection of this structure. This procedure is typically reserved for patients with existing ulcers that communicate with the joint or bone. Ulcer excision with metatarsal head resection are frequently performed concomitantly (12). This is appropriate in the absence of infection, if soft tissue envelope is amenable to a tension-free closure. If there are preulcerative lesions or superficial ulcerations, procedures that do not disrupt the metatarsal parabola are recommended over the metatarsal head resection.

Surgical Technique. The incisional approach depends on the presence and depth of ulceration. If the patient has no open ulceration or a superficial plantar ulcer, either a standard dorsal or medial incision centered over the first MPJ is performed. However, if there is a dorsal, medial, or deep plantar ulcer, an incision that encompasses the ulcer is preferred. This allows for direct exploration and debridement of soft tissue, excision of the ulcer, and primary closure. Because the metatarsal head is to be resected, there is less concern for contamination from the open wound.

A biplanar cut resects more bone plantarly and medially to avoid future prominences. K-wires, Steinman pins, Betadine splints, or taping techniques may be used based on the individual situation and surgeon’s preference.

Postoperative Management. Curative-type procedures, such as first metatarsal head resections, do not require healing of the bone, and hardware is not needed in most situations. Because of this, the postoperative course is primarily dependent on the location of the surgical incision. If plantar incisions were required, complete non-weight bearing for at least 3 to 4 weeks is needed to allow coaptation. However, more commonly, dorsal and medial incisions allow partial weight bearing in a postoperative shoe. Offweighting with padding or felted foam dressings is recommended if plantar ulcers were left to heal by secondary intention (Fig. 4.4).

Figure 4.4 If ulcers are left to heal by secondary intention following surgical intervention, plantar ulcers must be offweighted. A felted foam dressing or equivalent is recommended in this situation.

Complications and Outcomes. Potential complications after first metatarsal head resection include wound dehiscence, postoperative infection, flap toe, hallux malleus, and decreased propulsion. One of the more difficult complications to manage is transfer lesions. Patients often require accommodative padding and extra-depth shoes with close postoperative monitoring. These transfer lesions can develop quickly, and if managed incorrectly, can lead to infection and osteomyelitis. Future procedures may be necessary if padding cannot prevent these ulcerations from recurring.

OSTEOTOMIES OF THE PHALANX AND FIRST METATARSAL. Osteotomies of the proximal phalanx and first metatarsal should be considered for preulcerative regions of the first metatarsal head and for ulcerations that do not extend to the bone or joint. If persistent serous drainage is present, this may indicate synovial fluid from joint involvement and alternative procedures are recommended.

Indications, surgical technique, postoperative management, and potential complications and outcomes for these osteotomies do not differ from patients without diabetic neuropathy. The various types of osteotomies described are quite expansive and the osteotomy selected should address the underlying deformity.

FIRST METATARSOPHALANGEAL JOINT ARTHRODESIS

Indications. Arthrodesis of the first MPJ becomes necessary when severe malalignment or severe degenerative changes of the joint are present. This should also be considered in patients with severe and unstable structural deformities, such as HAV and hallux rigidus. These can be performed in the setting of ulceration, but infection must be eradicated and the ulceration should not extend into the joint or bone.

Surgical Technique. Various techniques have been described for fixation of this fusion, including screws, plates, and even external fixation; however, the critical element of this procedure...
is the hallux position relative to the metatarsal. To allow for proper motion of the interphalangeal joint, there should be no frontal varus or valgus plane rotation with the nail plate surface in normal orientation. The hallux should be abducted in the transverse plane 12 to 15 degrees, and a normal second toe can be used as a template for positioning, avoiding direct contact with this digit. Finally, there should be 10 to 20 degrees of dorsiflexion or 5 to 10 mm of hallux dorsiflexion above the weight-bearing surface.

Postoperative Management. Non-weight bearing is recommended for fusions until trabeculation across the site is seen. Generally, this takes 6 to 8 weeks for hallux and first MPJ arthrodeses.

Complications and Outcomes. Careful positioning of the hallux can reduce the likelihood of complications, such as interphalangeal joint arthrosis and plantar ulceration. Calise et al reported a nonunion rate of 2% to 23%. This included the nonunion rates from nine different studies and had a mean of 10% (17).

LESSER METATARSALS

As noted in the preceding section, diabetic neuropathy has been linked to intrinsic muscle wasting that leads to a cascade of biomechanical imbalances. Digital and MPJ stabilization is largely mediated by these muscles. Failure of this balance promotes digital deformity, such as hammertoes and claw toes. As the digits dorsiflex, the fat pad migrates distally. Simultaneously, the dorsiflexed digits exert a retrograde buckling force onto the metatarsal heads, further exaggerating plantar metatarsal head prominences (Fig. 4.5). Other causes of elevated plantar pressures include equinas, and plantarflexed or elongated metatarsals, as they bear more pressure for a longer period during the gait cycle (12). A biomechanical approach is vital to the treatment of these problems. Failure to appreciate this decreases the likelihood of success.

Clinical Assessment and Surgical Indication

Ulcerations plantar to the lesser metatarsal head are among the most common problems encountered in diabetic neuropathic patients (Fig. 4.6). As explained earlier, biomechanic and alignment assessment are critical. Radiographs can be used to search for osteomyelitis, stress fractures, and Charcot signs, but other more basic characteristics should be noted as well. Weight-bearing radiographs should be used to assess transverse, frontal, and sagittal plane alignment. Lesion markers are helpful in verifying areas of prominence.

Surgical Options

The primary goal of lesser metatarsal procedures is to reduce or eliminate high-pressure areas. A variety of procedures have been described for the treatment of prominent metatarsals and many of them can be divided into one of three categories: (a) condylectomy; (b) metatarsal osteotomy; or (c) metatarsal head resection.

CONDYLECTOMY

Indications. The most prominent site of a metatarsal head is usually below one of the plantar condyles. Typically, it is the lateral or fibular condyle that is most exposed. Curative procedures such as simple condylectomies may be appropriate for these bony prominences or increased focal pressure points. Enlarged plantar condyles may be most apparent on lateral radiographs and sometimes can be isolated with lesion markers.

Surgical Technique. DuVries first described this technique in 1953 and advocated removing 20% to 30% of the plantar metatarsal head as well as the distal 2 mm of articular cartilage. This was later modified by Coughlin and Mann. They eliminated the cartilage resection step and made the osteotomy cut parallel to the metatarsal shaft (18). The authors’ preferred technique is a direct approach for deep ulceration to allow for ulcer excision and soft tissue débridement. More frequently, a dorsal incision centered over the MPJ is employed. Once the lesser MPJ is exposed, a McGlamry elevator is used to lift the plantar aspect of the metatarsal head into full view. The condyle can then be resected with a sagittal saw and be removed.

Postoperative Management. A surgical shoe is worn while the incision heals, typically 2 to 3 weeks. If an ulcer is present, normal offloading techniques are observed. No bone healing is required and weight bearing is at the surgeon’s discretion.
Complications and Outcomes. The original procedure was reported to have a transfer lesion rate of 13%, and failed to resolve the original lesion in 5% of cases. The modified technique is believed to have a decreased transfer rate of approximately 5%, but formal studies have yet to be performed. Other complications from this procedure occur at a rate of roughly 5% and include digital clawing, fracture, or avascular necrosis of the metatarsal head (18).

Lesser Metatarsal Osteotomies
Clinical Assessment and Surgical Indications. Metatarsal osteotomies should be considered for preulcerative regions of the metatarsal head and ulcerations that do not extend to the bone or joint. If persistent serous drainage is present, this may indicate synovial fluid from joint involvement and alternative procedures are recommended (Fig. 4.7).

Surgical Options. As the options for different lesser metatarsal osteotomies are quite expansive, procedures will be limited to a select few that have been used specifically in the treatment of diabetic foot ulcers. Metatarsal osteotomies are selected based on the underlying deformity. For the purposes of this chapter, they can be broadly subdivided into shortening and elevating procedures.

Shortening Osteotomies
Indications. Lesser metatarsal osteotomies are performed in patients with either preulcerative regions or more superficial noninfected ulcerations. In the past, shortening techniques have included procedures such as osteoclasis but owing to a lack of reliability it has been replaced currently by the distal oblique osteotomy as described by Weil (19).

The Weil osteotomy is primarily indicated for long metatarsals and contracted digits with MPJ dislocation. This procedure achieves shortening of the metatarsal, decompression of the MPJ, and reduction in plantar pressures. Modifications of the Weil osteotomy have also been described to correct transverse and frontal plane deformities as well as plantarflexed metatarsal heads (19).

Surgical Technique. These osteotomies are approached through a dorsal incision because they are considered "clean" procedures and use internal fixation. The dorsal incision avoids weight-bearing surfaces and more importantly avoids contamination of the surgical site from the open ulceration.

The Weil osteotomy involves an osteotomy starting just adjacent to the dorsal articular cartilage edge of the metatarsal head, directed plantarly and proximally. The osteotomy is oblique to the metatarsal shaft and is kept parallel to the weight-bearing surface to avoid plantarflexion. The capital fragment is then allowed to retract a few millimeters proximally. The parabola is assessed and the plantar aspect of the metatarsal head is palpated to feel for prominences while the foot is loaded. The osteotomy can be fixated by various internal devices; however, screws are typically used.

Postoperative Management. Shortening osteotomies, such as the Weil osteotomy, allow partial weight bearing in a postoperative shoe because of its intrinsic stability. If ulcerations are present, felt foam or other padding can be used in the postoperative period to off weight the healing plantar wound. As with any surgery, edema control with compressive dressings and elevation help minimize wound healing complications. Physical therapy or taping of the digits is sometimes necessary to improve toe purchase.

Complications and Outcomes. The Weil osteotomy of the second metatarsal head has been shown to decrease plantar pressures by 36% and 65% in stance phase and heel rise, respectively (20). A study by Vandeputte et al found that the Weil osteotomy resulted in a mean 52% reduction of plantar pressure from preoperative pedobarographic exam. At a mean follow-up of 30 months, only 11% of the feet had developed a transfer lesion; 74% of the patients were lesion free, whereas only 5% had no visible improvement of their callus (21).

Beyond the complications already mentioned, a floating toe, believed to be secondary to the altered MPJ axis, has been reported in as many as 20% of these cases (22). Special attention is required to the balance of the soft tissue structures, with tendon transfers, lengthenings, and tenotomies are performed when necessary to minimize complications.

Elevating Osteotomies
Indications. Elevating osteotomies are reserved mainly for plantarflexed metatarsals. As mentioned, all lesser metatarsal osteotomies are performed in patients with either preulcerative regions or more superficial noninfected ulcerations.

Surgical Technique. As for elevating procedures, the two that have been most frequently reported in this setting are the V-osteotomy and the metatarsal base wedge osteotomy. The V-osteotomy, or vertical chevron osteotomy, is approached dorsally and is essentially an Austin-style cut rotated 90 degrees with the apex directed distally. Following the cut, the head should be raised to a plane parallel to the other metatarsals. This osteotomy is essentially stable within the transverse and frontal planes, but should be fixated with a 0.045-in K-wire to avoid sagittal displacement.

A proximal dorsiflexory wedge osteotomy has been described for a plantarflexed metatarsal. The wedge is oriented with the apex directed plantarily, carefully maintaining the plantar cortex. This is typically performed at the diaphyseal–metaphyseal junction; the size of the resected wedge is dependent on the desired correction. Screw fixation is appropriate for this technique, and non-weight-bearing is critical (23).
Postoperative Management. Elevating procedures are less intrinsically stable to resist bending forces, and some surgeons advocate non-weight bearing until trabeculation across the osteotomy is achieved. This is especially true for more proximal osteotomies, with 4 to 6 weeks of non-weight bearing recommended. If ulcerations are present, felted foam or other padding can be used in the postoperative period to offweight the healing plantar wound. As with any surgery, edema control with compressive dressings and elevation help minimize wound healing complications. Sometimes, physical therapy or taping of the digits is necessary to improve toe purchase.

Complications and Outcomes. With this procedure, Dreeben et al. found that 9% of patients developed a transfer lesion, whereas 4% had no change in the original callus (24). Tillo et al. examined the outcomes after a variety of osteotomies in 49 neuropathic diabetic patients. They used four procedures: (a) osteoclasis, (b) V-ostectomy, (c) shortening collectomy, and (d) oblique-sliding osteotomy. At a mean of 19 months, 55% showed no evidence of reulceration or transfer lesion. Of the 22 patients who did develop symptoms postoperatively, only four required a surgical revision. Within an average of 17 months, 13 patients developed transfer ulcerations, and by 19 months, three patients had a recurrence of their original ulcer. Twenty-seven percent of the symptomatic group had transfer calluses (25).

LESSER METATARSAL HEAD RESECTION

Indications. A portion of patients may not benefit from the previously described techniques. This is especially true if ulcers plantar to the metatarsals extend down to the bone or joint are infected (Fig. 4.7). In this situation, a lesser metatarsal head resection or complete joint resection is performed.

Surgical Technique. For solitary metatarsal head resections, two main approaches are recommended. A dorsal curvilinear incision centered over the metatarsals allows for a clean approach, but relies on the ulcer healing by secondary intention. This is typically reserved for patients unable to remain non-weight bearing.

The preferred approach, however, is a plantar incision that incorporates ulcer excision, removal of the metatarsal head, and primary closure without skin tension (Fig. 4.8). This is particularly recommended if any concern exists about the vascular status of the foot. Wounds left open to heal by secondary intention require more perfusion than wounds closed primarily. This approach also allows for excision of necrotic nonhealing tissues, direct inspection of the wound, and faster primary wound healing.

The ulcer is excised down to the bone. A full-thickness incision, made of two converging semielliptical incisions, is centered over the ulceration with a length-to-width ratio of 3:1 or 4:1. The osteotomy itself should be made proximal enough within the neck to remove any potentially infected bone and oriented dorsal-distal to plantar-proximal to prevent a prominent plantar edge. Slight modifications must be made when this procedure is performed on either the first or fifth metatarsal. For instance, in the case of the fifth metatarsal, lateral beveling is recommended to prevent a prominence laterally.

The base of the proximal phalanx should also be inspected. This bone is often involved, especially in the setting of osteomyelitis. If concern exists, the base should also be removed.

Other structures, such as the plantar plate and flexor tendons, should be sacrificed if infection is thought to be present.

Before wound closure, the area is inspected for any remaining bone spicules and aggressively irrigated. If a tourniquet was used, it is deflated prior to closure to ensure that resections were down to healthy bleeding bone and that there is adequate hemostasis (12).

The closure of these plantar wounds requires a very unique technique. Full-thickness wide retention sutures are evenly spaced with 2-0 or 0 nonabsorbable monofilament material starting centrally. These large wide retention sutures allow the surgeon to avoid using deep-buried knots, which can serve as a nidus for infection. Smaller 3-0 monofilament suture is then placed between these deeper retention sutures, providing eversion of the skin edges (Fig. 4.9).

There is a significant dead space created from this procedure, and closed-suction drains can be used to prevent hematoma. More commonly, the proximal portion of the incision is left open to drain and lightly packed until it heals over.

Postoperative Management. Patients are kept non-weight bearing until the plantar skin incision has healed. Usually, sutures are removed after 3 to 4 weeks, with partial weight bearing initiated by week four.

Complications and Outcomes. Transfer lesions or ulcerations are the most commonly reported complications. Accommodative padding and orthotic devices are recommended with close follow-up postoperatively to assess plantar pressure distribution. Other complications include wound dehiscence,
infection, flail or shortened toe, stress fractures, or development of Charcot neuroarthropathy. Wieman et al performed solitary and multiple metatarsal head resections in 101 patients with a mean follow-up of 35 months. They reported a 94% salvage rate, but noted that ulcer recurrence was a problem in 8% and new ulcer formation was a problem in 52%. Part of the study design was such that all wounds were expected to heal by secondary intention; therefore, none of the ulcers in this study were excised (11). An earlier study by Wieman reported the change in peak plantar pressure after metatarsal head resection. He noted a 70% reduction after a first metatarsal, but midline over the second interspace, midline over the fourth metatarsal, and midline to slightly lateral over the fifth metatarsal. Each of these incisions allows for adequate exposure and minimizes excessive tissue traction while preserving the vascularity of the dorsal skin. If the plantar approach is preferred, then a transverse incision is made just proximal to the sulcus of the toes. The exposure is not as extensive as the dorsal approach; however, careful planning allows for ulcer excision through the use of a transverse ellipse without multiple incisions (Fig. 4.10). Longitudinal incisions are then made over each metatarsal to gain exposure. A combination of both dorsal and plantar incisions is frequently employed. Plantar incisions are used to excise ulcers with resection of the metatarsal head through this incision, as previously described. Dorsal incisions are strategically placed to remove the remaining "noncontaminated" metatarsal heads. Resection of the metatarsals is described in the individual resection discussion. Bone cuts should be oriented dorsolateral to plantar-proximal to prevent a plantar edge. Both the first and fifth metatarsals should be beveled medially and laterally, respectively, to avoid prominences. Following metatarsal head resection, temporary digital stabilization with K-wires is

**Surgical Technique**

Many approaches have been discussed and recommended for this procedure. They include dorsal, plantar, and/or combined incisions. The success of each is dictated by the desired exposure but they are all essentially equivalent. In this chapter, a few select examples are discussed.

Using the dorsal approach, four longitudinal incisions are placed in the following locations: (a) midline or medial over the first metatarsal, (b) midline over the second interspace, (c) midline over the fourth metatarsal, and (d) midline to slightly lateral over the fifth metatarsal. Each of these incisions allows for adequate exposure and minimizes excessive tissue traction while preserving the vascularity of the dorsal skin.

![Figure 4.9](image1.png) To avoid buried knots in closing thicker plantar skin, large deep retention sutures reapproximate wound edges, whereas smaller peripheral sutures evert skin edges. This can be applied not only to metatarsal head resections with ulcer excision but anywhere on the plantar foot.

![Figure 4.10](image2.png) A transverse plantar incision can be used to excise ulcers. Additional access may be obtained through dorsal incisions to remove metatarsal heads without associated ulcerations.

**PANMETATARSAL HEAD RESECTION**

**Indications**

Given the fact that isolated resections are frequently associated with transfer ulcers, and that many patients require several trips to the operating room as new ulcers form, it is wise to consider a panmetatarsal head resection in the presence of multiple forefoot ulcers. Generally, once two or more metatarsal heads are resected, we advocate a panmetatarsal head resection. It is in the best interest of the patient, as we have found that this minimizes multiple surgical procedures and deconditioning of the patient. Before this procedure was popularized, transmetatarsal amputation was frequently the method of choice for multiple recurrent ulcerations. Panmetatarsal head resection is recommended over transmetatarsal amputation because it maintains the metatarsal parabola and foot length. This permits easier fitting within accomodative shoes and a more normal gait pattern.
recommended in the absence of deep ulcerations or osteomyelitis, and is typically used for digits undergoing a dorsal approach.

Maintenance of the parabola is imperative to the success of this procedure. A smooth parabola avoids creating new pressure points, and no metatarsal should be significantly longer than the adjacent one. In general, the second metatarsal is the longest. The first and third metatarsals are of equal lengths and should be just slightly shorter than the second metatarsal. This is followed by the fourth, and finally, the fifth metatarsal, which is the shortest. Although the preceding parabola is desired, it is not always possible because of prior débridements or metatarsal or ray resections. In these circumstances, the “desired parabola” is created with the remaining metatarsals with padding and accommodation customized postoperatively.

**Postoperative Management**

Postoperative care should typically include non-weight bearing until the incision is healed. If open ulcerations were present with concern for osteomyelitis, bed rest, elevation, compression dressings, and antibiotics are administered until wounds are dry. Sutures typically remain for 3 to 4 weeks. Once incisions have healed, protected weight bearing in a postoperative shoe is initiated. Patients are gradually progressed to full weight bearing in an athletic shoe or accommodative footwear with padding, depending on the particular situation.

**Complications and Outcomes**

Several studies have examined outcomes following this procedure in neuropathic diabetics. A 1993 paper reported the outcomes of this technique in 34 procedures after a mean of 20.9 months. Sixty percent of the procedures included primary ulcer excision with no complications in healing. Of the remaining patients, delayed healing occurred in one, whereas another had recurrence of the original ulcer. None of the patients required any type of amputation by the end of the study period and the overall salvage rate was 97%. A common complication of this procedure is new bone growth at the osteotomy sites; in this series, 29% developed this, resulting in new ulcers. A single revisional exostectomy was required, but in most cases conservative care was adequate. Petrov et al performed a similar study, examining 20 patients with a mean 6-year follow-up. Their reulceration rate was 25% and recurrence was most common at the third and fourth metatarsal sites (28).

**TENDO-ACHILLES LENGTHENING**

**Indications**

Regardless of the procedure performed, an adjunctive tendo-Achilles lengthening (TAL) is indicated for many neuropathic patients. Lengthening the Achilles tendon decreases the amount of forces at propulsion transmitted to the forefoot and midfoot, and reduces plantar foot pressures. Increased plantar foot pressures in diabetics are thought to be caused by a number of factors, including structural deformities and limited joint mobility (29). Glycation of the Achilles, thus causing inelasticity, stiffening, and shortening of this tendon, may further contribute to this problem (30).

**Surgical Technique**

There are many ways to lengthen this tendon, but one of the simplest and quickest techniques is the percutaneous triple hemi-incisional approach (Fig. 4.11). The medial one half of the Achilles tendon is transected via a stab incision approximately 1 cm from the superior aspect of the calcaneus. A second stab incision, 3 cm superior to this incision, transects the lateral half of the Achilles tendon. Finally, a third medial stab incision is made 3 cm superior to the second incision. The foot is then dorsiflexed under controlled pressure until the desired amount of dorsiflexion is achieved.

**Postoperative Management**

Patients are immobilized with the foot 90 degrees to slightly dorsiflexed, and kept non-weight bearing for a period of 3 to 4 weeks. However, weight-bearing status is often dictated by concomitant procedures.

**Complications and Outcomes**

Minimal complications are associated with this procedure. The most devastating is overlengthening or tendon rupture, causing the development of heel ulceration from a calcaneal gait. The incidence of heel ulceration following TALs is unknown, but is anecdotally reported to range anywhere from 2% to 10%. In the authors’ experience, this is a very rare complication; of greater concern is the recurrence of equinus and only transient relief of increased forefoot plantar pressures following this procedure. TAL may also decrease propulsion and reduce plantarflexory power. This is not considered a complication but a desired effect in this neuropathic patient population to reduce the risk for plantar pressures and ulcerations.

In a study by Armstrong et al mean plantar forefoot pressures decreased from 86 ± 9.4 N/cm² to 63 ± 13.2 N/cm² (p <0.001) following TALs (31). Other studies have found similar results, with healing of forefoot ulcers and prevention of recurrence of plantar foot ulcerations (32,33). Certainly, the benefits of TAL outweigh the potential risks and are highly recommended to reduce plantar foot pressures in many situations.
ULCER EXCISION

Indications
In addition to considering a TAL, ulcer excision is another adjunctive procedure that should always be considered, regardless of the planned procedure. If ulcer excision with primary closure can be reasonably achieved, it is highly recommended. This facilitates faster healing and therefore decreases risk of infections. Other indications for ulcer excision are to decrease the risk of reulceration. Wounds that are left to heal by secondary intention are inelastic and less durable and can make the skin prone to future breakdown. Primary closure may also decrease the length of offweighting and immobilization as well as the duration of hospital admissions. Primary closure is also recommended if there is any concern regarding perfusion to the area. Wounds that heal by secondary intention require a greater amount of blood supply. However, preoperative vascular workup and consultation are of absolute importance and optimized perfusion through bypass, stenting, and/or angioplasty may be required first. If the wound is very deep and large and avoidance of free flaps or large skin grafts is desired, a short period of negative pressure-wound therapy to decrease wound size may be employed before surgical intervention.

Surgical Technique

Timing of Ulcer Excision. Excising an ulcer without correcting its cause may achieve initial wound healing but reoccurrence of the ulcer can be expected. Therefore, the underlying cause of the ulcer must also be addressed. The ulcer excision may be an adjunctive or staged procedure, depending on the situation.

A single-staged approach combining correction of the underlying deformity with primary ulcer excision can be achieved successfully. Whether a simple exostectomy is employed or a complete realignment procedure with wedging and arthrodesis, it is recommended to excise the ulcer with primary closure at the time of reconstructive surgery.

The ulcer may be excised at the beginning or end of a case. If the ulcer is very large but redundant skin is expected following bone resection, the surgeon may elect to excise the ulcer following bone removal. The ulcer is covered with a sterile adhesive after the foot has been prepped with the adhesive corners stitched into place to prevent dislodging. The surgical reconstruction is then executed. Following closure and covering of the incisions, ulcer excision is performed.

When the ulcer is to be excised at the beginning of a case, two separate sterile tables are required intraoperatively. One small table contains a blade, forceps, rongeur, irrigation, and any other instrument used for excision of the ulcer. The other larger table contains all necessary instrumentation for the reconstructive part of the case. The foot is prepped with an additional sterile towel placed beneath the foot, and the ulcer is completely excised down to healthy fascia or bone and irrigated. The ulcer is then passed from the operative field, along with the towel, irrigant, and contaminated instrumentation (Fig. 4.12). The surgeon’s gloves and gown are changed and the reconstructive part of the procedure begins.

ULCER EXCISION. First, the ulcer is typically circumferentially incised down to healthy tissues or bone, depending on its depth. The ulcer is raised as a single layer, starting from the periphery and working centrally (Fig. 4.13). All pathologic and bursa-type tissue should be removed and hemostasis should be maintained throughout the excision. The ulcer is removed from the operative field and the surgical site is copiously irrigated.

If the case allows the underlying procedure to be performed through the ulcer excision site, this open area is often taken advantage of and is incorporated into the incision (Fig. 4.14). Various techniques have been described to prepare excision site for closure. Two converging semielliptical incisions centered over the ulcer may be used. The ulcer diameter is measured and the length-to-width ratio should be either 3:1 or 4:1 (Fig. 4.15). Typically, this technique is reserved for ulcers less than 2.5 cm, as larger ulcers require alternative approaches, such as rotational or advancement flaps.

Timing of Ulcer Closure. The surgeon must also determine whether to close the ulcer at the time of excision or at the conclusion of the case. If the case allows the underlying procedure to be performed through the ulcer excision site, the ulcer excision site is closed at the conclusion of the case. This frequently occurs when simple exostectomies are planned, but have
also been used to incorporate medial or lateral realignment arthrodeses procedures to minimize skin bridges and additional incisions.

If the incisions for a procedure do not involve the ulcer site, the ulcer should be primarily closed immediately following ulcer excision. This is especially important in reconstructive cases, as manipulation and realignment of the foot alter the incision and anatomy, making closure very difficult if not impossible at the end of the case.

**SKIN GRAFTS AND FLAPS.** Skin grafts or flaps are also frequently employed because of the large size of many plantar neuropathic wounds. Wounds that are primarily closed under too much tension result in wound dehiscence and skin necrosis. If the incision has excessive skin tension during closure, the surgeon should consider these alternative measures.

Split-thickness skin grafts from either the leg or thigh do well if placed on non-weight-bearing surfaces of the foot. Bolster or compression dressings help decrease graft failure from seroma and hematoma formation. After the graft has been secured, a nonadherent dressing protects the skin graft from the dressings. Negative pressure therapy is then placed over the area and left on continuous suction for 5 days.

Rotational or local random flaps are better suited for weight-bearing surfaces such as the ball of the foot, lateral column, and heel. The adjacent skin has similar properties to help prevent future skin breakdown. For medial and lateral ulcers, V-Y skin plasties can be very effective. When ulcers are more centrally located, a medially based flap from the arch is often rotated laterally onto the weight-bearing surface ulcer excision site. A split-thickness skin graft is then placed over the non-weight-bearing medial arch surface.

If there is any concern about a dead space, especially after bone resection, this can be filled by an intrinsic musculature flap. The flexor digitorum brevis muscle is ideally located in this region, making it a common muscle to detach distally and move into a dead space. A medial plantar artery fasciocutaneous flap can then be rotated over the intrinsic muscle flap, allowing for a durable, strong, and tension-free covering (Fig. 4.16).

Many plastic surgery techniques are available to cover wounds, and it is recommended to follow basic soft tissue principles and provide flap coverage that works best for each unique situation.

**Figure 4.14** Example of a plantar-medial ulcer that had been excised with preoperative photograph depicted in Figure 4.17. The incision was then extended proximally and this open area allowed access for subsequent medial column joint preparation.

**Figure 4.15** Electronic drawing of the desired ulcer ellipse incision. A 3:1 or 4:1 relationship with smooth edges prevents “pear-shaped” excisions causing tension and dog ears from occurring.

**Figure 4.16** Example of a large heel ulcer excision requiring a medial plantar artery fasciocutaneous flap over a flexor digitorum brevis muscle flap. Split-thickness skin grafting allows coverage over non-weight bearing surfaces. (Courtesy of Philip Basile.)
Postoperative Management

The weight-bearing status following ulcer excision is largely dependent on the location and method of closure. Primary closure over nonmobile, non-weight-bearing surfaces may allow partial weight bearing with immobilization depending on surgeon preference. However, closure over joints or weight-bearing surfaces requires strict immobilization and a period of an average of 6 to 8 weeks of non-weight bearing. In certain cases, wires, pins, or external fixation is of great benefit to effectively offload an area. Drains are used if concern exists for hematoma formation. Adequate compression over the incision, elevation, and immobilization of the foot are also critical.

Complications and Outcomes

This single-stage approach, combining noninfected ulcer excision with concomitant deformity correction, has frequently been used not only in our institution, but also in others. Blume et al reported on a retrospective review of 67 patients undergoing ulcer excision, correction of deformity, and primary wound closure with use of a local random flap in noninfected diabetic foot ulcers. Ninety-seven percent of the wounds healed within a total median time of 30.8 ± 40 days. Ulcer recurrence rate was only 10.4% over the course of a mean 2.5-year follow-up (34).

Wound complications are frequent and even expected in the diabetic population, but most are minor and can be effectively treated without additional problems. The most common complication encountered is wound dehiscence. Other problems include skin slough or graft failure, postoperative infection, seroma or hematoma formation, and reulceration.

MIDFOOT

When existing midfoot ulcers have failed conservative measures, they usually do not heal or become reulcerated unless the overall structure is assessed. If perfusion is adequate and the soft tissues and bone are free of infection, then the primary problem is typically neuropathy mixed with structural deformity.

Charcot neuroarthropathy is a common structural cause of midfoot problems in neuropathic diabetic patients. Collapse of the arch creates increased plantar foot pressures and ulcerations from the rocker-bottom deformity. Ulcerations can be found in any region, depending on the underlying bony malalignment.

The most frequent midfoot ulcer locations are plantar medial from either the first metatarsal-medial cuneiform joint, navicular, or talus (Fig. 4.17), followed by plantar lateral ulcers from cuboid dislocation, peroneal insufficiency, or the styloid process. The least common are more plantar central ulcers from collapse of the central tarsal-metatarsal region.

It is important to realize that a strict algorithm does not and should not exist for treatment of these problems. Instead, a more flexible approach is required, keeping in mind the goals of surgery: stability, realignment, a plantigrade foot amenable to bracing or accommodation, and reduction of pressure points. This can be done with or without ulcer excision combined with exostectomies, realignment osteotomies with arthrodeses, or a combination of these procedures, depending on the situation. Every deformity is different and basic principles help guide the surgeon on the best procedure for each patient.

Regardless of the procedure performed, an adjunctive TAL is usually indicated for many neuropathic patients. Lengthening the Achilles tendon decreases the amount of force transmitted to the forefoot and midfoot during the propulsive phase of gait. Ulcer excision with primary closure is also preferred and may require additional skin grafting or flaps.

EXOSTECTOMY

Indications

An exostectomy is a very simple technique to address bony prominences within the foot when offloading and conservative measures have failed. It can be very effective when used in the right circumstances. Neuropathic patients with midfoot collapse often have bony prominences causing increased pressures, resulting in callus formation and ulceration. If this deformity is rigid and stable, an exostectomy may be the best choice. Exostectomies may also be considered in the very elderly, minimally ambulatory patient when the primary goal is to close a wound quickly to prevent infection. If osteomyelitis is present, an exostectomy can be curative as well as corrective. However, if any motion or instability exists or the resection has the potential to cause instability because of its size or location, then this isolated procedure should be avoided. In this setting, a more formal deformity correction, including arthrodesis, should be considered.

Surgical Technique

INCISIONAL APPROACHES. Incision placement is influenced primarily by the depth, but also the size, location, and quality of the overlying tissues and ulcer. These four factors
help determine whether to approach the exostectomy directly or indirectly. For indirect approaches, a separate skin incision is made on non-weight-bearing surfaces away from the ulcer site, whereas direct approaches involve excising the ulcer and approaching the exostosis directly through this site.

Indirect approaches are typically used when the exostosis is located on the plantar-medial or plantar-lateral aspects of the foot. Incisions can be placed on the side of the foot, avoiding the non–weight-bearing surface. These approaches are reserved for more superficial ulcers that do not communicate with the bony exostosis. The overlying soft tissues should also be free of pathologic tissues and bursa formation.

Deeper ulcers or ulcers that can be excised with primary wound closure are more amenable to a direct approach, as previously discussed. If there is active infection or a history of osteomyelitis, the bone and ulcer can be directly excised. Underlying bursa tissue, even with overlying superficial granular tissue, should persuade the surgeon to opt for a direct approach for concomitant bursa excision.

**Osseous Resection.** Once soft tissue impediments have been removed, the actual resection of bone can occur. Various techniques are available and are dictated by exposure and shape of the bone. Planing via saw is efficient, but the blade’s excursion often limits its use. Thermal necrosis is not a concern because the goal is to prevent regrowth of the bone. However, the plantar location of these wounds often makes it very difficult to use power instrumentation; instead, a combination of standard and curved osteotomes is useful when osseous surfaces curve abruptly. The rongeur is appropriate for small prominences and shaping of residual bone. The goal of these procedures is to create a flat surface without leaving a new ridge or step-off. Following resection, a rasp should smooth the surfaces as needed. The site should be irrigated; closure may include ulcer excision, and a local flap if deemed necessary.

**Postoperative Management**

Drains are used if concern exists for hematoma formation, especially after resection of cancellous bone. Adequate compression over the incision, elevation, as well as immobilization of the foot is also critical. If incisions are on the weight-bearing surfaces of the foot, non–weight-bearing bearing is recommended for at least 3 weeks. However, patients typically require an average of 6 to 8 weeks without placing weight on the foot.

**Complications and Outcomes**

In a 1997 study, which looked at the outcomes following lateral column exostectomies, 32 feet in 31 patients underwent an exostectomy alone \( n = 7 \), with primary closure \( n = 17 \), or a rotational flap \( n = 8 \). Of these, 25% required additional resection or flap coverage. The overall success rate was 89% (35). Catanzariti et al performed 27 procedures; 18 were for the treatment of medial column ulcerations, whereas the remaining nine were lateral column wounds. They reported a 74% healing rate; however, 85% of those patients who did not heal initially had lateral column ulceration. Fifty-five percent of the patients with lateral column ulcers initially required revisional surgery to facilitate healing. They reported a statistically significant difference in the rate of complication based on ulcer location. They concluded that the lateral column is less predictable and often requires an adjunctive soft tissue procedure to be successful (36). Pinzur et al used exostectomy in eight patients, and found that 100% were ambulatory in accommodative footwear after 3.6 years (37). Brodsky and Rouse found that 11 of 12 patients remained healed after a mean follow-up of 25 months (38).

**Realignment Midfoot Osteotomies with Arthrodesis**

**Indications**

When exostectomy fails, instability or motion exists or significant deformity of the midfoot has occurred secondary to Charcot neuroarthropathy, a more stabilizing aggressive approach is recommended (Fig. 4.17). Controversy exists with regard to surgical timing in neurogenic osteoarthropathy. Many practitioners had originally advocated for a delayed approach, in which reconstruction efforts were used during the remodeling phase of the Charcot process. Recently, this practice has come into question and many practitioners are choosing instead to intervene earlier. The rationale behind this change focuses on the neurotraumatic theory of Charcot joint formation. Assuming that an initial Charcot episode presents to the clinic, treatment begins by approaching the event as an acute fracture. Offloading techniques are used until both edema and erythema are controlled. Once this has stabilized, usually within 5 to 7 days, an aggressive reconstructive approach centered on arthrodesis and deformity correction is employed. With this approach, we believe that we can prevent more severe deformities from occurring by stabilizing the foot in the initial phases. At our institution, we have found a high degree of success with this approach, but a formal analysis of outcomes has yet to be performed. Publication of our results is planned once a larger number of patients have achieved longer follow-up.

**Surgical Technique**

**Surgical Planning.** Typically, the apex of the deformity is first identified. Second, it is determined if the deformity exists in either one or a combination of transverse, sagittal, or frontal planes. At this point, multiple options are available to the surgeon. The decision whether to perform acute or gradual correction is determined. If acute correction will not compromise the neurovascular structures and there is adequate soft tissue for primary closure, acute correction is preferred. Options for acute correction include single or multiplane midfoot realignment osteotomies via closing or opening wedge arthrodeses, removal of bone wedges, and removal of entire extruded midfoot bones.

Attention to restoring normal or “more normal” anatomy is important. It is not recommended to fuse the foot in its current position. If reduction is difficult, removal of bone, joint releases, and assisted external fixation distraction can be very helpful.

It is also important to remember that Charcot does not typically involve only the medial or lateral column, but occurs transversely through an entire section of the foot (Fig. 4.18).
Because of this, the entire foot must be addressed. Even if the deformity primarily involves one joint or one column, both the medial and lateral columns need to be addressed for long-term stability and success. Arthrodesis of isolated joints is no longer recommended because of failure rates and the progressive nature of this condition (Fig. 4.19A–C). Instead, more aggressive fusion techniques and hardware configurations are being employed. In addition, by fusing additional joints proximal and distal to the Charcot deformity, the threads of the screws pass beyond the pathologic bone, thus improving stability and compression across the surgical site (Philip Basile, personal communication) (Fig. 20A,B).

Single Plane Realignment Osteotomies with Arthrodesis. Midfoot Charcot neuroarthropathy may only involve deformity within one plane. If this is present, it is typically a midfoot collapse in the sagittal plane without abduction of the forefoot. It is less common to have only a transverse plane deformity without sagittal collapse. If deformity is within only the sagittal plane, a single complete medial to lateral osteotomy through the midfoot with manipulation can achieve correction. However, if there is an isolated transverse plane deformity, opening or closing wedge osteotomies are usually necessary. If a single osteotomy was employed to correct an abducted or adducted midfoot deformity, translation of the forefoot medially or laterally, respectively, would create additional bony prominences and problems.

Incisional Approaches. This single plane correction lends itself to either an open or more minimally invasive approach. If more formal joint preparations are desired or wedges of bone are to be removed or added, curvilinear incisions are placed on the medial and/or lateral aspects of the midfoot, centered over the joints that are to be fused. However, it is possible to perform the osteotomy without direct visualization with the use of fluoroscopy and a Gigli saw in sagittal single plane deformities (39) (Fig. 4.21). If it is elected to perform this percutaneously, small incisions placed directly over joints allow a small burr or osteotome to gain access for joint preparation.

Surgical Technique. Following soft tissue dissection, the dorsal and plantar soft tissue structures should be bluntly reflected from the bone. If desired, K-wires may be driven transversely across the deformity apex under fluoroscopy to use as a guide.
for the osteotomy (Fig. 4.22). If a wedge of bone is to be removed, two converging K-wires can be used to facilitate accuracy of wedge resection cuts.

If the problem lies within only the sagittal plane, often bone wedges do not need to be removed. Instead, a through-and-through single osteotomy directed transversely across the apex of the deformity can be used. This can be performed with the use of a power saw, osteotomes, rongeurs, or other modalities. The soft tissue structures, both dorsally and plantarly, must be protected and the surgeon’s free hand can be placed on the dorsum of the foot to help use tactile vibratory responses to prevent overzealous dorsal blade displacement. It is recommended that the surgeon performs an incomplete osteotomy dorsally. The bone resection is then completed with an osteotome or osteoclasis via manipulation to ensure safety of the dorsal neurovascular structures.

Once the transverse midfoot osteotomy is complete, the foot can be manipulated into position easily. The joints are prepared for fusion based on surgeon’s preference. This may be done by curettage, osteotomes, rongeurs, or other modalities. The forefoot is then plantarflexed until the bisection of the talus is collinear with the bisection of the first metatarsal. Guide wires or temporary K-wires are then used to hold the osteotomy in place for fixation.

**MULTI-PLANE REALIGNMENT OSTEOTOMIES WITH ARTHRODESIS.** More commonly, Charcot neuroarthropathy involves both sagittal and transverse plane deformities. These types of deformities may be corrected with either biplanar closing or opening wedge osteotomies.

**Figure 4.20** When dealing with midfoot Charcot, additional joints both distal and proximal to the pathologic bone should be included into the surgical planning along with additional larger fixation for long-term success and stability. **A.** Example of a combination of multiple intra-medullary rodtings. **B.** This fixation was further backed up with a static circular external fixation device. (Courtesy of Barry Rosenblum and Philip Basile.)

**Figure 4.21** In patients with absolute contraindications to tourniquets and are on anticoagulants because of recent vascular bypasses, a minimally invasive midfoot osteotomy via Gigli saw technique may be advantageous. (Courtesy of Philip Basile.)

**Figure 4.22** A transverse K-wire may be transversely driven across the apex of the deformity to serve as a guide for the osteotomy.
**Incision.** Because wedges of bone are either being removed or added to osteotomies or joint fusion sites, it is more challenging to use minimally invasive approaches in this situation. Curvilinear incisions are placed directly over the medial and lateral columns. The medial incision typically extends from the talus to the medial first metatarsal-cuneiform joint, with care being taken to be centered directly over the medial column. The lateral incision is similar to the incision described for a triple arthrodesis and can be extended proximally if access to the subtalar joint is desired.

**Surgical Technique**

*Closing Wedge Osteotomies.* Closing wedge osteotomies involve removing a large bimanual wedge of bone at the apex of the deformity (Fig. 4.23). If the deformity involves sagittal midfoot collapse and abduction, more bone will be removed plantarly and medially. However, if there is midfoot collapse and forefoot adduction, a plantar lateral wedge of bone is removed. A similar technique to the single plane wedge removal is employed, except that the correction is biplanar. Converging K-wires are placed transversely under fluoroscopy as a guide for wedge resection. The dorsal and plantar soft tissues are protected and the wedge resections are performed. The bone is removed and the foot can then be manipulated into place. Sometimes, additional reciprocal planing is useful to improve realignment and bony apposition.

*Opening Wedge Osteotomies.* Opening wedge osteotomies are more commonly used in the severely abducted foot and are more frequently thought of as lateral column lengthenings. Bone allograft has been shown to be successful (40) and is often chosen over autograft to minimize donor site morbidity. Tricortical iliac crest allograft usually works well. The only exception is when large noninfected bone resections are removed from one area, such as the medial column, and can be placed in another area, such as the lateral column. Even then, additional allograft may be necessary to achieve enough deformity correction. Bone allograft also may be placed dorsally in the osteotomy or joint fusion space to plantarflex the forefoot (Fig. 4.24). Conversely, allograft can be placed medially to abduct a foot, or plantarly to dorsiflex the forefoot. The use of a temporary monorail may sometimes be used to distract and open the area to help achieve correction in more severe deformities.

**Figure 4.23** Example of a biplanar wedge resection in midfoot closing wedge arthrodeses

**Figure 4.24** Example of an opening wedge arthrodesis with an allograft wedge placed dorsally to plantarflex the forefoot. (Courtesy of Barry Rosenblum.)

If frontal plane deformity coexists, the forefoot can also be rotated through the osteotomy site to either increase pronation or supination. To maintain bony apposition, additional reciprocal planing may be necessary with this technique. Guide wires or temporary K-wires are then used to hold the correction in place for fixation.

**Positioning and Fixation Techniques.** Whether single osteotomies, opening or closing wedge arthrodeses are employed, the ultimate goal is to achieve a stable, plantigrade foot with good alignment, thus preventing skin breakdown and future ulcerations. First, alignment of the rearfoot to the leg and then to the forefoot should be assessed. The longitudinal bisection of the talus should be as close to collinear as possible to the bisection of the first metatarsal on the sagittal and anterior-posterior views. This is very important because undercorrection of a collapsed medial arch does not correct the initial problem, and an over-plantarflexed medial column can lead to first metatarsal head ulcerations in neuropathic patients. Other important intraoperative angular measurements to consider include the metatarsus adductus angle, talocalcaneal angle, and the cuboid abduction angle. The metatarsus adductus angle (normal: 0–15 degrees) is measured from the anterior-posterior views and helps evaluate the transverse position of the forefoot to the rearfoot. The cuboid abduction angle (normal: 0–5 degrees) also evaluates the transverse correction and is particularly important when ensuring adequate correction of abduction deformities. Finally, the talocalcaneal angle (Kite’s Angle) (normal: 15–35 degrees), is primarily used to evaluate frontal plane correction. This angle increases with pronation and decreases with subtalar joint supination.

Once proper alignment of the midfoot correction has been achieved, a number of different fixation modalities have been effective. As stated, even if the deformity involves mainly one joint or column, both medial and lateral columns are typically addressed. Additional and larger fixation in neuropathic patients is also recommended with fusion extending both proximally and distally past the pathologic bone. A subtalar arthrodesis is frequently included for a midfoot correction.

Fixation first begins by addressing the realigned primary deforming force. Because a collapsed medial arch is often the most common and severe aspect of these deformities, fixation of the medial column is often addressed first. Achieving...
collinearity of the talus and first metatarsal is stressed and often requires a more extended fusion of the medial column. Whether screws, staples, plates, wires, pins, or external fixation is used, it is important to have compression, strength, and stability across the fusion sites. It is common to use additional fixation, fuse additional joints, and increase the fixation device by size and length from baseline when dealing with neuropathic patients.

Rodding Techniques. Medial column rodling has been shown to be a very successful fixation device in this situation (41–43). Its function is more analogous to an intramedullary nail procedure that helps resist cantilever bending forces. It also ensures complete realignment and collinearity of the first metatarsal to the talus with preservation of cortical integrity. Fixation and compression are directly perpendicular to the joints being fused. Finally, medial column rodling procedures reduce soft tissue and bone trauma and are not prominent. Disadvantages are that it requires damage to the cartilage of the first metatarsal head; however, this is less of a concern in neuropathic patients. The screw may back out or break, which is why it is critical to use a larger screw, such as an 8-mm diameter dual threaded screw (43).

The first MPJ is exposed through a limited dorsal incision and a guidewire is advanced under fluoroscopy through the first metatarsal, medial cuneiform, navicular, and into the talus, while holding the foot into a corrected position. Alternatively, the correction may be stabilized with strategically placed K-wires that do not interfere with screw placement. The image intensifier must be used to ensure adequate reduction of the deformity and central placement of this wire on both anterior-posterior and lateral views. Once this had been achieved, a large dual threaded 8-mm partially threaded cannulated screw is placed over this wire and advanced until the threads are completely within the body of the talus and the head of the screw is seated below the joint surface into the metaphyseal aspect of the first metatarsal head (Fig. 4.25A,B). The advantage of a dual-threaded screw is that the threaded head and tip are seated completely within the first metatarsal head and talus, respectively. This achieves compression and stabilization across the entire medial column when the threads compress the cancellous bone of the first metatarsal head and body of the talus together.

As mentioned, medial column fusions are typically accompanied by lateral column stabilizing procedures in midfoot Charcot neuroarthropathy. Lateral column rodling is a very solid technique to achieve this goal. First, it is determined which lesser metatarsal (third, fourth, or fifth) is the most collinear with the cuboid. This MPJ is exposed through a minimal dorsal incision, and a long guidewire is advanced under fluoroscopy through the lesser metatarsal, cuboid, and calcaneus. Once adequate deformity reduction and wire alignment have been achieved, this wire is retrograded through the entire calcaneus and posteriorly through the skin. A large dual threaded 8-mm partially threaded cannulated screw is then placed over this wire and advanced from the calcaneus and into the cuboid and base of the lesser metatarsal (Philip Basile, personal communication) (Fig. 4.26).

Circular External Fixation. Circular external fixation has been used alone or in combination with internal fixation for correction of these midfoot deformities. Because acute correc-
tion has already been achieved, the external fixation device is used as a static construct in this situation. When used in combination, the construct helps back up the internal fixation by helping to eliminate deforming forces while the fusion consolidates. Two tibial rings and a foot plate below help provide additional stability. An additional contact ring below the foot plate allows for attachment of a shoe tread.

Postoperative Management

Drains are used if there is concern for hematoma formation postoperatively. The patient is kept non-weight bearing and immobilized with compression either in a posterior splint, or protective below-the-knee cast. Serial radiographs are obtained and patients are transitioned to partial weight bearing in the frame or below-the-knee cast or brace once signs of trabeculation appear. Partial weight bearing most commonly begins by the eighth week with full weight bearing by week 12. Patients should be kept in either a protective cast or below-the-knee brace until an appropriate brace or accommodative shoe gear is constructed.

Complications and Outcomes

Complications should be anticipated and handled quickly. Wound healing problems frequently occur. Other complications may include, but are not limited to, nonunions, delayed unions, malunions, infections, hardware complications, reulcerations, pin track infections, and postoperative edema.

REARFOOT

Elective rearfoot surgery is undertaken when one or a combination of the following goals needs to be achieved: stability, realignment of the rearfoot to the leg and midfoot, and prevention of infection and subsequent amputation from skin breakdown or ulceration.

Instability in combination with malalignment is often the primary underlying cause of chronic ulcerations. This combination can have devastating consequences, leading to skin breakdown, infection, and eventual amputation. Although the risk of surgical complications is greater when the primary deformity is more proximal, so is the risk of amputation when conservative measures fail. Bracing and customized shoes are often a challenge. When conservative measures cannot heal a chronic ulceration, aggressive surgical intervention may prevent limb amputation and an unnecessary course of prolonged non-weight bearing and patient deconditioning. The severity of these problems usually requires some form of arthrodesis procedure.

TRIPLE ARTHRODESIS

Indications

Triple arthrodesis can be a powerful procedure, achieving all the goals of rearfoot surgery in the neuropathic patient: stability, realignment of the rearfoot to the leg and midfoot, and prevention of infection from skin breakdown secondary to deformity. It is usually performed in combination with a TAL for many neuropathic patients. Lengthening the Achilles tendon first helps mobilize the calcaneus to aid in correction as well as decrease the amount of propulsive forces transmitted to the forefoot following fusion of these joints (Fig. 4.27). In addition, a modified triple arthrodesis is sometimes necessary in neuropathic patients, especially in the setting of Charcot neuroarthropathy. By fusing additional joints, screw purchase and stability improve because the threads of the screws are bypassing the pathologic bone (Fig. 4.20B).

Surgical Technique

INCLUSION. Following the TAL, the triple arthrodesis classically begins with a lateral incision that starts just inferior to the lateral malleolus and ends at the base of the fourth and fifth metatarsals. Excellent exposure of the calcaneal-cuboid and subtalar joints can be obtained through this approach. The lateral aspect of the talonavicular joint also may be visualized, but a second medial incision is often required to gain full access to this joint, especially with an abducted foot. Exposure is obtained in layered dissection, reflecting the extensor digitorum brevis superiorly and peroneal tendons inferiorly. It is sometimes necessary to resect the calcaneal-fibular ligament to gain access to the subtalar joint; therefore, it should be repaired at the conclusion of the case to avoid future lateral ankle instability.

The medial incision begins just anterior to the medial malleolus and curves over the talonavicular joint, ending at the inferior aspect of the navicular-cuneiform joint. This incision can be extended distally if additional medial column joints require formal fusion. Complete visualization of the talonavicular joint as well as the dorsal talar neck can be achieved through this incision (44).

JOINT PREPARATION. With the calcaneal-cuboid, subtalar, and talar-navicular joints exposed, the surgeon may use the method of choice to remove the cartilaginous surfaces. If wedges of bone are removed to correct bony malalignment, a power saw or osteotome may be used, but care must be taken to avoid thermal necrosis. Wedging procedures can be very effective in correcting all planes of deformities. Alternatively, if shortening prohibits wedging, a curettage technique may be employed. This preserves bony contours and prevents loss of foot height that may sometimes cause shoe irritation from the malleoli postoperatively. Regardless of the technique, all cartilage is denuded and the bone surfaces are fenestrated with a K-wire or shingled with a small osteotome to promote subchondral bleeding.

Malalignments can also be corrected with interpositional bone allografts. An interpositional allograft placed within the subtalar joint can help correct varus or valgus deformities. Allograft is also frequently interposed between the calcaneus and cuboid to lengthen the lateral column in severely abducted feet.
Sliding of the tarsal bones can also be used to alter arch height, but can be difficult to perform if the deformity is very rigid.

**POSITIONING.** Whether wedging, sliding or interpositional grafting is performed, preservation of bone contours is employed. The ultimate goal is to achieve good alignment, thus preventing skin breakdown and future ulcerations. First, alignment of the rearfoot to the leg should be assessed. The heel is best evaluated from a posterior orientation and should be rectus to slightly everted in relation to the leg. In the sagittal plane, the calcaneal inclination angle should be 15 to 20 degrees and the lateral process of the talus should bisect the longitudinal axis of the tibia. Finally, the foot should be placed in 10 to 15 degrees of abduction in the transverse plane. With the rearfoot now aligned to the leg, the forefoot-rearfoot relationship should be assessed. The subtalar joint is placed in 5 to 10 degrees of valgus, with the talar-calcaneal angle 15 to 35 degrees. The longitudinal bisection of the talus should be as close to collinear as possible to the first metatarsal on the sagittal plane views.

**FIXATION TECHNIQUES.** Once proper alignment of the triple arthrodesis has been achieved, a number of different fixation modalities have been effective. Traditionally, the subtalar joint is fixed first, however, in severe deformity correction; the fixation order may need to be altered. Particularly in the setting of Charcot, our institution advocates fixation across the primary deformity first. Because a collapsed medial arch is often the most severe aspect of these deformities, fixation of the medial column is often addressed initially. Achieving collinearity of the talus and first metatarsal is stressed and sometimes requires a more extended fusion of the medial column. Furthermore, like midfoot arthrodeses, it is our institution’s experience that it is necessary to use more fixation and sometimes requires a more extended fusion of the medial column. Additionally, any remaining bony prominence can lead to future ulceration in neuropathic patients. Whether screws, staples, plates, wires, pins, or external fixation is used, it is important to have compression, strength, and stability across the fusion sites.

**Postoperative Management**

If necessary, closed suction drains are used to prevent hematoma formation and the incisions are closed in a layered fashion. The foot is dressed with a dry sterile dressing and a compressive posterior splint is applied to the leg. The patient is kept non-weight bearing with elevation and once the drain is removed and edema controlled, a below-the-knee fiberglass cast is applied. It is important to cast only after swelling has gone down, as severe wound problems can occur from cast irritation in neuropathic patients. If concern exists, a bivalve cast may be applied until the surgeon is comfortable placing the patient in an enclosed fiberglass cast. Sutures may need to remain in for up to 3 to 4 weeks and the patient is kept immobilized and non-weight bearing until radiographs demonstrate evidence of consolidation. Typically, the patients are progressed to partial weight bearing at 6 to 8 weeks with fullweight bearing in a below-the-knee walking boot or cast at 10 to 12 weeks. Physical therapy is frequently needed during the postoperative period because of activity adjustments and deconditioning.

**COMPLICATIONS AND OUTCOMES.** Wound healing problems in this patient population are essentially expected, but with proper debridement and wound care, are seldom an issue. Other complications include but are not limited to postoperative infection, edema, nonunions, delayed unions, malunions, and hardware complications.

**REALIGNMENT CALCANEAL OSTEOTOMIES**

Realignment calcaneal osteotomies are an effective and powerful way to realign the rearfoot to the leg. These may be isolated procedures or can be built into a fusion procedure, depending on the situation (45). Two procedures that are commonly used in neuropathic patients are the Evans and posterior calcaneal displacement osteotomy.

**Lateral Column Lengthening**

Evans lateral column lengthening can achieve triplanar correction when there is primarily forefoot abduction combined with some valgus deformity and sagittal collapse. Although lateral column lengthening is traditionally recommended for flexible deformities, it can be built into triple arthrodesis procedures as well by lengthening through the calcaneal cuboid fusion. The lateral column lengthening swings the forefoot out of abduction and concomitantly tightens the peroneus longus. This indirectly increases arch height by plantarflexing the first ray, and supination of the subtal joint is also achieved. A concomitant medial column arthrodesis or plantarflexory osteotomy may be necessary to achieve balance and avoid new areas of preulcerative lesions in neuropathic patients (46).

**Posterior Calcaneal Displacement Osteotomy**

When dealing with primarily frontal plane valgus deformities, a posterior calcaneal displacement osteotomy (PCDO) or Koutsoiannis osteotomy may be beneficial. Like the Evans, this procedure is also typically recommended for flexible deformities without arthritic rearfoot changes. However, this osteotomy may be used in conjunction with subtal or triple arthrodesis. In fact, this is preferred over trying to obtain frontal plane correction through the subtal fusion site with bone resection and/or allograft wedges. Correcting frontal plane deformities through subtal fusion site can be very difficult and technically demanding because of its shape. Instead, a PCDO may be done in addition to the planned subtal fusion with two large screws capturing both the osteotomy and STJ fusion site (Fig. 4.28). It is also recommended to bevel and smooth the prominent cortical shelf after medial translation of the calcaneus. Any remaining bony prominence can lead to future ulceration in neuropathic patients.

![Figure 4.28](image-url) Calcaneal osteotomies may be used to correct frontal plane malalignment in conjunction with a subtal joint arthrodesis. (Courtesy of Philip Basile.)
OTHER REARFOOT AND ANKLE ARTHRODESES

Other triple-like variations may be required depending on the amount and location of deformity. More extensive fusions such as a pan-talar fusion or a rodding of the entire medial and lateral column may be necessary. When malalignment or significant instability of the ankle joint exists to the point that there are preulcerative regions or ulcerations with bracing, it should be fused in neuropathic patients. Multiple studies have evidenced that Charcot deformity of the ankle, which accounts for 5% of the patterns, can have the most devastating results (47–49). The goals of surgery and indications are similar to the triple arthrodesis. However, it cannot be emphasized enough that positioning of the joints is critical and malalignment can cause problems that are worse than the original deformity. It is also important to remember to evaluate the entire extremity. The location of the primary deformity must be determined and more proximal mal-alignments should be addressed first.

TIBIAL-CALCANEAL ARTHRODESIS FOLLOWING TALECTOMY

Indications

It is important to address the talus and determine its overall integrity. Neuropathic patients with severe malalignment may be ambulating directly on a malleolus or a portion of the talus (Fig. 4.29). Sometimes the talus may not be salvageable if it has had osteomyelitis, avascular necrosis, or destruction from Charcot neuroarthropathy. The role of the talectomy traditionally has been reserved for residual pediatric deformities, but is also indicated in this situation (50–55). Prior to reconstructive surgery, resolution of infection and wound closure should be attempted. This may require off-loading techniques, staged débrideaments with antibiotic beads, skin grafts, and flaps.

Surgical Technique

Surgical technique is demanding, and attention to alignment with respect to the entire limb is critical. Complications should be expected and treated early. The tibial-calcaneal fusion can be performed in the supine position with the limb draped proximal to the knee and patella forward for proper alignment planning. A transfibular lateral approach allows excellent exposure for talectomy and preparation of the articular surfaces.

Proper alignment with good apposition of bony surfaces is critical for long-term success. Direct contact between the calcaneus to the tibial plafond without remodeling or en bloc bone graft will result in an iatrogenic calcaneal gait position because of the angulation of the calcaneal posterior facet. To avoid this, femoral head allograft fashioned intraoperatively has been utilized for our group to achieve good apposition, deformity correction, and minimization of leg length discrepancies (56, Philip Basile, personal communication) (Fig. 4.30A,B). The

Figure 4.29  Ankle Charcot is often unstable and progressive requiring major arthrodesis procedures. This is an example of a medi ally subluxed talus in which a neuropathic patient was ambulating on.

Figure 4.30  A,B. Following talectomy, allograft can be used to maintain proper positioning of the rearfoot to the leg to avoid a calcaneal gait following arthrodesis. (Photographs courtesy of Philip Basile.)
final foot position should be in neutral sagittal plane position to the leg, 0 to 5 degrees of frontal plane valgus, 5 to 10 degrees of external rotation, and slight medial and posterior translation of the foot. This step in the procedure is the most time consuming but is necessary for success.

Fixation Techniques. A variety of fixation techniques have been described including screws (57,58), Steinmann pins (59), plates (60–62), external fixation (63–65), and intramedullary nailing (66). Each modality has its advantages and disadvantages; there is no consensus on the best method of fixation.

Our institution advocates use of a circular external fixation device over a retrograde intramedullary nail (IMN) when facing tibial-calcaneal arthrodesis following talectomy in neuropathic patients (Fig. 4.31). With regard to strength and stiffness, IMNs have been found to be significantly stiffer in all bending and torsional directions compared with crossed lag screws (67,68). Recent literature has also demonstrated that uniplanar IMNs were equivalent to blade plates but have the advantage of less dissection, do not rely as much on bone mass or quality, and can be dynamically locked (69). The external fixator is also minimally invasive and acts as an additional stabilizing force. This load-sharing combination allows for a quicker transition to protected weight bearing as the frame helps to eliminate damaging forces and promotes coaxial weight bearing through the fusion site.

Postoperative Management

Serial radiographs are obtained and patients are transitioned to partial weight bearing in the frame once signs of trabeculation appear. Partial weight bearing most commonly begins by the eighth week, with full weight bearing in the circular frame by the 12th week. Patients should be placed in either a protective cast or below-the-knee brace following frame removal until a custom locked nonarticulated ankle-foot orthoses (AFO) is constructed.

Complications and Outcomes

Complications should be expected and handled quickly and aggressively. Mendicino et al illustrated the increased risk of diabetes to develop major complications in IMN procedures (70). Stuart and Morrey experienced a complication rate of 78% if Charcot was present (71). This includes but are not limited to nonunions, delayed unions, malunions, infections, wound healing problems, hardware complications, pin track infections, tibial fractures, postoperative edema, and a number of serious medical complications, including the increased risk of deep vein thrombosis and pulmonary embolus.

Calcanectomies

Heel ulcerations are a frequently encountered clinical entity, often the result of prolonged static bed rest. They are typically located along the posterior surface; however, plantar heel ulcers occur too. Nonhealing wounds should be evaluated for chronic infection or osteomyelitis. Most importantly, the vascular status must be carefully assessed in this setting.

Indications

Depending on the size of the problematic bone, a simple exostectomy may be adequate; however, for more extensive involvement, some type of calcanectomy may be required (Fig. 4.32). Calcanectomies are only recommended for well-perfused limbs when ulceration with osteomyelitis exists or if the patient is minimally ambulatory and primary wound closure is desired. The goals of a calcanectomy are to remove infected bone and create redundancy for primary wound closure, which should help facilitate wound healing to avoid more proximal amputations.
Chapter 4 Elective Surgery for the Neuropathic Diabetic Foot

CALCANECTOMY CLASSIFICATION. There are three degrees of calcaneectomy; the most extreme is the total calcaneectomy. Indications for a total calcaneectomy are limited and often result in destabilization of the ankle joint. More commonly, the partial and subtotal calcaneectomies are used to achieve the goals previously mentioned. The exact definition of each procedure has not been previously described and is generally related to the amount of bone resected. At our institution, we consider the procedure to be a partial calcaneectomy if at least one third of the calcaneus is resected. However, if the resection requires removal of the calcaneal tuber and therefore Achilles tendon detachment, it is classified as subtotal calcaneectomy (Table 4.3).

Surgical Technique

A longitudinal elliptical incision encompassing the ulceration is made on the posterior surface of the calcaneus. After isolation of the calcaneus, an oblique osteotomy, large enough to include all infected bone is oriented dorsal-proximal to plantar-distal (Fig. 4.33). This may be performed with a power saw starting laterally, but should be finished off with an osteotome or laminar spreader to avoid damaging the medial neurovascular structures. The planter edges are then rounded off with a rongeur and then smoothed with a rasp.

If possible, the wound is closed using nonabsorbable suture over a closed suction drain (Fig. 4.34). If infection was present or significant loss of soft tissue, it may be left open to heal by secondary intention. Once infection has been eradicated, open wounds should be closed quickly and adjunctive measures may be indicated in these situations. Whether negative pressure wound therapy, advanced wound care products, bioscaffold, skin grafts, or flaps are used, the goal is to prevent further patient deconditioning and reinfection from open ulcerations. If the procedure is a subtotal calcaneectomy, the Achilles tendon is typically not reattached, but is left to fibrose to surrounding tissues. Reattachment requires an advancement of the Achilles tendon and an anchoring device, which could serve as a nidus for infection.

Postoperative Management

Postoperative care consists of prolonged non-weight bearing and immobilization until the soft tissues heal. Patient counseling regarding a realistic postoperative course must be discussed. Wound healing complications are frequent, especially when surgical sites can not be primarily closed, and is generally a long drawn-out process. Certain factors can predictably lengthen the recovery period, including Grade 3 Wagner ulcers, patients with poor albumin levels, those infected with methicillin-resistant Staphylococcus aureus (MRSA), and those with peripheral vascular disease. Long-term postoperative care requires the use of an accommodative shoe and AFO (72).

Complications and Outcomes

Cook et al reported the results of 51 calcaneectomies (39 partial, 12 subtotal) with a mean follow-up of 33 months. Overall limb salvage was achieved at 1 and 4 years in 89% and 80%, respectively. There was a 69% healing rate; 65% of the patients were ambulatory by the conclusion of the study. Thirty-five percent of patients required some form of revision, most frequently skin grafting or local flap, to achieve wound closure (72).

### TABLE 4.3

<table>
<thead>
<tr>
<th>Class</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Total calcaneectomy</td>
<td>Complete removal of the calcaneus</td>
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<tr>
<td>Subtotal calcaneectomy</td>
<td>Partial resection of the calcaneus, including removal of the calcaneal tuber</td>
</tr>
<tr>
<td>Partial calcaneectomy</td>
<td>At least one third of the calcaneus resected but Achilles tendon still intact</td>
</tr>
<tr>
<td>Calcaneal débridement</td>
<td>Removal of less than one third of the calcaneus with an intact Achilles tendon</td>
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INTRODUCTION

There has been a significant emphasis on the association of peripheral arterial disease (PAD) and diabetes with very little written about venous disease in the diabetic population. Although there is not a direct causal relationship between diabetes and venous disease, there are factors that increase the risk of both diabetes and venous disease, for example, obesity. There are also multiple publications discussing the possible links between arterial and venous disease (1,2). Venous disease is common in the diabetic population and can be the etiology of lower extremity ulcers and also a negative factor for healing ulcers or wounds of any etiology. Worldwide, it is estimated that 3% to 5% of the population has venous disease. Venous ulcers occur in 1% to 2% of the population. In America, it is estimated that 500,000 patients have venous ulcers with an annual healthcare cost of $1 billion per year (3,4).

Diabetic patients already have multiple factors that have a negative impact on wound healing; the presence of venous disease and/or edema can be an additional negative healing factor. In the diabetic patient, venous insufficiency and/or edema represents a significant risk factor for ulceration or poor wound healing. Regardless of the etiology of wounds or ulcerations, the coexisting presence of edema and/or venous insufficiency represents a risk factor for poor healing. The presence of edema and/or venous insufficiency also represents a risk factor for wound complications in elective surgical procedures on the diabetic foot. Therefore, when managing the diabetic foot, it is important to understand and manage venous insufficiency and/or edema.

Edema may be caused by venous insufficiency or secondary to other medical illnesses. In our vascular surgery clinic, 40% of patients referred with a diagnosis of venous insufficiency had a completely normal venous duplex scan, and it was determined that the edema was caused by cardiac dysfunction or other medical conditions. It is important to distinguish between the two types of edema. Edema secondary to venous insufficiency can be selectively treated surgically, although the mainstay of treatment is external compression. Diuretics play no role in the management of edema secondary to venous insufficiency. Edema secondary to cardiac dysfunction is treated by improving cardiac performance and diuretics in addition to external compression. The presence of edema secondary to cardiac dysfunction may also indicate that the patient has significant congestive heart failure, making that patient at higher risk for perioperative cardiac complications. If edema is present in diabetic patients, the etiology of the edema should be assessed and treated prior to elective reconstruction of the diabetic foot. If the edema is because of cardiac dysfunction, a preoperative cardiac evaluation is indicated.

VENOUS ANATOMY

There are three components of the venous system in the lower extremity: the deep veins, the superficial veins, and the perforator veins. The deep veins are located adjacent to the major arteries of the lower extremity and have the same names: the common femoral, profunda femoral, femoral (previously called the superficial femoral), popliteal, posterior tibial, anterior tibial, and the peroneal veins. The anterior tibial, posterior tibial, and peroneal veins are also referred to as the calf veins. The deep veins are the major system for venous return to the heart. It is estimated that 80% of the venous return flows through the deep venous system. The superficial veins are the greater saphenous, the accessory greater saphenous, and the lesser saphenous veins. The perforator veins connect the superficial and deep venous systems and have valves that normally direct venous flow from the superficial veins into the deep veins. The perforator veins are generally classified into one of four groups, depending on the location. The Hunterian perforators are located in the thigh. Dodd and Boyd perforators are located above and below the knee. The Cockett perforators are located in the calf. The superficial and deep veins have a series of one-way valves that direct flow toward the heart and prevent reflux flow toward the feet.
PHYSIOLOGY

Flow in the venous system is dependent on three factors: the muscle pump, competent valves, and a vis a tergo, or force from behind. If a patient is paralyzed and cannot move the muscles in the lower extremity, edema will accumulate. This is seen in patients with paraplegia or stroke. If patients do not ambulate, edema can accumulate because of inactivity of the muscle pump. When the muscles contract, the blood is propelled toward the heart, and reflux (reversed flow) does not occur because of the one-way valves. With the combination of the muscle pump and the competent valves, the pressure in the deep veins is low during activity and gradually returns to baseline following activity. Because the muscle pump is so important in promoting venous return, it is not surprising that exercise designed to improve calf muscle function has been shown to help patients with venous insufficiency. If there is obstruction of the venous system or incompetent valves, the pressure in the veins stays high, even with activity. This is referred to as ambulatory venous hypertension. Ambulatory venous hypertension leads to the clinical syndrome of venous insufficiency.

VENOUS PATHOLOGY

Venous insufficiency can be caused by either valvular incompetence, venous obstruction, or a combination of the two. Primary valvular incompetence of the superficial venous system is the most common. It has been estimated that as high as 15% of the adult population has a component of valvar dysfunction in the superficial veins. Primary valvular dysfunction can also occur in the deep veins or the perforator veins, although it is not very common. Primary valvular dysfunction accounts for 90% of the venous pathology. Primary valvular dysfunction commonly leads to varicose veins and less commonly leads to significant stasis dermatitis and/or ulceration. Secondary valvular dysfunction occurs as a result of obstruction and/or incompetence of the deep venous system most commonly from previous deep vein thrombosis (DVT). Obstruction or incompetence of the deep vein system leads to secondary reflux of the perforator veins, leading to secondary reflux in the superficial venous system. Perforator incompetence is associated with the skin changes and ulcerations seen with venous insufficiency. It is estimated that up to 66% of patients with significant lipodermatosclerosis or ulcers have perforator incompetence in addition to superficial and/or deep venous reflux. The CEAP classification (clinical, etiologic, anatomic, and pathologic) is used to classify venous diseases (5–7).

Venous insufficiency is a general term indicating that there is something insufficient in the venous system. The problem can be valvular incompetence, obstruction, or a combination of both. Venous insufficiency refers to the physiologic consequence of either venous obstruction, valvular incompetence, or a combination of the two. Venous obstruction and/or incompetence leads to ambulatory venous hypertension. Ambulatory venous hypertension affects the microcirculation leading to increased vascular permeability with leakage of plasma and erythrocytes into affected tissue. Increased levels of leukocytes are found in tissue exposed to venous hypertension. It has been theorized that activated leukocytes release free radicals that contributes to tissue necrosis. Another mechanism that may contribute to skin changes and/or venous ulcers is a local deficiency in the fibrinolytic process resulting in a pericapillary fibrin cuff. The fibrin cuff can lead to tissue hypoxia and cellular death. Before labeling a patient as having venous insufficiency, it is important to evaluate the venous system documenting that there is indeed obstruction and/or incompetence of the venous system. Patients with other causes of edema can have many of the secondary skin changes usually associated with venous insufficiency; however, the treatment is different. A venous duplex scan is used to evaluate the presence or absence of true venous insufficiency. Figure 5.1A-B illustrates the difference between a true venous ulcer and ulceration associated with edema in patients with congestive heart failure.

DIAGNOSIS

The patient should be questioned about any history of DVT. In addition, a history of blunt extremity trauma and/or fractures involving the extremity or prior surgery of the extremity can be important. DVT can occur in these conditions and can go undiagnosed because the edema was felt to be secondary to the trauma or the operation. Any family history of varicose veins can be important because of the familial tendency of superficial venous incompetence. The history should also evaluate the presence of medical conditions that may contribute to edema. Patients should be questioned about changes in the degree of edema during the day. In general, edema, because of either venous insufficiency or a medical condition, decreases during the night when the patient is recumbent and increases during the day if the patient is on his or her feet. Edema that does not decrease at night and stays stable during the day is most likely lymphedema. If the patient wears support hose, that should be noted in the history. A prior history of ulceration or poorly healing wounds can be important.

The physical exam includes documenting the presence and location of varicose veins. This is best determined with the patient in a standing position. The presence, degree, and location of edema should be documented. Edema extending onto the dorsum of the foot and involving the toes is generally an indication of lymphedema. This may lead to square-shaped toes referred to as the Stemmer sign (8). Hyperpigmentation, stasis dermatitis, atrophic blanche (white scarring at the site of previous ulceration), or lipodermatosclerosis should be documented. Any skin ulceration or scars from previous ulceration should be noted. A tourniquet test (Trendelenburg test) may be performed to localize perforators and distinguish deep from superficial venous reflux. The test is initiated with the patient supine to empty the varicosities. The patient then assumes an upright posture with a tourniquet applied at various levels. If the varicosities do not fill with a high-high tourniquet, this indicates saphenofemoral incompetence at the groin level. If the varicosities fill with a high-high tourniquet in place, this indicates perforator incompetence below the tourniquet. By repeating the test with the tourniquet at various levels, the location of the perforators can be identified.

Although a history and physical exam can be very suggestive of venous disease, the definitive diagnosis of venous disease is made with a color/venous duplex scan. Therefore, if the history and physical exam suggest venous insufficiency, a venous duplex scan is indicated. The exam should be performed by an
experienced vascular technician, and it should include an examination of all three venous systems: the deep, superficial, and perforator veins. The exam documents the presence and location of venous reflux and/or obstruction. A normal duplex scan indicates that the edema and/or skin changes are from another etiology, most commonly cardiac dysfunction (9,10). Other systemic causes of edema include nephrosis, liver disease, and endocrine disorders. Edema may also be secondary to medications, for example, calcium channel blockers used for the treatment of hypertension, nonsteroidal anti-inflammatory agents, and oral hypoglycemic agents.

TREATMENT

If the history, physical exam, and venous duplex scan document venous insufficiency, the patient should be treated. The first-line treatment of venous disease is external compression. If compression fails to control the patient’s symptoms and/or heal a venous ulcer, the patient may be a candidate for venous surgical intervention. There are multiple surgical options available for treatment of venous insufficiency. If a patient has isolated superficial incompetence or a combination of superficial and deep vein incompetence, then treating the superficial system is the usual initial step. There are several options available for treatment of superficial venous insufficiency. The traditional method of treatment was ligation of the saphenofemoral junction with or without stripping of the greater saphenous vein and micro phlebectomies of additional varicosities in the leg (Fig. 5.2). The less invasive endovascular treatment of varicose veins is replacing traditional ligation and stripping in a high percentage of patients. This procedure is less invasive and avoids some of the morbidity of traditional ligation and stripping (11–13). The endovascular obliteration of varicose veins can be accomplished with either laser or radiofrequency. Figure 5.3A–E illustrates the endovenous obliteration of varicose veins using a laser catheter. For patients with incompetent perforators, an above-mentioned procedure should be performed to eliminate the superficial component of reflux; if the patient still has ulcers in the area of the perforators, a more focused attempt to ligate or clip these perforators is performed. One of the procedures used to treat incompetent perforators is subfascial endoscopic perforator surgery (SEPS), in which a scope is placed in the subfascial plane of the leg and the perforators are clipped. Other options include foam or liquid sclerotherapy of the perforator veins (14,15). Radiofrequency has also been used to treat incompetent perforators. Treatment of incompetent perforator reflux can play an important role in the management of chronic venous insufficiency and stasis ulceration. Open ligation of the perforators (the Linton procedure) is
of historical interest only because these procedures created large wounds often difficult to heal (16). In regard to therapy of deep venous reflux, compression is the mainstay with some centers performing venous valve transplant and/or valvuloplasty (suture repair of the valve) for severe deep venous reflux. Venous bypass procedures are another option for severe obstructive disease of the deep venous system (17,18). The type of surgical procedure depends on the type and location of the venous insufficiency. The details of these procedures are beyond the scope of this chapter; however, the procedures can treat the underlying cause of the venous insufficiency and decrease the edema and/or risk of wound problems associated with venous insufficiency. Direct operative procedures of the venous system have also been shown to decrease the recurrence rate of venous ulcers (17,18).

Compressive therapy is the first-line treatment of choice for venous insufficiency and may be required even if the patient has surgical correction of venous insufficiency. Prior to the application of compressive therapy, a pulse exam should be performed. If the patient has palpable pulses, compression can be applied. If pulses cannot be palpated, an ankle-brachial index (ABI) should be performed. The details of this exam are part of the arterial chapter. If a diabetic patient has ABIs <0.7 or noncompressible vessels, graded support hose carry a risk of causing skin breakdown (Fig. 5.4). The degree of compression depends on the degree and type of venous insufficiency. The degree of compression is listed as mm Hg compression. The mm Hg indicates the average measurement of compression at the ankle. Ready-to-wear lightweight compression stockings are available in 8 to 15 mm Hg and 15 to 20 mm Hg. These stockings are used mainly for comfort and prevention. Indications include minor varicosities, minor varicosities during pregnancy, minor edema, and post-sclerotherapy. Medical grade class 1 support hose (20–30 mm Hg) are indicated for moderate to severe varicosities, mild to moderate edema, prevention of recurrent venous ulcers, superficial thrombophlebitis, and deep vein thrombosis. Medical grade class 2 support hose (30–40 mm Hg) are indicated for severe varicosities, severe edema, chronic venous insufficiency, venous ulcers, deep vein thrombosis, and reversible lymphedema. Medical grade class 3 support hose (40+) are indicated for severe edema, lymphedema, and the management of active ulcers with post-phlebitic syndrome (19).

Patients with edema from medical causes can also be helped with support hose, although they should also be treated with diuretic therapy. The same precautions apply to reference, assuring adequate arterial perfusion prior to the application of compression therapy.

Patients may also develop edema in the postoperative period following reconstruction of the diabetic foot. Although this may be a direct consequence of the procedure, it may be an indicator of DVT or cardiac decompensation. Cardiac decompensation generally causes bilateral lower extremity edema. Unilateral postoperative edema may be a sign of DVT. This can be ruled out with a venous duplex scan. Postoperative edema is a negative factor for healing; therefore, the etiology and appropriate treatment should be determined. Edema that develops with resumption of ambulation following surgical reconstruction can lead to wound breakdown, so again the etiology should be determined and the edema treated. Many times following complex reconstruction procedures, external compression cannot be applied, and edema is controlled with bed rest and elevation.

Intermittent pneumatic compression (IPC) can be used to control edema in patients with venous insufficiency or edema.

**Figure 5.2** Ligation and stripping of the greater saphenous vein. A. Lower extremity demonstrating a small venous ulcer, lipodermatosclerosis, and varicose veins. B. Greater saphenous vein isolated at the level of the knee. Once the vein is isolated, a stripper can be passed from the lower incision to an incision in the groin. C. A stripper that is passed through the vein. D. Removed greater saphenous vein.
Figure 5.3  Endovenous treatment of varicose veins.
A. Ultrasound-guided access of greater saphenous vein.
B. Placement of sheath into the greater saphenous vein.
C. Ultrasound image of laser catheter inserted into the greater saphenous vein and positioned just below the saphenofemoral junction using ultrasound guidance.
D. Laser activated and withdrawn to ablate the vein intraluminally.
E. Example of prelaser and postlaser treatment of varicose veins.
because of other etiologies. This can be very useful in the initial control of edema and can be used long-term with external compression (20).

VENOUS ULCERS

Venous ulcers generally occur as a result of ambulatory venous hypertension and perforator incompetence leading to local tissue venous hypertension, inflammation, and ischemia. The ulcers are usually located in the so-called gaiter area above the medial or lateral malleoli (Fig. 5.1A). Venous ulcers occur in the location of incompetent calf perforator veins. Venous ulcers do not occur on the feet; however, if a patient develops an ulcer on the foot from any etiology and has associated edema and/or venous insufficiency, it can be a negative healing factor. Ulcers that occur in the pretibial area are often a result of edema from other etiologies. A clue can be a history of rapid accumulation of edema followed by blistering that lead to ulceration. This is most commonly seen in patients with poorly controlled congestive heart failure (21).

Apparent venous ulcers that do not respond to treatment after 6 weeks should be considered for biopsy. Other indications to biopsy an ulcer include an ulcer in an abnormal location or an ulcer that has an atypical appearance (22). The biopsy should include tissue for pathologic examination as well as tissue for culture. Cultures for mycobacteria as well as fungi should be included. In addition to ruling out malignancy, pathologic exam can document vasculitis, collagen vascular disease, as well as dermal manifestations of other systemic diseases. Patients with sickle cell disease can also present with ulcers that resemble venous ulcers. Documentation of these conditions can be very important if considering elective reconstruction of the diabetic foot in patients who have mixed disease. Apparent venous ulcers that are failing to heal, increase in size after débridement, and are painful may represent pyoderma gangrenosum.

Pentoxifylline, used in addition to moist wound care and compression therapy, has been demonstrated to improve healing of venous ulcers. Although there is currently no strong evidence, the addition of pentoxifylline in diabetic patients with venous disease may prove to be an adjunct to healing of the reconstructed diabetic foot in this population with mixed disease (23).

The initial treatment of venous ulcers is débridement, moist wound care, and external compression. In the acute stage of a venous ulcer, multiple layers of external compressive dressings are preferred to graded support hose (24,25). If a venous ulcer is not healing with appropriate wound care and external compression or if a venous ulcer reoccurs, reconstruction of the venous system should be considered (21). (See the preceding section on surgical treatment of venous disease.) In a patient with a venous ulcer that has both superficial and deep venous disease as well as perforator disease, the first-line approach is treating the superficial venous disease and the perforator incompetence. Only if these procedures fail, direct surgery on the deep venous system may be indicated for treatment of venous ulcers.

Venous ulcers are prone to develop bacterial colonization that contributes to poor healing. If increased colonization is suspected because of increased drainage or failure of epithelialization, the addition of topical antibacterial agents is indicated. These antibacterial dressings, for example, silver dressings are used in addition to external support. Systemic antibiotics should be avoided unless the patient develops signs of cellulitis. Cellulitis around a venous ulcer is most common because of streptococci or staphylococci and should be treated with appropriate antibiotics.

Although cytokine growth factor has been suggested as an adjunct to healing venous ulcers, there is no strong evidence to support their use. Topical application of oxygen-derived free radical scavengers or fibrinolytic agents have been reported to improve healing, although further controlled studies are required to document their potential benefit.

The addition of living cell therapy in conjunction with external compression improves the healing rate of venous ulcers (26). Apligraf is approved by the FDA for the treatment of noninfected partial- or full-thickness venous leg ulcers that have not adequately responded to at least 4 weeks of conventional therapy.

Wound bed preparation using negative pressure therapy can be helpful in preparing a wound for a split thickness skin graft (STSG). Although STSG may provide temporary coverage, the underlying ambulatory venous hypertension still needs to be addressed. Skin grafting of a venous ulcer without treating the underlying venous disease is not a good long-term solution (27).

Once a venous ulcer is healed, graded support hose are still indicated to decrease the incidence of recurrence. The 5-year recurrence rate of healed venous ulcers can be as high as 40%.
Support hose have been shown to decrease the recurrence rate. One study demonstrated a 19% rate of recurrence with the use of support hose and 69% recurrence rate in patient not wearing support hose after the ulcer was healed (7, 24–28).

**CONCLUSION**

Venous insufficiency and/or edema can result in lower extremity ulcers in the diabetic patient. More commonly edema and/or venous insufficiency can be a significant risk factor for poor healing of ulcers of any etiology or poor healing of surgical incisions. The presence of edema and/or venous insufficiency represents a risk factor for wound complications in elective surgical procedures on the diabetic foot. Therefore, when managing the diabetic foot, it is important to understand and manage venous insufficiency and/or edema.

**REFERENCES**

CHAPTER 6

Vascular Assessment and Reconstruction of the Ischemic Diabetic Extremity

INTRODUCTION

Before any elective or emergent reconstruction of the diabetic foot, it is important to evaluate the adequacy of arterial perfusion to the foot and lower extremity. Inadequate perfusion can contribute to lack of healing and tissue breakdown and predisposes to infections. Inadequate perfusion should be corrected before elective procedures with endovascular therapy, traditional bypass procedures, or a combination of both. With emergent procedures on the diabetic foot, for example, incision and drainage of an abscess, adequacy of perfusion should be evaluated as soon as possible and inadequate perfusion should be corrected before any further definitive procedure. In general, inline pulsatile flow is needed to heal a typical diabetic foot ulcer or major reconstruction of the diabetic foot.

ANATOMY

The basic anatomy of the arterial tree to the lower extremity starts with the abdominal aorta, which then bifurcates into the common iliac arteries. These subsequently divide into the internal (hypogastric) artery that feeds the pelvis and the external iliac artery, which becomes the common femoral artery (CFA) after crossing the inguinal ligament. The CFA then divides into the profunda (deep) femoral artery and the superficial femoral artery (SFA). The profunda artery is an extremely important artery in regards to limb viability as it provides important collaterals as the SFA is prone to atherosclerosis. The SFA becomes the popliteal artery at the adductor hiatus in the thigh and the below-knee popliteal artery divides into the anterior tibial artery that becomes the dorsalis pedis artery as it crosses the ankle; the peroneal artery that runs in the deep posterior compartment and the posterior tibial artery which runs behind the medial malleolus (Fig. 6.1).

An understanding of basic vascular anatomy is critical to successful reconstruction of the diabetic foot. In addition to the mentioned arterial anatomy, the foot and ankle are composed of five distinct angiosomes (1). An understanding of the angiosomes is important in planning elective surgical procedures and also critical in planning effective revascularization of the ischemic foot. Taylor and Minabe defined an angiosome as an anatomic unit of tissue, fascia, muscle, and bone supplied by a source artery, for example, each of the three infrapopliteal arteries supplies specific angiosomes (2). Although there are connections between these units, the connections may be incomplete or interrupted with peripheral arterial disease or surgical procedures. Incorrect placement of surgical incisions can contribute to worsening of ischemia in an already compromised foot by interrupting collateral flow between angiosomes. Failure of traditional bypass procedures or endovascular therapies to achieve limb salvage can be the result of inadequate restoration of pulsatile flow to the appropriate angiosome. An understanding of regional ischemia and regional reperfusion of the foot is critical to limb preservation. The result of the traditional approach of supplying pulsatile flow to any of the infrapopliteal vessels may be inadequate revascularization. The goal of revascularization should be to supply pulsatile flow to the involved angiosome. Bulan et al reported on direct versus indirect revascularization of the ischemic foot and reported a 9.1% failure rate with direct revascularization to the involved angiosome versus a 33% failure rate with indirect revascularization. They concluded that revascularization to the involved angiosome results in a higher rate of limb salvage (3).

PATHOPHYSIOLOGY

The primary cause or underlying pathophysiology of peripheral arterial disease (PAD) in the diabetic patient is atherosclerosis. PAD in the diabetic patient has a different pattern than in the non-diabetic patient (4). The diabetic patient can have aortoiliac and femoral arterial disease; however, there is a tendency to develop more severe infrapopliteal disease with patency of the pedal vessels (5). As atherosclerosis progresses toward occlusion, particularly in multiple infrapopliteal vessels, it can lead to limb-threatening ischemia. Diabetic patients that present with...
Diagnosis of Peripheral Arterial Disease

Figure 6.1 Arteries of the lower extremity (anterior view).

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<tr>
<th>Table 6.1</th>
<th>Fontaine Classification of PAD</th>
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<td>Fontaine I—Asymptomatic PAD</td>
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<td>Fontaine II—Claudication</td>
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<td>Fontaine III—Ischemic rest pain</td>
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<td>Fontaine IV—Ulceration and tissue loss</td>
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**TABLE 6.1**

Fontaine classification of peripheral arterial disease (PAD). Classification is based on the patient’s symptoms.

A classification scheme of lower extremity arterial occlusive disease is the Fontaine classification scheme, which separates patients by symptoms (Table 6.1). It is as follows: I asymptomatic; II claudication; III ischemic rest pain; and IV ulceration and tissue loss (10). The arterial system functions like basic economics. It functions on the principles of supply and demand. If demand for blood supply exceeds the supply, patients develop symptoms. When patients are walking, there is more demand for blood supply to the legs. If there is PAD, demand can exceed capacity and patients develop lower extremity muscle pain (claudication). Claudication is pain in the lower extremity muscles that meets the following criteria: pain on exertion; pain relieved with rest; and pain that is reproducible and consistent every time the patient walks. Patients with significant PAD generally present with claudication although, patients with diabetes may have silent PAD caused by associated neuropathy. With a thorough history using the preceding criteria, claudication generally can be distinguished from musculoskeletal pain or pain from other etiologies. Patients with musculoskeletal pain complain of pain, not only when they are walking, but also when they are standing or changing positions. Musculoskeletal pain also follows a less consistent pattern. Patients with severe PAD may present with ischemic rest pain, which is defined as severe pain over the forefoot and toes, worsened with elevation and relieved with the leg in the dependent position. Rest pain should not be confused with leg cramps that occur in the calf.
or leg muscles. Leg cramps can be associated with many conditions and are generally not a sign of ischemia. The most important component of the vascular physical exam is the palpation of pulses. Although many systems of grading pulses have been suggested, unless the pulses are clearly palpable, further studies are indicated (11). Capillary filling times can be very misleading, especially in the diabetic patient with limb-threatening ischemia. In addition, the involved extremity may be cool and has atrophic thin skin with hair loss, although these signs are not specific for PAD.

**VASCULAR LAB**

If there is any question of PAD on the physical exam, a referral to the noninvasive vascular lab is appropriate, especially if the patient has a wound or a surgical procedure is contemplated. The noninvasive vascular lab can be very helpful in diagnosing PAD and identifying the location of the disease. The ankle brachial index is the next step in the workup of these patients after the physical examination. It is obtained by comparing the highest brachial systolic pressure with the highest pressure at the ankle (either the DP or PT). This can be performed with a hand held Doppler probe and a blood pressure cuff. If there is no PAD, the ankle pressure will be the same as the arm pressure. This gives an ankle brachial index of 1.0. As PAD develops, the ankle pressure decreases and the index therefore decreases. An ABI of <0.6 generally indicates inadequate perfusion to heal a wound on the foot. However, it is possible to have an ABI that is higher and still have significant regional ischemia of the foot. An ABI <0.3 is compatible with severe ischemia, ischemic rest pain, and tissue death (12). The Doppler signal heard at the ankle can also be characterized as triphasic, biphasic, or monophasic. As PAD progresses, the signal will change from triphasic to biphasic and with severe PAD to monophasic. The potential problem with the ABI in the patient with diabetes is that the ABI can be falsely elevated because of calcification in the arterial wall making the artery noncompressible (13). This can be deceiving in that the diabetic patient without palpable pulses may have an ABI of >1.0. The digital vessels are usually spared from calcification; therefore, toe pressures are more accurate in quantifying PAD in the diabetic patient (14). A toe pressure of 55 mm Hg or greater has been correlated with the ability to heal a foot ulcer in diabetic patients. Normal ABIs in the face of monophasic Doppler signals also indicates the ABIs are falsely elevated. Segmental pressures can be measured using four cuffs on the leg. There is a high-thigh cuff, an above-the-knee cuff, a below-the-knee cuff, and an ankle cuff. Pressures are measured at each level. By looking for pressure gradients between the cuffs, the location of the PAD can be determined (15).

Other noninvasive tools in the vascular lab include direct visualization of the artery performed with a duplex scan. This tool can help in identifying anatomy as well as localizing the areas of stenosis by measuring the velocity of the blood flow. In addition, transcutaneous oxygen tension (TcPO2) is an extremely valuable tool in examining the metabolic state of the target tissue in question. It is performed by placing probes on the foot and leg and using the chest as a reference site. TcPO2 levels of 20 mm Hg or less are indicative of severe lack of blood flow to the area, indicating a requirement for revascularization (16).

The diagnosis of PAD in the diabetic patient can be even more challenging because the diabetic patient may have significant PAD and be asymptomatic. The lack of symptoms can occur because of associated neuropathy or a lack of activity. The first manifestation of PAD may be a nonhealing ulcer or a surgical wound that is not healing. Therefore, it is very important to assess for PAD in the patients with diabetes, even if they are asymptomatic, especially if a surgical procedure on the foot is contemplated. The indications for a vascular consultation include an ABI <0.7. Toe pressures <40 mm Hg or transcutaneous oxygen tension (TcPO2) <30 mm Hg. A nonhealing foot ulcer is an additional indication for a vascular evaluation looking for regional ischemia in the diabetic foot. In a diabetic patient, the absence of palpable pedal pulses is an indication for vascular consultation if elective reconstruction of the foot is contemplated.

**RADIOLOGIC STUDIES**

PAD can further be evaluated with the use of radiologic studies (Fig. 6.2). Magnetic resonance angiography (MRA) is a noninvasive imaging technique that can be useful in evaluating PAD. There are some limitations with this imaging modality, including motion artifact and venous contamination, making the studies difficult to interpret (17). Computed tomography angiography (CTA) with subsequent reconstruction can allow for excellent visualization of the arterial tree, especially with the newer multislice scanners (18). CTA does require a high dose of contrast and therefore can be limited in diabetic patients with a component of renal failure. The standard for diagnosing PAD is digital arteriography, which allows for visualization of the arterial anatomy, including vessels in the foot and allows for the potential of concurrent therapeutic intervention. In planning elective surgical procedures in patients with PAD, it is important to have visualization of the vessels in the foot. This is also important when planning revascularization procedures. Using nonionic contrast and gadolinium when performing an arteriogram can limit the contrast insult to the kidneys (19). With the currently available endovascular technologies, many arteriograms are done with the intention to treat. By using the noninvasive vascular lab, the presence of vascular disease has already been established. The arteriogram gives an additional road map and sets the platform for going ahead with endovascular treatment at the same setting. This avoids having the patient go through two arteriographic procedures—one for diagnosis and one for treatment.

**PERIPHERAL ARTERIAL DISEASE AND LOWER EXTREMITY COMPLICATIONS**

PAD is a major factor contributing to complications of elective surgical procedures and/or amputations in the diabetic patient. There are multiple factors that contribute to ulceration in the diabetic foot to include neuropathy, foot deformity with altered biomechanics, altered immune response, infection, and PAD. Although not generally the cause of the ulceration, once an ulcer is present in patients with diabetes, PAD can be a major factor in nonhealing or progression of an ulcer. Figure 6.3 illustrates the difference between PAD as a cause of
Figure 6.2 Radiographic techniques for evaluation of PAD. A. MRA. B. CTA. C. Digital arteriogram. D. Digital arteriogram with selective foot films.

Figure 6.3 Illustrates the difference between PAD as a cause of ulceration and associated PAD as a negative factor for healing in a patient with a neuropathic ulcer. A. Ulceration of the toes caused by severe PAD. B. Neuropathic ulcer in a diabetic patient with neuropathy and foot deformity. The patient has associated arterial disease that can be a significant factor in the healing of the ulcer; however, the ulcer was not caused by PAD. Note that the toes distal to the ulceration do not have changes of ulceration or gangrene.
ulceration versus PAD as a negative factor for healing a neuropathic ulcer. Diabetic patients with PAD have a significantly increased risk of amputation. If there is a delay in the diagnosis of associated PAD, the patient can develop progressive tissue loss and be at increased risk for infection. The longer a diabetic foot wound is present, the more likely it is that the patient will develop osteomyelitis, resulting in a major amputation. Timely evaluation of PAD and early revascularization decreases the rate of amputation (10,20).

**TREATMENT**

The treatment of PAD involves treatment of the systemic atherosclerosis and selective treatment of the occlusive complications of the disease. The most basic form of treatment is lifestyle modification. For example, patients who smoke should be assisted in a cessation program and every patient with mild claudication should be placed on an exercise regimen. Every patient with any evidence of atherosclerosis should be on medical treatment of the disease. This includes risk factors modification as well as medical therapy (20). Glycemic control in the diabetic patient is as critical as any form of operative therapy. This is generally accomplished with a combination of dietary modification and the use of insulin or oral hypoglycemic agents. In addition to glycemic control, the use of a category of drugs called statins has proved useful in the treatment of hyperlipidemia as well as the inflammatory component of atherosclerosis. There are promising studies demonstrating that treatment with statins can stop the progression of atherosclerosis (21).

Once the mentioned therapies have been enacted, further vascular therapy in the diabetic patient generally follows the same guidelines as for nondiabetic patients. The indications for intervention would be severe lifestyle limiting claudication, rest pain, and tissue loss. Another indication would be to augment perfusion before elective reconstruction of the diabetic foot in patients who have inadequate perfusion to heal a surgical wound. The goal of treatment of the occlusive complications of PAD is to restore a balance between supply and demand. Patients can have significant occlusive disease and still meet their demands. An example is a diabetic patient with significant PAD who does not walk and does not have rest pain or ulcers. Although this patient has arterial occlusive disease, no invasive treatment is required. On the other hand, if surgery is planned on the leg or foot, the demand will be increased. In that case, it is important to identify the disease before surgery and assure that there is adequate perfusion to heal the surgical incisions. If a foot wound or significant infection is present, or an elective major operation on the foot is planned, the goal is to restore pulsatile flow to that portion of the foot. Referral to a vascular specialist should be initiated, and from there, the appropriate noninvasive workup as described will decide further therapy.

Arterial reconstruction of the foot can be accomplished by traditional bypass surgery, endovascular therapy, or a combination of the two. The choice of procedures is based on the location of the disease, patient comorbidities, and the severity of the ischemic process. In planning treatment of lower extremity ischemia, the critical information is defining the inflow vessel, outflow vessel, and choice of conduit. A basic principle of treatment of PAD is to treat the most proximal disease first (inflow). Diabetic patients with limb-threatening ischemia have multilevel disease, and if a patient has an iliac artery stenosis plus tibial vessel occlusive disease, the iliac lesion should be treated first. This combination might lead to an iliac stent plus a tibial bypass, thus combining endovascular therapy with traditional bypass surgery. Operative procedures or endovascular therapy is associated with better outcomes on larger vessels. The more distal the revascularization procedure, the poorer is the long-term outcome.

The presentation of PAD has a significant impact on the type of revascularization required. In a patient with claudication and intact skin, augmentation of inflow may be all that is required. This may be accomplished by treating the proximal disease in a patient who has multilevel disease. In a patient who presents with rest pain but has intact skin, the patient generally has multilevel disease; however, augmentation of inflow may be all that is required to relieve the rest pain. In a patient with a significant wound on the foot, inline flow to the appropriate angiosome will result to the best rate of limb salvage (3). Therefore, it is important to identify and treat disease before the development of a significant wound. In a patient that has the combination of significant iliac disease and superficial femoral disease, and an elective foot operation is planned, it may be sufficient to just treat the iliac disease. In a patient with the combination of iliac stenosis, tibial disease, and an infected foot, ulcer treatment of the iliac disease as well as a distal procedure will be required.

**OPEN ARTERIAL SURGERY**

A critical component of planning a bypass procedure is the preoperative identification of the anatomy. An inflow vessel is identified, a target outflow vessel is identified, and a decision is made to reference the conduit to connect the inflow vessel to the target vessel. The proximal portion of the bypass is performed at the lowest level with good inflow and the distal portion of the bypass is performed where there is a patent outflow vessel. With a significant wound, the outflow vessel would be the vessel providing the best inline flow to the involved angiosome. If aortoiliac disease is present, it should be treated first before doing an infrapopliteal bypass.

In the case of the diabetic patient with a wound on the foot or requiring surgery on the foot in the presence of nonpalpable pulses, the majority of cases require an infrapopliteal bypass procedure. In performing a distal bypass to the tibial or pedal vessels, the most distal inflow vessel should be used. Often the SFA or popliteal artery is spared, allowing for a more distal inflow site. This scenario is very common and is actually an advantage in diabetic patients, as shorter bypass grafts are often required and this has been shown to lead to better graft patency (22).

The greater saphenous vein is the conduit of choice for infrapopliteal bypass procedures. It can be configured in three ways because of the valves within the vein that allow for one-way flow. The first and most common technique is to mobilize and remove the vein from its natural subcutaneous location and reverse the vein; the second way is in situ, in which the vein is exposed for its entire length but left in its natural subcutaneous location, followed by ligation of all of the tributaries with the proximal and distal ends being mobilized only and with use of a valvulotome to lye the valves within the vein; the last technique is translocation, in which the vein is mobilized and removed from its natural subcutaneous location, the valves are lysed, and
the vein is used in a nonreversed configuration. Although no studies have revealed any appreciable difference among these three modalities, the main advantage to an in situ or translocated vein is that it overcomes the size mismatch that occurs with the reversed vein in that the larger proximal portion of the saphenous vein is anastomosed to the smaller tibial artery (23). If there is an inadequate greater saphenous vein, the lesser saphenous vein or arm veins may be used (24). Other options include a cryopreserved allograft vein or prosthetic graft. The best long-term patency is seen with autologous vein. If a vein is not available and a prosthetic graft is used, then adjunctive techniques such as distal vein patch or cuff or an arteriovenous (AV) fistula at the distal anastomosis should be employed along with anticoagulation to improve the poor patency of these prosthetic infrainguinal bypass procedures (25). Figure 6.4A–E illustrates a distal greater saphenous vein bypass to the dorsalis pedis artery in a patient with an open transmetatarsal (TMA) that failed attempts with endovascular revascularization.

Figure 6.4  A distal greater saphenous vein bypass to the dorsalis pedis artery. A. Open TMA that was failing to heal because of inadequate perfusion to that portion of the foot. B. Arteriogram demonstrating a patent dorsalis pedis artery. C. Preparation of the greater saphenous vein that will be used as the conduit for the distal dorsalis pedis artery. D. Distal anastomosis on the dorsum of the foot above the open TMA. E. Following a dorsalis pedis bypass, the patient had pulsatile flow to the involved angiosome, and the wound could be closed with a split thickness skin graft.
ENDOVASCULAR ARTERIAL SURGERY

In considering endovascular procedures, the same concept of identifying inflow and outflow vessels is present; however, the conduit in these patients will be their own diseased or occluded artery. There are no long-term results of endovascular therapy in these patients; however, in a patient who is deemed to have advanced cardiac disease and unlikely to safely undergo an open bypass procedure, it can be a useful alternative to open surgery in the critically ischemic limb. The advantage of the endovascular procedures is that they can be performed under local anesthesia in an outpatient setting. The physiologic insult associated with these procedures is less than open bypass surgery. In addition, repeat procedures also can be performed for recurrent disease.

Numerous modalities are available for endovascular therapy and the most basic is percutaneous transluminal angioplasty (PTA). This technique involves simply placing a balloon across a stenotic or occluded segment of the artery and dilating the artery. There are two responses of the artery to this controlled dissection. The first is positive remodeling, in which the artery heals and remains in its dilated position. The second is negative remodeling, in which the insult to the artery (the angioplasty) has the opposite effect and causes a reaction in which the artery again becomes stenotic or occluded (26). Numerous forces to include elastic recoil on top of the negative remodeling can cause the artery to become stenotic or occlude. To combat this common phenomenon, stents can be placed to prevent the negative remodeling and elastic recoil. These stents can become lined with thrombus (clot) and this is the major reason

**Figure 6.5** Endovascular revascularization in a patient with a large necrotic ulcer following a failed femoral peroneal bypass. A. Large ischemic ulcer occurring in the area of a distal surgical incision made for a femoral peroneal bypass. The bypass was complicated by thrombosis of the graft and a necrotizing infection leading to the large ulcer. B. Arteriogram demonstrating occlusion of the popliteal artery and a single vessel going to the foot (peroneal artery). C. Patency of the popliteal artery after passage of a wire and treatment with CryoPlasty balloon. D. Healed ulcer. The ulcer required debridement, wound bed preparation using a negative pressure wound therapy (NWPT), and split thickness skin graft (STSG). NWPT was used as a bolster for the skin graft.
for failure of stents. Available adjuncts to PTA and stenting are other types of balloons such as the cryoballoon in which CO₂ is delivered to expand the balloon and create an area of cell death (apoptosis) and control the negative remodeling phenomenon. Other balloons such as the cutting balloon have sharp metallic edges that create a controlled cut in a vessel. These are particularly useful in the setting of a bypass vein stenosis as these lesions tend to be fibrous and resistant to traditional angioplasty. Angioplasty can be combined with the use of covered stents, that in essence, create a synthetic bypass within the arterial lumen. Heparin-bonded covered stents are now available to potentially improve patency. Other modalities include the use of a laser to open occluded arteries by creating a channel in these vessels as well as the use of mechanical atherectomy devices that remove plaque from the artery and restore luminal diameter without the need of a stent. Figure 6.5A–D illustrates revascularization of an ischemic lower extremity with a large ulcer using angioplasty with a CryoPlasty balloon.

Obviously, as technology evolves, endovascular options will likely surpass open procedures in the treatment of lower extremity ischemia. In recent years, the lower profile devices have made a significant impact, but at the moment we do not have the data to compare it with open bypass procedures, which are still the golden standard in the treatment of lower extremity ischemia. Bypass procedures and endovascular therapy are not independent of each other; often, a combination approach is necessary to achieve limb salvage.

**CONCLUSION**

The assessment and selective treatment of PAD is an important component of reconstruction of the diabetic foot. Failure to identify and treat PAD can lead to surgical failures and significant complications leading to amputation.

**REFERENCES**

Surgical Treatment of Chronic Nerve Compression in the Patient with Diabetic Neuropathy

INTRODUCTION

The neuropathy epidemic is now upon us (1–3). Conservatively, 50% (4) of the 30 million diabetic people in the United States have neuropathy. There may be the same number of people with neuropathy of unknown cause (5,6). Current chemotherapy strategies using Taxol and Platin derivatives (7,8), and now thalidomide for multiple myeloma (9), add cancer survivors to this list of patients with neuropathy. In general, with the exception of glycemic control for those with diabetes, there is no neuropathy cure or prevention available: Neuropathy treatment is directed at amelioration of the pain symptoms (10–12). It is predictable that this epidemic will create a greater number of wounds to heal, of lower extremities to amputate, and of falls associated with loss of balance. Morbidity related to upper extremity, hip, and foot fractures, especially in the elderly with neuropathy, is well known (13,14). The burden to the healthcare system and society is enormous, with that cost in 2002 having been estimated to be $132 billion (15).

It is now observed, reported, and agreed that among patients with neuropathy—a systemic problem—there are many who also have localized nerve compression, with that percentage estimated to be 33%, including sites in the upper and lower extremities (16,17). Since the early 1980s, it has been my approach that these compressed nerves can be treated surgically, with relief of symptoms, but clearly without changing the underlying metabolic neuropathy (18). Certainly, appropriately trained surgeons have the techniques available to them to decompress these localized compressions. It is the purpose of this chapter to review my current approach to diagnosis and surgical treatment of chronic nerve compression in the patient with neuropathy.

Although my involvement in this subject spans the last quarter century, the main message remains confused or at least misrepresented by the medical community, in particular, a small group of diabetologists and neurologists (19,20). They continue to miss the point that this chapter will make perfectly clear: Every patient with neuropathy should not have a peripheral nerve decompression. Peripheral nerve decompression is reserved for the patient with neuropathy who has a demonstrable compression of a peripheral nerve in a known site of anatomic narrowing. It remains appropriate to debate how to make the diagnosis of that nerve entrapment in the presence of neuropathy, as making the diagnosis of a nerve entrapment is still debated even in the upper extremity for carpal tunnel (21,22) and cubital tunnel syndrome (23) in the non-neuropathic patient, in which electrodiagnostic studies have a false-negative finding in 33% of symptomatic people (24). The comprehensive study by Bril et al continues to be the best arbiter of this problem (25); they found that electrodiagnostic studies could not distinguish reliably the presence of carpal tunnel syndrome in the patient with diabetic neuropathy, and they concluded that the physician should rely on the physical examination in making the diagnosis. My experience has demonstrated that the presence of a positive Tinel sign over the tibial nerve in the tarsal tunnel gives a 92% positive predictive value for good to excellent results after nerve decompression in the diabetic with neuropathy and 88% in the patient with idiopathic neuropathy (26). Therefore, the physical examination, and primarily the presence of a positive Tinel sign, rather than confirmatory electrodiagnostic results, will remain the critical indication that a chronic nerve compression exists in the patient with neuropathy.

INDICATIONS AND CONTRAINDICATIONS

The ideal neuropathy patient to choose for decompression of peripheral nerves is someone who has:

1. Symptoms, sensory and/or motor, in the distribution of the peripheral nerve
2. Physical findings of a compressed peripheral nerve at the known sites of anatomic narrowing, which are in the lower extremity:
   a. Common peroneal nerve (CPN) at the fibular neck
   b. Superficial peroneal nerve (SPN) in the distal third of the leg
Positive Outcomes With This Surgical Procedure

1. Sensation is restored in 80% of people (Table 7.1).
2. Pain is relieved in 80% of people (see Table 7.1).
3. New ulcerations are prevented (see Table 7.1).
4. In the presence of sensation and in the absence of ulceration, amputation will be prevented as well (27).
5. In the presence of sensation, balance is restored: Falls and fractures will be reduced (28).

### TABLE 7.1

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DETAILED SURGICAL TECHNIQUE

GENERAL CONSIDERATIONS

The surgeon must have spent time learning how to do this procedure, preferably in a workshop in which cadaver dissection has been provided and an experienced surgical teacher has demonstrated the procedures both in a cadaver and a living patient. If this type of instruction is not available within the residency training program, then a formal workshop environment should be sought for this postgraduate education. Microsurgical experience is required to do an intraneural dissection. The surgeon must have a thorough understanding of the regional anatomy and the variations of the anatomy of the nerves to be decompressed.

The surgery is done as an outpatient procedure and can be performed in a surgery center under general anesthesia. An antibiotic is administered intravenously (IV) by the anesthesiologist prior to inflating the tourniquet. A tourniquet is used, and set to 300 mm Hg pressure. A bipolar coagulator is used. Loupe magnification is used. Appropriately delicate instruments and technique are required.

COMMON PERONEAL NERVE AT THE FIBULAR NECK

A 3- to 4-cm incision is made obliquely across the fibular neck, and deepened into the subcutaneous tissue. Care is not taken to injure the lateral cutaneous nerve of the calf, which is sometimes present. The deep fascia is palpated to identify the common peroneal nerve. This fascia is lifted and then incised to identify the common peroneal nerve (CPN) (29,30). This nerve often has a yellowish color and appears like a lipoma. Only the epineurium should be grasped in the forceps. The fascia is released into the popliteal fossa. Unless there has been trauma, this fascia is not attached to the CPN. The entrapment site is distal, beneath the peroneus longus muscle. The fascia of this muscle is divided transversely and longitudinally, the muscle retracted anteriorly. Beneath the muscle, there is often a fascial band that must be released (Fig. 7.1). The CPN will be indented beneath this band, and appear flattened. If the nerve is firm, an intraneural dissection may be done. The CPN must be elevated and any fascial bands on the lateral head of the gastrocnemius muscle beneath the CPN must be cauterized and then divided. The opening into the anterior compartment may be too narrow, in which case the soleus origin must be cauterized and then divided at the fibular neck to enlarge this entrance. This completes the dissection. A local anesthetic is put into the skin edges, avoiding getting any on the CPN. The dermis is sutured with interrupted absorbable suture, 4-0 Monocryl is preferred, and the skin is sutured with continuous 5-0 nylon, with one additional interrupted 5-0 nylon placed in the center.

SUPERFICIAL PERONEAL NERVE IN THE LEG

The superficial peroneal nerve (SPN) is depicted as being in the lateral compartment (31). However, it is also in the anterior compartment at least 25% of the time, and sometimes it is in both compartments. The SPN exits the fascia of the lateral compartment, on average, about 10 to 12 cm proximal to the lateral malleolus. The incision for neurolysis of the SPN is typically parallel to the fibula, but anterior to the fibula to permit access to both anterior and lateral compartments. The incision may be more proximal or more distal depending on the patient’s height and the location of the positive Tinel sign. The incision is made into the subcutaneous plane. Occasionally, the SPN may already be in this plane and care must be taken to avoid injury. A small elevation from the fascia accompanied by a small blood vessel and some fat often marks the spot of the entrapment as the SPN travels from deep in the fascia to enter the subcutaneous plane. The fascia must be incised for about 15 cm so that the SPN is totally free from constriction and a new small muscle herniation is not created through a small fascial window.

Evaluate both the anterior and the lateral compartment, even if an SPN is found in the first compartment you enter. If

Figure 7.1 Neurolysis of the common peroneal nerve at the fibular neck. A. The common peroneal nerve of the left leg is noted at the knee after opening the deep fascia. Note the nerve is compressed below the peroneus longus muscle by a white fibrous band. The peroneus muscle is retracted. B. The white band has been excised. Note the indentation in the common peroneal nerve.
there is no SPN in either compartment, then it will lie within the septum itself (32). Open the septum very carefully to be sure that you do not injure an SPN branch located within the septum (Fig. 7.2).

Cauterize the incised fascial edges, as the fascia is well vascularized and can cause either a postoperative hematoma or a seroma. Close the skin with interrupted intradermal 4-0 Monocryl and continuous and interrupted 5-0 nylon.

DEEP PERONEAL NERVE OVER THE DORSUM OF THE FOOT

The deep peroneal nerve (DPN) has been described as becoming entrapped in the anterior tarsal tunnel, which is a wide and deep space beneath the extensor retinaculum (33). In the absence of trauma to this region, this is not the site of compression in the patient with neuropathy.

The DPN becomes entrapped in the patient with neuropathy beneath the extensor hallucis brevis tendon and the underlying bones, at the juncture of the first and second metatarsals and the cuneiforms. This is the site at which the Tinel sign will give a distal radiation.

The incision is made obliquely across this region. In the subcutaneous tissue, blunt dissection must identify the superficial peroneal branches so they can be retracted and not injured. The extensor hallucis brevis tendon is identified unambiguously, and then a 2-cm section of it is resected. An exploration is then done to identify the DPN medial or lateral to the dorsalis pedis artery (Fig. 7.3).

Remember that about 5% of people do not have a dorsalis pedis artery. Remember that there is no DPN in some people, and those fibers are all carried by the SPN.

Even in the absence of trauma, the DPN may be adherent to the underlying bone requiring a gentle neurolysis of the very small nerve. Typically, the nerve is swollen proximally and is released until the inferior extensor retinaculum is reached.

The skin is often too thin to place an intradermal suture, in which case the skin is closed with interrupted and continuous 5-0 nylon sutures.

TIBIAL NERVE AND ITS BRANCHES AT MEDIAL ANKLE

First, it is important to appreciate that there are four tunnels to decompress: (a) the tibial nerve in the tarsal tunnel, (b) the medial plantar nerve in the medial plantar tunnel, (c) the lateral plantar nerve in the lateral plantar tunnel, and (d) the calcaneal nerve in one or more calcaneal tunnels (Fig. 7.4).

The tibial nerve in the tarsal tunnel is approached through an incision that is posterior to the medial malleolus, and midway to the Achilles tendon (34,35). It begins just proximal to the medial malleolus. An incision too close to the medial malleolus can cause a painful scar because of a neuroma of a posterior branch of the saphenous nerve (36). The flexor retinaculum is open and its edges cauterized to prevent them from reattaching postoperatively. If there is a mass within the tarsal tunnel, from an anomalous muscle or a ganglion, which is quite rare, it is removed. There is no need to do anything to veins in this region. The tibial nerve must be separated from the artery and vein, and inspected. The epineurium is opened, and a clear division of the medial and lateral plantar nerves within the tarsal must be observed. If there is intraneural fibrosis, an intraneural neurolysis is necessary. In about 5% of patients, there is a high division of the tibial nerve into the medial and lateral plantar nerves (37). The tarsal tunnel is not usually the site of the chronic compression. This exposure permits the rest of the decompressions to proceed safely, and permits decompression of intraneural pressure within the tibial nerve if it exists. The tarsal tunnel ends when the flexor retinaculum divides to encompass the abductor hallucis brevis muscle (AHB).

To approach the medial and lateral plantar nerves, an incision is made toward the planter aspect of the foot at the site of the lateral plantar tunnel. This incision is brought proximally to join the incision for the tarsal tunnel release. The superficial fascia of the AHB muscle is incised and gently spread. Care
Figure 7.4  Illustration of the four medial ankle tunnels. (a) Overview with flexor retinaculum open to show the tarsal tunnel. Note this tunnel ends at the abductor hallucis brevis (AHB). (b) The AHB has been retracted. Note the small nerve from the medial plantar nerve crossing the vessels to enter into the skin of the medial arch. This nerve must be protected. (c) The roof of the medial and of the lateral plantar tunnels has been divided. (d) The septum between the two tunnels is being divided. (e) The septum has been removed and the medial calcaneal tunnel has been decompressed. (Reproduced with permission from Dellon.com.).
must not be taken to injure the small (<1 mm) nerve that goes from the medial plantar nerve superficial to the vessels, enters into this fascia, and emerges to innervate the medial ankle skin at about the site where the typical incision is made for a plantar fascia release (38). Injury to this small nerve will create a painful distal tarsal tunnel incision (39). The ABH muscle is then swept off the underlying transverse ligament from which it is arising. The medial and lateral plantar tunnels are each cannulated with a straight clamp, demonstrating their tightness as the site of compression, and providing the pathway to divide the roof of each of these tunnels. The two tunnels are separated by a septum of varying thickness and length. It must be cauterized longitudinally, and then excised along with the roof of each of the two tunnels. The index finger is then placed into this space pushing distally. Additional fibrous bands are divided until the index finger enters the plantar aspect of the foot (Fig. 7.5).

The medial calcaneal tunnels are identified in one of two ways. First, there can be calcaneal nerves arising from the tibial nerve within the tarsal tunnel. These are identified in the posterior fat below the tibial nerve and are followed distally to where they enter their tunnel. Second, from the fibrous roof of the lateral plantar tunnel, that fascia is traced proximally and is found to form the roof of the calcaneal branches that arise from the lateral plantar nerve before it enters its own lateral plantar tunnel. Each of these tunnels is gently spread and then the roof carefully divided so as not to injure one of the small branches of the calcaneal nerve. None of these branches is the one described by Baxter, which is a branch arising just before the motor innervation and goes to the periosteum of the medial calcaneal tubercle.

Marcaine 0.5% is infiltrated into the skin edges. The skin is closed with multiple 4-0 Monocryl intradermal sutures. Finally, the skin is closed with interrupted and continuous 5-0 nylon sutures. The dressing is Xeroform, sterile 4 gauze, then a Kling or Kerlix gauze wrap, and finally a bulky cotton, Robert Jones type supportive dressing. This is also held on with Kling, paper tape, and finally an Ace wrap. The tourniquet is then let down. The Ace wrap is removed in half an hour and is used to just during the reflex period of vasodilation that exists after using the tourniquet (Fig. 7.6).

**POSTOPERATIVE MANAGEMENT**

Postoperatively, the patient is allowed full weight bearing immediately and uses a walker for 3 weeks. The goal of walking is to minimize ankle range of motion so that the sutures do not pull out, yet still permit nerve gliding. The dressing is removed after the seventh day, and the patient is allowed to get the sutures wet, but must apply Betadine twice a day to the incisions. The patient changes chairs each hour while awake to permit nerve gliding and minimize the risk of a deep vein thrombosis. The sutures at the knee are removed at the 14th day and at the foot/ankle level at the 21st day. Following removal of the sutures at the ankle, the patient is begun on water walking in a heated pool as a form of therapy. This should occur at least twice a week and preferably three times a week. Usually, no other therapy is necessary. The patient will then progress through increasing degrees of ambulation and activity as tolerated.

As pain diminishes, pain medication is decreased. In the patient who did not have preoperative pain and who experiences pain because of nerve regeneration, a regimen of neuropathic pain medication can be started and the opioids continued as needed. Repeat neurosensory testing is done at 6 to 12 weeks postoperatively to document sensory recovery. It may be done sooner if the patient is experiencing significant pain, as the neurosensory test documents a nerve regeneration pattern that is reassuring to both the patient and the physician.
The contralateral side may be operated on as early as 6 weeks later, if there has been sufficient documentation of pain relief or sensory recovery. Typically, most patients wait about 3 months to have surgery on the contralateral side. The longest time interval has been 1 year.

TIPS TO AVOIDING COMPLICATIONS

The most common “complication” is that 10% to 20% of patients do not improve following this surgery. The most common cause for this is previous bypass surgery with residual symptoms in the legs from the back problem. This is extremely difficult to identify preoperatively in the presence of a neuropathy and peripheral nerve compressions. A second cause of failure to improve is another site of nerve compression. Just recently, we have focused upon entrapment of the tibial nerve proximally, at the calf level, where the tibial nerve goes beneath the soleus arch. There will be tenderness at the location and weakness in toe flexion. This site can be decompressed through a medial calf incision, going deep to the medial gastrocnemius muscle, and dividing this arch.

The second most common complication is wound healing problems. The most common site is the medial ankle incision. In about 5% of patients, this may become red or open. The sutures create a problem with the skin with early amputation, but such amputation is critical to prevent the tibial nerve from becoming scarred in the surgical site. The patient is given IV antibiotics prior to inflating the tourniquet during the surgical procedure and for 1 week postoperatively. With advanced neuropathy, there is no pain at this incision site. We recommend that the patient be aware that the ankle is moving too much. Use of the bulky supportive bandage the first week and the walker for 3 weeks, with the patient initiating each step by lifting the knee first minimizes suture and skin trauma. In my personal experience, no wound has had to be skin grafted. Six patients over 20 years have required secondary healing. Also, be careful not to cauterize the dermis while obtaining hemostasis.

Preoperative attention to blood flow is critical to wound healing. To date, none of my patients with neuropathy has required secondary vascular surgery intervention. If a patient has had a previous bypass arterial graft, our current recommendation is not to use a tourniquet during the surgery (59,60).

An occasional patient has developed a deep vein thrombosis. We seek to prevent this by using compression stockings in the operating room on the contralateral leg, and having the patient ambulate immediately and often, albeit for short distances, during the early postoperative period. If the patient is driving >1.5 hours home after surgery, they are told to stop the car each hour and get out and then get back into the car through the opposite side of the car.

Patients must be informed that they may have a neurologic downgrade in motor or sensory function, but they are usually quite impaired prior to surgery, and this downgrading is extremely rare, happening <0.5% of the time. Prevention requires attention to the preceding surgical details and meticulous, gentle, peripheral nerve surgical skills.

EXAMPLE OF SURGERY

A 66-year-old man had a 5-year history of numbness progressing to burning pain in both of his feet. The symptoms involved each foot to about the same degree. He did not have lumbar spine problems. He was told he had a neuropathy of unknown etiology. The neuropathy was confirmed by electrodiagnostic studies. He was placed on Neurontin to help manage his level 8 out of 10 pain. He was overweight and had a family history of diabetes. His cholesterol and blood pressure were both elevated and he was on appropriate medications for each of these conditions. Three years ago, he was given the diagnosis of non-insulin–dependent diabetes mellitus, and his foot symptoms were said to be because of diabetic neuropathy. He was taking an oral medication for his diabetes and his last HbA1c was 6.8. He had begun to lose his balance and had fallen twice without having sustained a fracture. He did not have a history of ulceration in his foot.

At the time he was first examined, he was found to have a positive Tinel sign bilaterally over the CPN at the fibular neck, the DPN over the dorsum of the foot, and the tibial nerve in the tarsal tunnel, demonstrating that he did have localized sites of chronic nerve compression present in each lower extremity. He did not have a Tinel sign over the superficial peroneal nerves, nor was the tibial nerve tender behind the calf. He had mild wasting of his abductor hallucis, but he did not have clawing of his toes. He had weakness in his extensor hallucis longus muscle. He had normal strength in his toe flexors. There was a strong posterior tibialis pulse present bilaterally and no pedal edema.

His initial neurosensory test with the pressure-specified sensory device documented a sensory neuropathy with axonal loss (Fig. 7.7A).

He was determined to be an excellent candidate for peripheral nerve decompression, and was scheduled to have a neurolysis of the CPN at the fibular neck, neurolysis of the DPN over the dorsum of the foot, and a decompression of the four medial ankle tunnels. (Because three incisions are made, this has been termed the Dellon triple.)

On the left foot surgery, the CPN was found to be infiltrated by fat and to be severely compressed (Fig. 7.8A–C). The tibial nerve in the tarsal tunnel also demonstrated signs of fatty infiltration and tightness in the medial and lateral plantar tunnels (Fig. 7.9A,B).

In the recovery room immediately after surgery, it felt ticklish and he laughed (a positive test tickle sign) when his left plantar skin was gently stroked (Fig. 7.10). After surgery, his pain level in the left foot fell to 4 out of 10, and by the third postoperative month, his repeat neurosensory testing demonstrated nerve regeneration in his left foot.

At 4 months after the first surgery, he had the same surgery on his right foot.

By 7 months after the first surgery, with neurosensory testing documenting recovery to almost normal levels of sensibility in both of his feet (Fig. 7.7B), he had regained his balance and had no further falls. With recovery of sensibility, his likelihood of ever developing ulceration or having an amputation (other than for vascular reasons) was greatly reduced. He was asked to return in 1 year for follow-up.
Figure 7.7  Neurosensory testing with the pressure-specified sensory device. **A.** Preoperative testing documents a bilateral sensory neuropathy with axonal loss. The red bar represents the right foot and the blue bar represents the left foot. The y-axis represents pressure applied for the patient to be able to distinguish the stimulus. The black horizontal lines are the 90% confidence limit for age-matched normal data. The red and blue bars are symmetrically elevated for both the peroneal and tibial nerves, consistent with neuropathy. The asterisk means that two-point discrimination distance is abnormal, consistent with axonal loss. **B.** Postoperative testing demonstrates regeneration of sensory axons, now to almost normal levels.

Figure 7.8  Example of surgery on the left common peroneal nerve entrapment site. **A.** Note the yellowish color of the common peroneal nerve as it approached the peroneus longus muscle. **B.** Common peroneal nerve after neurolysis. Note indentation of the nerve.
REFERENCES


Figure 7.9 Example of surgery on the left tarsal tunnel. A. Note yellowish change in color in the tibial nerve in the tarsal tunnel. B. Within the tarsal tunnel, the tibial nerve has divided into medial and lateral plantar and calcaneal nerve. The retractor elevates the abductor hallucis, demonstrating the white roof of the medial and lateral tunnels that remains to still be divided.

Figure 7.10 This patient in the recovery room smiles as his wife tickles his foot (a positive test tickle sign), indicating that the decompression has permitted reversible ischemia of the nerves to allow some of the sensory nerves (those with a conduction block but not degeneration) to function again. His balance will be regained after he has surgery bilaterally to decompensate these nerves.
INTRODUCTION

Infections in the diabetic foot may lead to limb loss. Recognition of infection and the ability to manage it surgically is often a challenge. An aggressive approach to managing these cases has been shown to reduce the overall rate of major amputations. Efficient and definitive surgical intervention, combined with appropriate antibiotic therapy, is the cornerstone of limb salvage in the infected diabetic foot.

DECISION-MAKING FACTORS FOR SURGICAL INTERVENTION

The surgical approach to the infected diabetic foot is dependent on an aggressive physical exam. The physician needs to understand that surgery should be considered an integral part of the overall approach to diabetic foot infections. Upon initial examination of a diabetic foot wound, care should be taken to adequately assess for signs of infection. Although many patients present with cardinal signs of infection—erythema, warmth, swelling, and drainage—there are often those patients in whom the presentation of infection is more subtle. It is in these patients that a more aggressive examination becomes imperative to determine the need for and extent of surgical intervention.

A probe passed into a wound may identify involvement of fascial planes or tendon sheaths, as well as areas of fluctuance or abscess formation that may not be appreciated on a cursory exam (Fig. 8.1). Failure to adequately identify a deep-space infection either by a limited exam, or any other delay (often while awaiting the results of diagnostic testing, such as nuclear medicine scans, CT, or MRI) may result in further tissue loss, with resultant compromise of limb salvage. An experienced surgeon understands that as little as 24 hours of undrained sepsis will determine whether the patient requires a partial foot amputation or even minimal tissue loss.

In conjunction with the patient’s clinical exam, the other potential signs of systemic infection need to be evaluated as well. However, although fevers, chills, hypoglycemia, and leukocytosis may be present, it is not uncommon to have these patients present with an absence of these signs or symptoms. Frequently, they present with just elevated blood sugar. The physical exam is most often all that is needed to determine the timing and extent of incision and drainage (I&D). In fact, the examination should not be done without a sterile I&D kit (blunt probe, scissors, forceps, and disposable scalpel) readily at hand, not only to drain an abscess, but also to aid in the aggressive physical exam (Fig. 8.2).

CLASSIFICATION OF INFECTION

To properly guide treatment, the practitioner should understand a classification system for infection. The preferred system at our institution keeps it simple. It categorizes infections into non-limb-threatening and limb-threatening infections (Table 8.1) (1, 2).

Non–limb-threatening infections are superficial ulcerations that do not involve bone and do not have significant ischemia or systemic toxicity. Cellulitis does not extend beyond 2 cm around the wound. The patient is medically stable and can be treated in an outpatient setting (Fig. 8.3A, B). Surgery is usually a minor débridement with an in-office incision and drainage (Fig. 8.4A, B). Wound culture is obtained by removing a small piece of tissue as deep as possible. This is followed with an oral antibiotic, which has predominantly gram-positive coverage. X-rays are done to evaluate for osteomyelitis. The patient is then re-evaluated in 1 week. A more aggressive I&D is warranted if the patient is not responding to therapy.

Limb-threatening infections are characterized by wounds with cellulitis of >2 cm, significant swelling, abscess formation, lymphangitis, gangrene, necrotizing fascitis, and osteomyelitis (Figs. 8.5A, B and 8.6A–G). Often, these patients are medically unstable and have significant hyperglycemia or labile blood sugars. In addition to a complete history and physical, an aggressive physical exam of the entire lower extremity is most important to determine the degree of surgical intervention and need for hospitalization. Adjunct parenteral broad spectrum antibiotics are started. Empiric coverage of methicillin-resistant Staphylococcus aureus (MRSA) should also be considered. Tentolouris et al (3) in 1999 and Cook et al (4) in 2007 reported significant delay in wound healing and increased amputation rates when MRSA was the primary pathogen compared to wounds infected with methicillin-susceptible Staphylococcus aureus (MSSA). When faced with a severe limb-threatening infection, a multidisciplinary approach is indicated.

Surgical Management and Stepwise Approach to Diabetic Foot Infections
TABLE 8.1

<table>
<thead>
<tr>
<th>Non–limb-threatening infection</th>
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</thead>
<tbody>
<tr>
<td>Superficial: No bone or joint involvement</td>
</tr>
<tr>
<td>Minimal or no cellulitis</td>
</tr>
<tr>
<td>No significant ischemia</td>
</tr>
<tr>
<td>No systemic toxicity</td>
</tr>
<tr>
<td>Microbes: Usually gram-positive</td>
</tr>
<tr>
<td><strong>Limb-threatening infection</strong></td>
</tr>
<tr>
<td>Deep ulcer (≥ bone or joint involvement)</td>
</tr>
<tr>
<td>Superficial ulcer: If foot is ischemic</td>
</tr>
<tr>
<td>Cellulitis: &gt;2 cm</td>
</tr>
<tr>
<td>Lymphangitis</td>
</tr>
<tr>
<td>Systemic toxicity</td>
</tr>
<tr>
<td>Microbes: Polymicrobial or methicillin-resistant Staphylococcus aureus (MRSA)</td>
</tr>
</tbody>
</table>

**Figure 8.1** Small benign-appearing ulcer is always probed for an abscess, undermining of tissue, or extension to bone.

**Figure 8.2** Sterile, inexpensive incision and drainage kit with disposable no. 15 blade for office and bedside use.

**Figure 8.3** A.B. Incision and drainage without delay at the bedside.
Figure 8.4  A,B. Non-limb-threatening infections. Note incision in (B), which was done in the office during the initial examination.

Figure 8.5  A,B. Plantar heel ulcer with deep abscess intraoperatively and 10 days postoperatively awaiting closure.

approach becomes necessary. These patients, who are at times medically unstable, still need to be taken to the operating room. Such life-threatening infections necessitate immediate surgical attention without delay (1). They should be considered for emergent incision and drainage, débridement, and if necessary, guillotine amputation. A delay in surgical decision making may manifest itself as further tissue loss, loss of limb, or even, as Joshi et al. in 1999 reported, loss of life in up to 40% of diabetic patients who had necrotizing fasciitis (5).

Appropriate clinical evaluation of perfusion to the foot is also necessary before aggressive incision and drainage. However, if a severe limb-threatening infection needs to go to the operating room urgently, vascular studies are done subsequent to the incision and drainage. The foot and ankle surgeon needs to fully
Figure 8.6 A–G. Hidden deep infection requiring aggressive blunt separation of infected tissue planes.
understand the detriments of arterial insufficiency and its effect on wound healing and infection control, and must take this into account when planning incisions. In these situations, it is of the utmost importance to have an experienced foot and ankle surgeon involved with the initial evaluation and intraoperative decisions. It is preferable to make incisions in a linear fashion and completely filet open the infected area along tissue planes. A limited approach with simple stab incisions is not recommended. The authors have found that less experienced foot and ankle surgeons are hesitant to completely open all questionable areas and remove nonviable tissue (Fig. 8.7A–D). An example of this is an exposed tendon that does not yet appear

![Figure 8.7 A–D. Complete excision of all infected tissue in a limb-threatening abscess with osteomyelitis](image-url)
Assessment of the patient's vascular status is paramount to the diagnosis of osteomyelitis. On rare occasions, magnetic resonance imaging is employed to differentiate osteomyelitis from a neuropathic joint. Film radiographs are obtained to determine the extent of osseous erosion as well as to assess anatomy for surgical planning. When this occurs, a Gram stain of the bone specimen may be helpful in determining the infecting organism. Currently, at the authors’ institution, the diagnostic approach to a patient with frank osteomyelitis includes osteoclast activation, fibroblast proliferation, and new bone formation. The residual larger sequestrum is eventually surrounded by a rim of reactive bone forming an involucrum, which is a sheath of live bone encasing dead bone. Often, the involucrum is perforated by openings, thus forming sinus tracks from which pus may track to the skin surface. The involucrum is often the first sign of osteomyelitis on radiographic examination.

OSTEOMYELITIS

In 1996, a patient with the diagnosis of diabetes carried a 15% lifetime risk of developing a foot ulcer (7,8). Diabetic foot ulcers which extend to bony structures increase the risk of osteomyelitis. The triad of diabetes, ulceration, and bone infection has increased in prevalence and are now the leading cause of nontraumatic lower-extremity amputations. Despite the tremendous advances in prosthetic limbs, the 5-year mortality rate following major amputation ranges between 39% and 80% (9,10). The urgency and consequences of this pathology are well understood; however, discordance remains with regard to the best treatment for osteomyelitis. The treatment options for osteomyelitis include treatment with antibiotics alone or in combination with surgical excision.

The conclusive diagnosis of osteomyelitis is obtained by bone biopsy. However, many times a wound culture of a soft tissue sinus tract serves as diagnostic. Although antibiotic therapy is initiated based on sinus tract cultures, the course of treatment may be less certain or require broader-spectrum antibiotics, even if the soft tissue infection resolves or improves based on sinus tract cultures. Mackowiak et al in 1978 stated that cultures obtained from draining sinus tracts and soft tissue specimens at the level of infected bone frequently fail to identify the organisms responsible for creating the osteomyelitis, except for Staphylococcus aureus or a monomicrobial infection (11). Their data showed that of 183 cultures taken from 35 patients, 102 did not coincide with operative cultures. Lavery et al in 1995 also reported that organisms isolated from soft tissue cultures were only found in 36% of 36 patients with osteomyelitis (12).

When antibiotic therapy is initiated before a bone biopsy can be obtained, the bacteria may be suppressed and therefore can interfere with accurate identification of the infecting organism. When this occurs, a Gram stain of the bone specimen may be helpful in determining the infecting organism. Currently, at the authors’ institution, the diagnostic approach to a patient with suspected osteomyelitis in a wound that probes to bone, plain film radiographs are obtained to determine the extent of osseous erosion as well as to assess anatomy for surgical planning. On rare occasions, magnetic resonance imaging is employed to differentiate osteomyelitis from a neuropathic joint. Assessment of the patient’s vascular status is paramount to the success of the surgical débridement. The presence of vascular disease is a contributing factor in the development of the infection as well as a cause for delayed healing and continued sepsis (13). A consult to an experienced vascular surgeon may be necessary to restore adequate perfusion to the foot and allow for healing.

Osteomyelitis is described as an infection of bone and marrow. Suppuration of bone cortex without marrow extension is referred to as osteitis, and contamination of periosteum alone is termed periostitis (14). Differentiation of these maladies is rarely done. The plethora of literature advocating emphasis on medical therapy, however, should require definitive identification of each. As would be expected, complete eradication without recurrence varies greatly when treating just periostitis versus frank osteomyelitis.

When the practitioner is faced with the decision to act quickly and aggressively in a diabetic patient with pedal osteomyelitis, it is more important to consider whether it is acute or chronic. Acute osteomyelitis, in addition to presenting different clinically, has definitive characteristics histologically. The pathologist describes it as an intense neutrophilic inflammatory infiltrate at the site of bacterial invasion accompanied by edema, vascular congestion, and small vessel thrombosis. In the early acute disease, the vascular supply to the bone is compromised by infection of the surrounding soft tissue and the bone becomes necrotic within a matter of days. When the medullary and periosteal blood supply is compromised, large areas of dead bone (sequestra) may be formed. When this occurs, the bacteria can be difficult to eradicate even after intense host response, surgery, and antibiotic therapy (14). The experienced clinician understands that this requires expedient ablative surgery and in many instances primary amputation.

On the other hand, although surgery eventually provides a definitive cure, chronic osteomyelitis does not require such emergent treatment. The clinician can treat the soft tissue infection with débridement and antibiotics, which converts the acute soft tissue infection into a chronic wound (Fig. 8.8A–D). This allows the option to single-stage surgical resection with flap or primary closure (15). If a large dead space exists, the area could be temporized with antibiotic impregnated beads in preparation for second-stage reconstruction. Such temporizing is evidenced by the different histologic presentation of chronic osteomyelitis. The slow insidious onset of the disease is characterized by an influx of chronic inflammatory cells into the focus of osteomyelitis, which initiates a repair reaction that includes osteoclast activation, fibroblast proliferation, and new bone formation. The residual larger sequestrum is eventually surrounded by a rim of reactive bone forming an involucrum, which is a sheath of live bone encasing dead bone. Often, the involucrum is perforated by openings, thus forming sinus tracks from which pus may track to the skin surface. The involucrum is often the first sign of osteomyelitis on radiographic examination (14).

SURGICAL VERSUS MEDICAL MANAGEMENT OF OSTEOMYELITIS

The requisite duration of antibiotic therapy following resection of osteomyelitis is unclear in the diabetic foot (16). This is, in large part, because of the lack of experimentally derived
treatment duration. Currently, treatment relies heavily on physician preference, personal experience, and/or knowledge from case series (17).

Because of the wide range of recommendations within the literature by diabetic experts, antibiotic duration may range from 1 week to 6 months (18–20). Longer antibiotic durations are often employed because of the paucity of data showing infection recurrence rates for treatments shorter than 4 weeks (19,21). The Infectious Diseases Society of America (IDSA) has published guidelines that indicate four scenarios in which osteomyelitis in the diabetic foot can be treated without surgical treatment (22):

1. Surgical resection causes excessive loss of function
2. Unreconstructable vascular disease and trying to avoid amputation
3. Risk of surgery is too high because of medical conditions
4. Infection is confined to the forefoot

According to the IDSA, patients who present with any of these four scenarios are advised to follow a course of 3 to 6 months of parenteral antibiotics that may eventually be amenable to oral therapy (22).

However, if sepsis or purulence is present, immediate débridement of bone and soft tissues supersedes all of the preceding IDSA recommendations. Furthermore, as concern over antibiotic resistance worsens, caregivers should carefully consider the consequences of prolonged medical therapy, particularly in cases involving the forefoot. Among the causes of resistant organisms is extended antibiotic therapy (23). In fact, overuse of antibiotics has become a major public health threat, with antibiotic resistance spreading worldwide (23). MRSA, S. aureus with intermediate vancomycin resistance, and vancomycin-resistant enterococci are on the rise (24). At one time, a patient with osteomyelitis or a history of prior hospitalizations for the same wound was at the highest risk for MRSA (hospital-acquired resistance). However, with the rapid emergence of community-acquired strains, there is increased urgency to modify treatment paradigms to decrease the overall use of antibiotics. Microbiological data are available at all hospitals. It is helpful to have an understanding of resistance patterns

Figure 8.8 A–D. Exposed first metatarsal head (confirmed chronic osteomyelitis). Limited resection of metatarsal head removes infected bone and debulks the area to allow for flap closure. The acute soft tissue infection was resolved with initial débridement and 5 days of intravenous antibiotics while hospitalized.
given the significant rise of MRSA. Proper selection of empiric antibiotics should be based on recent local data, not historical dogma. A review of the Beth Israel Deaconess Medical Center, Boston, Massachusetts (BIDMC) antibiogram from July 1, 2006 to June 30, 2007 revealed only a 45% sensitivity rate to oxacillin and cefazolin for 1892 *S. aureus* isolates. Levofloxacin had a 42% sensitivity rate for *S. aureus*. Consequently, vancomycin had a 100% sensitivity rate (BIDMC Inpatient antimicrobial susceptibilities for aerobic bacteria, Caregroup performance manager, 7/1/2006 to 6/30/2007). However, a complete understanding of minimum inhibitory concentration (MIC) breakpoints, which is beyond the scope of this chapter, would alert the practitioner to consider alternative coverage for MRSA.

Traditionally, treatment for diabetic foot osteomyelitis has consisted of 6 weeks of parenteral antibiotics. However, treatment using long-term antibiotics has been disappointing given recurrence rates as high as 30% (22). Furthermore, the cost of long-term parenteral antibiotics can range from $3500 to $10,000 (20). Gordois et al in 2003 reported that the overall cost of treating a diabetic foot ulcer complicated with osteomyelitis is $45,579 (25).

Several studies have advocated the use of long-term antibiotics for osteomyelitis in the diabetic foot, an approach that is rarely employed at our institution. The often-cited article by Bamberger et al in 1987 studied 51 patients with osteomyelitis (26). All patients in the study received at least 4 weeks of intravenous antibiotics or had combined intravenous and oral antibiotics for 10 weeks. The authors stated that diabetic foot osteomyelitis in the absence of extensive necrosis or gangrene usually responds to antimicrobial therapy without the need for an ablative procedure. In this study, only two patients had bone biopsies performed. An additional six patients had specimens sent after a below-knee amputation and two were sent after partial amputation. Of the eight patients, all had pathologic evidence of osteomyelitis. Therefore, only 10 patients out of 51 had histopathologic evidence of osteomyelitis, which poses this question: Did the patients indeed have osteomyelitis? Tice et al in 2003 reviewed 454 patients who had osteomyelitis diagnosed by clinical and physical assessment, wound culture, and radiographs (27). In this study, antibiotics were administered for 25 to 28 days ± 10 to 15 days. Mean follow up was between 6 to 120 months. Three hundred fifteen patients (69%) were cured; 139 (31%) recurred. Of the recurrences, 56% recurred within 3 months, 78% recurred within 6 months, and 95% recurred within 13 months. All patients in the study did not have histopathologic-proven osteomyelitis.

The standard treatment for chronic osteomyelitis at BIDMC is surgical excision of the infected bone (Fig. 8.9A–C). The

![Figure 8.9 A–C. Complete surgical resection of osteomyelitis is essential for success. This is an example of resection of a clean bone margin following removal of the third metatarsal head. This patient received 12 days of organism-specific antibiotic and was primarily closed following excision of osteomyelitis.](image)
subsequent route and duration of antibiotic therapy depends on the type of bone infected. We have shown that when osteomyelitis is excised from the forefoot (metatarsal or toe), our cure rate is 94%. The mean duration of predominantly oral “mop-up” antibiotic therapy is 12.2 days (28). All specimens were confirmed histologically to be osteomyelitis. Not only will surgical resection of all necrotic bone decrease the duration of antibiotics, but also the bone culture is paramount to determine accurate speciation and resistance of the offending organism for proper antibiotic selection. The authors do not agree with other experts that forefoot osteomyelitis should be treated primarily with antibiotics alone (22,24). In the study by Embil, long-term use of oral antibiotics for osteomyelitis was advocated (24). Diagnosis of osteomyelitis was made by bone culture in only 27% of episodes, and never included pathologic examination. The remainder of cases were diagnosed through a variety of methods, including probe to bone and radiographic signs. Ninety-three percent of the sites were in the forefoot, a distribution similar to our previously reported data. However, they excluded patients if there was a prior abscess, acute osteomyelitis, or a resistant organism. Although it is encouraging that their data support the efficacy of oral antibiotics, for what has traditionally been regarded as a parenteral antibiotic disease, the mean duration of 40 ± 30 weeks of therapy is just too long.

Several studies support primary surgical resection of osteomyelitis (29–31). Henke et al found that of 237 patients with digital osteomyelitis, surgical débridement was associated with greater wound healing (odds ratio 3.9, 95% CI 1.2–4.2, p = 0.02). Patients who had prolonged preadmission antibiotics, and thus a delay in surgical management, were found to be associated with decreased wound healing (odds ratio 0.2, 95% CI 0.05–1.1, p = 0.07) and greater limb loss (odds ratio 0.34, 95% CI 0.15–0.77, p = 0.009) (29).

The importance of surgical resection is also seen in the study by Ha Van et al, which divided 67 patients into two groups (30). Group I had 35 patients with histopathologic evidence of osteomyelitis treated with antibiotic therapy, offloading, and wound care. Group II had 32 patients treated with the same medical treatment and conservative surgery consisting of limited resection of the infected part of the phalanx or metatarsal bone. The results showed that 20/35 (57%) patients healed in group I, and 25/32 (78%) patients healed in group II. The duration of healing in group I was 462 ± 98 days, and in group II was 181 ± 30 days. The duration of antibiotic therapy in group I was 246.9 ± 252 days and 111 ± 121 days in group II (12). This study showed that surgery would shorten healing times as well as decrease the need for long-term antibiotic therapy, thus limiting the emergence of resistant strains.

We are less certain about antibiotic duration in midfoot and rearfoot bones. Longer antibiotic durations and higher reinfection rates may be encountered. The anatomic variation and increased cancellous composition make it more difficult to determine with certainty that all infected bone has been resected. Simpson et al (31) further emphasize this point. The study prospectively followed 50 patients with osteomyelitis divided into three groups based on the “completeness” of surgical bone resection:

**Group I:** Wide excision of all necrotic bone with >5 mm of clean margins (n = 15, no recurrence)

**Group II:** Excision of all necrotic bone with <5 mm of clean margins (n = 29, 28% recurrence)

**Group III:** Intralesional biopsies with incision, drainage, and soft tissue débridement (n = 6, 100% recurrence)

All patients received 6 weeks of intravenous antibiotic therapy followed by 6 weeks of oral therapy. The mean length of follow-up was 26.2 months. Because the results showed that in group I there was no recurrence, and in group III all recurred within the first year, it emphasized the importance of complete excision of all necrotic bone with a higher degree of surgical clearance at the margin.

In conclusion, an aggressive surgical approach to osteomyelitis shortens healing times and decreases the need for long-term antibiotic therapy. This should help to limit the emergence of resistant bacteria, and greatly reduce both inpatient and outpatient costs. In the authors’ opinion, lower extremity osteomyelitis is primarily a surgical disease. Our 6% reinfection rate confirms that aggressive and expedient surgical resection of all infected tissue in conjunction with a brief course of an organism-specific antibiotic is successful. Specifically, when forefoot osteomyelitis has been completely resected, the authors have experienced excellent results with an average of 2 weeks of organism-specific, predominantly oral, antibiotics. Part of this success is because of expedient wound closure once infection has been eradicated by surgical débridement. Osteomyelitis involving bones with greater cancellous composition may require more extensive débridement and longer antibiotic durations.

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Surgical Versus Medical Management of Osteomyelitis

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RECOMMENDED READINGS

INTRODUCTION

The past two decades have brought significant advances in the assessment and management of diabetic foot wounds. The implementation of evidence-based practice has led to more efficient use of new technologies and better understanding of the wound environment that is present in the diabetic foot. However, management of the diabetic wound continues to have an overbearing economic impact on the healthcare system and, more importantly, on the physical and emotional well-being of those patients suffering from nonhealing chronic wounds that often result in lower extremity amputation. This chapter reviews the key principles that are absolutely necessary in the advanced treatment of diabetic foot wounds.

Diabetes and diabetes-related complications have become a problem of truly epidemic proportions. The worldwide prevalence of diabetes is predicted to reach 366 million people in 2030 (almost doubling from 2000) if current trends continue (1). Approximately 15% of persons with diabetes develop a foot ulcer during their lifetime (2). A chronic foot ulcer invokes costs that include economic, mental, and physical damage to the diabetic patient (3,4). Some estimates place diabetic patients at 10 to 30 times higher risk of amputation than nondiabetic patients (5,6). Further, there is a significantly increased probability that a lower extremity amputation will be preceded by foot ulceration (2,7,8). Early assessment and intervention are not simply an option, but are absolutely important if we are to successfully address this public health concern.

Acute wounds can be readily treated with standard wound care therapies, whereas chronic wounds may require more advanced treatment modalities. No absolute threshold exists as to when an acute wound becomes a chronic wound. However, the typical wound in a healthy patient is expected to heal either through primary intention or secondary intention within 10 to 14 days with continued remodeling that lasts several months to a year. The diabetic chronic wound becomes stagnant and ceases to decrease in size and epithelialize. A wound may be considered chronic in nature when it ceases to decrease 10% to 15% every week or 50% over a 1-month period (9). We now understand that this wound healing “trajectory” is a highly reliable predictor of healing versus nonhealing. Further, a wound that is >2 cm², >2 months in duration, and in full thickness or deeper has a 79% decreased likelihood of healing within 20 weeks (10). Some of the more common reasons why an acute wound transition into a chronic wound include ischemia, neuropathy, infection (including soft tissue and/or bone), and pressure (Tables 9.1 and 9.2).

TREATMENT OF A DIABETIC WOUND

Various treatment options are available to wound care specialists for healing the acute and chronic diabetic wound. The science of medicine helps guide the clinician in assessing the effectiveness of treatment therapies; however, it is the art of medicine that assists the wound care specialist in the proper treatment of a specific problem wound scenario. A flexible treatment algorithm that incorporates known evidence is necessary to effectively manage a problem diabetic wound. A wound that has stalled must be quickly recognized as a chronic wound, and an appropriate change in the treatment plan should be implemented.

DÉBRIDEMENT

Débridement is a fundamental first step in the treatment of most chronic diabetic wounds (11,12). Débridement involves the removal of necrotic, fibrotic tissue (which may be space occupying and have a high bacterial bioburden), and inhibitory factors including matrix metalloproteinases (MMPs). Débridement alone may not be sufficient in healing a chronic wound, but should always be conducted prior to the use of any adjunctive wound-healing modality. There are multiple débridement techniques, including enzymatic, mechanical (wet to dry dressing change,
Table 9.1

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Intact skin; hyperkeratotic lesion around or under bony deformity</td>
</tr>
<tr>
<td>1</td>
<td>Superficial ulcer; base may be necrotic or viable with early granulation tissue</td>
</tr>
<tr>
<td>2</td>
<td>Deeper lesion extending to bone, ligament, tendon, joint capsule, or deep fascia; no abscess or osteomyelitis</td>
</tr>
<tr>
<td>3</td>
<td>Deep abscess, osteitis, or osteomyelitis</td>
</tr>
<tr>
<td>4</td>
<td>Portion of the toes or forefoot is gangrenous (moist or dry)</td>
</tr>
<tr>
<td>5</td>
<td>Complete involvement of foot; no foot healing or local procedure is possible</td>
</tr>
</tbody>
</table>

Saline irrigation), autolytic, biologic, surgical, and ultrasound (13,14).

Enzymatic débridement should generally be reserved for smaller wounds and for patients who are poor surgical candidates. This type of débriding agent typically involves the daily application of an ointment formulation of a collagenase and/or papain/urea. These products work to gradually break down collagen, fibrin, and eschar formation in the wound base over the course of weeks to months. The application of this ointment should be restricted to the area of the wound with a gauze dressing applied on top. Enzymatic débridement can be painful to the sensitve patient, but it has the advantage of being nonsurgical and can be managed primarily at home or in a nursing facility. Weekly monitoring of the wound is necessary to remove the accumulation of the liquefied material within the wound and to observe for signs of infection.

Mechanical débridement can be conducted in two ways. The first is through the use of wet to dry dressing changes. This involves placing a moist dressing material (typically a gauze dressing) into the wound site, then allowing this to dry and adhere to the surface of the wound. After drying has occurred, the dressing is removed along with adhered superficial necrotic and fibrotic tissue. This process can be painful, is only marginally effective, and is nondiscriminatory, because both viable and nonviable tissue may be removed. Further, a draining wound prevents the drying process from occurring, thereby making this débridement technique ineffectual. Autolytic débridement is the technique through which the body’s own wound enzymatic processes débride the wound through the use of an occlusive dressing. Because of the occlusive nature of this dressing, heavily exudative wounds cause maceration to the surrounding healthy tissue. Regular cleansing of the wound debris is essential for this process to be effective.

An example of biologic débridement is “maggot therapy” (15). This débridement technique involves the placement of medical grade sanitary fly larvae onto the wound site. These medical larvae are incapable of maturing into adult flies. The larvae are contained through the use of a material resembling cheese cloth attached to the surrounding skin using a hydrocolloid. Dressing material is applied on top of this construct to sequester waste material produced by the larvae and to capture any drainage from the wound. This outer dressing material is changed daily. The larvae should be removed after 2 to 4 days and can be replaced with new larvae. The larvae will débride only necrotic tissue, leaving healthy tissue behind. This débridement can be physically and psychologically uncomfortable for the patient. However, this may be a good débridement modality for patients who cannot tolerate alternative methods of débridement.

Surgical débridement can be conducted in the office or operating room with the use of sterile scalpels, curettes, and other hand instrumentation (12,16). Sharp débridement of fibrotic and necrotic tissue around the wound edges and wound base is essential to remove inhibitory factors such as proteases and collagenases (Fig. 9.1A,B). For larger and deeper wounds, débridement in a sterile environment, such as an operating room, is more appropriate. Débridement with a curette (wound base) and scalpel (wound edges) should be conducted until bleeding occurs. Thorough irrigation with copious amounts of sterile saline is then used to remove gross contaminants.

Hydrotherapy can also be used as a mechanical means of débridement. This subcategory includes older technologies such as whirlpool and newer modalities such as hydrosurgical débridement. Whirlpool removes debris through the agitation of water and the production of air bubbles. This débridement technique may be less painful than other forms of mechanical débridement, but there is a potential for cross-bacterial contamination if the bath is not sanitized properly. Newer technologies are being developed for débridement that combine the effectiveness of sharp surgical techniques with hydrotherapy-based instrumentation. For example, a novel technology called Versajet hydro scalpel (Smith & Nephew, Cambridge, UK) uses high-pressure sterile saline (15,000 psi) with continuous lavage and evacuation. The Versajet hydro scalpel has been reported to be faster and more precise in the débridement of problem wounds as compared with a handheld dermatome (17). This technology uses a small handpiece with a nozzle that shoots high-pressure irrigation horizontal to the débridement plane, while a suction component rids the area of debris (Fig. 9.2A–D). These surgical débridement techniques may be painful, which

Table 9.2

The University of Texas Health Science Center at San Antonio—Ulcer Classification System

<table>
<thead>
<tr>
<th>Grade 0</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre- or postulcerative lesions completely epithelialized</td>
<td>Superficial wound not involving tendon, capsule, or bone</td>
<td>Wound penetrating to tendon or capsule</td>
<td>Wound penetrating to bone or joint</td>
</tr>
<tr>
<td>Infected</td>
<td>Infected</td>
<td>Infected</td>
<td>Infected</td>
</tr>
<tr>
<td>Ischemic</td>
<td>Ischemic</td>
<td>Ischemic</td>
<td>Ischemic</td>
</tr>
<tr>
<td>Infected and Ischemic</td>
<td>Infected and Ischemic</td>
<td>Infected and Ischemic</td>
<td>Infected and Ischemic</td>
</tr>
</tbody>
</table>

Stage A Pre- or postulcerative lesions completely epithelialized
Stage B Infected
Stage C Ischemic
Stage D Infected and Ischemic

These surgical débridement techniques may be painful, which
Figure 9.1  Plantar ulcer sharp débridement. A. Plantar first metatarsal wound site with necrotic skin margins and deep tissue fibrosis. B. Viable granular wound base following sharp débridement of all wound margins.

Figure 9.2  Hydrosurgical débridement. A. Necrotic wound. B. Hydrosurgical débridement with Versajet handpiece showing viable proximal wound base. (continued)
may limit the degree of débridement conducted. The use of local anesthetics or general anesthesia is often necessary to ensure a thorough débridement.

Ultrasound-based technologies are a rapidly emerging class of débridement instrumentation that shows great promise. These devices use various levels of ultrasound energy with handpieces that are designed for specific sites and types of wounds. Ultrasound débridement can be delivered through direct wound contact or indirectly by treating just above the wound base. These systems use saline as a vehicle to deliver the ultrasound energy to the wound base which have enabled practitioners to offer more effective and more widely available débridement to their patients. These instruments are designed for outpatient clinical use, but are also finding utility in the operating room for débridement and wound bed preparation when grafting.

Débridement is fundamental for diabetic wound healing. Débridement should be conducted before the implementation of other wound care therapies. Further, serial débridement is often necessary to remove the accumulation of inhibitory factors such as foreign debris, necrotic and fibrotic tissue, and detrimental enzymes.

**OFFLOADING**

Vertical and horizontal forces play an important deleterious role in the development and chronicity of diabetic wounds located on the plantar aspect of the foot. Vertical forces (e.g., plantar pressure) have been found to be elevated in areas of ulceration and joint breakdown (18–21). The role of horizontal forces (e.g., shear) have not been as well elucidated (22–25). Regardless, these forces are profound in the environment of a foot that is insensate, is lacking in mobility, has decreased soft tissue density, and has a potentially compromised blood supply. Ideally, prevention of wound development through the use of functional and accommodative devices and/or extra depth shoes with multidensity insoles is the goal; however, delayed recognition of a diabetic foot at risk results in a chronic wound.

Although there are numerous ways to offload a foot wound, the ideal situation is complete nonweight bearing with crutch ambulation or wheelchair use. This degree of total nonweight bearing is impractical and unrealistic for the majority of wound patients. Some of the more commonly used offloading devices that permit weight bearing but reduce plantar pressure include total contact cast (TCC), removable cast walkers (RCW), halfshoes/wedge shoes, extra depth shoes, and aperture pads. Evidence tells us that these modalities do not equally offload an ulcer site (26,27). It is important to think about the forces not only at the wound site, but around the wound periphery as well. For example, a donut-shaped pad with a central aperture would seem to sufficiently offload a small ulcer. The reality is that the forces are transferred to the periphery of the wound. Increased stress around the periphery of the wound has been coined as the “edge effect” and could potentially inhibit wound closure (24,28). Further, it is important to evaluate the degree of mobility or immobility of the surrounding joints, which affects the forces experienced at the wound site. The goal of offloading is to redistribute forces evenly throughout the plantar aspect of the foot. This ensures that new ulcers on different sites are not formed as a consequence of focal stress reduction.

**TOPICAL WOUND TREATMENTS**

There are various topical solutions used for the conservative management of wounds in the form of pastes, ointments, and gels. These include débriding agents (discussed in a previous section), topical antibiotics, and progranulation formulations. The ease of application and noninvasive nature make these products a simple but effective adjunct to wound care.

Commonly used topical antibiotics include triple antibiotic, mupirocin, gentamicin, silver sulfadiazine, and cagedomer iodine. Triple antibiotic is a formulation of bacitracin zinc, neomycin sulfate, and polymyxin B sulfate. Topical antibiotics have been shown to be effective against uncomplicated soft tissue infections and can have a place in the management of mild diabetic wound infections (29,30). Bacitracin zinc is effective against gram-positive bacteria, including *Staphylococcus*. Neomycin sulfate belongs in the class of the aminoglycosides, hence has activity against gram-negative bacteria with some gram-positive coverage. Polymyxin B sulfate is effective against gram-negative bacilli such as *Pseudomonas*. Mupirocin primarily has activity against staphylococcal and streptococcal species. Further, mupirocin has been demonstrated to be effective against MRSA (31,32). Gentamicin belongs to the aminoglycoside class of antibiotics, with broad-spectrum activity, including pseudomonal coverage. As a whole, topical antibiotics should be reserved for mild superficial infections associated with diabetic wounds. Topical antibiotics can be used in combination with oral antibiotics for infection control. We do not recom-
mend prolonged use of the topical antibiotics because of the potential development of resistance. Daily application for the management of a mild infection associated with a chronic wound or in patients who cannot tolerate oral or parental antibiotics are examples of good uses for this type of therapy.

Two other commonly used antibacterial topical ointments include silver sulfadiazine (Silvadene, King Pharmaceuticals, Inc., Bristol, TN) and cadexomer iodine (Iodosorb/Iodoflex, Smith & Nephew PLC, London). Silver sulfadiazine is a commonly used topical cream that has a broad spectrum of activity, including both gram-positive and gram-negative organisms. Caution should be used for patients with sensitivity to sulfonamides because of the potential of cross-reactivity. Cadexomer iodine ointment consists of a starch polymer bead infused with 0.9% iodine. Exudate is absorbed by the starch polymer with a subsequent release of the iodine that acts as an antibacterial in the wound site. Although this product has been primarily used for venous stasis ulcers, it has been effectively used in exudative diabetic wounds (33). Silver sulfadiazine and cadexomer iodine can be used to decrease the likelihood of infection in an uninfected wound site. Hence, these products can be used for a sustained duration.

There are also topical products that promote granulation in the wound site. This discussion focuses on the two more commonly used products, becaplermin and hydrogels. Becaplermin (Regranex Gel, Johnson & Johnson, New Brunswick, NJ) consists of recombinant human platelet-derived growth factor (PDGF). Becaplermin should be applied daily to the wound site and covered by a saline-moistened gauze dressing. Débridement should be performed at each patient visit. This product requires refrigeration between applications. Studies have demonstrated that becaplermin is a safe product that promotes wound healing at a quicker rate compared with a placebo gel (34–36), although the Food and Drug Administration (FDA) has raised some recent concerns about becaplermin having a role in increased development of cancer. Hydrogels (e.g., Amerigel Wound Dressing, Anurex Health Care Corp., Clearwater, FL; and Curasol Gel Wound Dressing, Health Point Ltd., Fort Worth, TX) have been shown to be effective, relatively inexpensive products used to promote wound healing (37). Hydrogels create a sustained moist wound environment with daily application. Hydrogels generally consist of polymers (e.g., polyethylene glycol), water, humectant (promoter of moisture retention), and other added ingredients that come in various forms, including gels and sheets. These added ingredients may include antibacterial components and débriding agents. This product should be reserved for smaller, superficial, minimally exudative wounds.

Topical preparations are simple and effective wound care modalities. The application is uncomplicated, and the patient takes an active role in his or her treatment. Further, these treatment options are not invasive and are relatively inexpensive. However, their application may be limited to uncomplicated wounds.

**BIOENGINEERED ALTERNATIVE TISSUE**

There is growing interest in human and animal “skin” products for healing wounds in the lower extremity. Many different terms have been used to describe these new technologies, including “bioengineered skin,” “bioengineered skin substitutes,” “biological skin substitutes,” “tissue engineered skin,” and “cultured skin equivalents” (38–46). The use of these different terms has added to the confusion over the numerous products available and what they actually offer to the wound. Further, some of the terms simply do not describe these products accurately. We propose a new umbrella term that better describes these products. We believe that the term bioengineered alternative tissue (BAT) is a more accurate general descriptive phrase. The word bioengineered describes chemical and biological processes that are involved in the production of these products, including the infusion of certain components that promote wound healing. The term alternative tissue denotes the fact that these products are not autogenous skin, hence should not be treated as such. This is where the greatest point of confusion takes place which has led to the misuse of these products, because they have been mistakenly chosen in lieu of split- or full-thickness skin grafts (STSG). BAT products promote the conversion of a stagnant wound to an acute wound and are used in different wound types and at different wound stages than autogenous skin grafts.

Living cell-based BAT products generally stimulate the wound-healing processes in the wound bed or serve to deliver growth factors extrinsically when applied to the wound. Some BATs contain living fibroblasts and keratinocytes in addition to growth factors. When selecting a particular BAT product, it is important to keep in mind the different layers of tissue and their architecture. In many cases, a specific product choice can be made to match the wound depth and nature. When BAT products are used incorrectly, the results have a lesser degree of predicted success; therefore, the clinician may wrongly conclude that the product is ineffective or inferior. Proper selection of BAT products increases the likelihood of successful wound closure.

Not all BAT products are the same. Each product has been specifically designed to interact with the wound environment in a unique way. However, there are some broad categories that can assist in the proper selection of BAT products (Table 9.3). The first category is living tissue, which includes products such as Apligraf (Organogenesis, Inc., Canton, MA); Dermagraft (Advanced Biohealing, Inc., La Jolla, CA); Epicel (Genzyme Tissue Repair Corp., Cambridge, MA); Laserskin/Vivoderm (Fida Advanced Biopolymers, Italy); and OrCel (Ortec International, Inc., New York, NY). These products are derived from living cell cultures that contain human living keratinocytes and/or fibroblasts embedded within the product. Generally, these products should be reserved for superficial wounds.

The other broad category of BAT products is considered bioactive adjuncts. Examples of this class of products include Integra (Integra Life Sciences Inc., Plainsboro, NJ); Oasis (Healthpoint, Ltd., Fort Worth, TX); Gamma Graft (Promethean LifeSciences, Inc., Pittsburgh, PA); GraffJacket (Wright Medical Technology, Inc., Arlington, TX); EZ-Derm (Brennen Medical, Inc., St Paul, MN); AlloDerm (LifeCell Corp/KCI, Woodlands, TX); Biobrane (Dow Hickam/Bertek Pharmaceuticals, Sugar Land, TX); TransCyte (Advanced Biohealing, Inc., La Jolla, CA); and Orth ADAPT (Pegasus Biologics, Irvine, CA). These products function as nonliving, acellular tissue scaffolds that allow for a supportive structural environment for cellular ingrowth. These products generally should be used for deeper
wounds that allow the base of the wound to be built up. We focus our attention on those BAT products that have been more rigorously studied in the peer-reviewed literature for chronic and problem wounds.

We begin our discussion with the two most commonly used BAT products in the living tissue category, Apligraf and Dermagraft. Apligraf is a bilayered tissue construct that microscopically resembles true human skin. It is composed of bovine type I collagen and living human cells (keratinocytes and fibroblasts) derived from neonatal foreskin. After application, the living cells contained in the graft continue to produce matrix proteins and growth factors that aid in the healing process (Figs. 9.3A–C, 9.4, and 9.5A–C). This product is approved by the FDA for the treatment of chronic, venous ulcers and diabetic foot ulcers. Apligraf’s efficacy in the promotion of wound healing in the lower extremity has been supported by published case reports and clinical trials (47–55).

Dermagraft is composed of growing, living, allogeneic fibroblasts on a polyglactin mesh. Similar to Apligraf, fibroblasts are obtained from neonatal foreskin, and after implantation remain viable and continue to secrete matrix proteins and growth factors. The polyglactin mesh is biodegradable and is reabsorbed after 3 to 4 weeks. Dermagraft has also been reported to have positive efficacy in healing wounds in the lower extremity (56–61).

The bioactive adjuncts category encompasses many products that serve as scaffolds for wound healing. These BAT products contain no living cells. Three of the products that fall into this category include Integra, GraftJacket, and Oasis. The prototype in this category is Integra. Integra is a nonliving matrix composed of bovine type I tendon collagen and chondroitin-6-sulfate that has been historically used in the management of acute burn wounds (62–67). Integra has more recently been used by wound care specialists in the treatment of chronic ulcerations in the lower extremity with good success (68,69). Integra’s ability to

<table>
<thead>
<tr>
<th>Table 9.3</th>
<th>Commonly Used Bioengineered Alternative Tissues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>Components</td>
</tr>
<tr>
<td>Apligraf</td>
<td>Bilayered bovine matrix embedded with living human keratinocytes and fibroblasts</td>
</tr>
<tr>
<td>Dermagraft</td>
<td>Polylactin mesh embedded with living human fibroblasts</td>
</tr>
<tr>
<td>Oasis</td>
<td>Acellular porcine small intestine submucosa</td>
</tr>
<tr>
<td>AlloDerm</td>
<td>Nonliving dermal replacement made of cadaveric skin</td>
</tr>
<tr>
<td>Integra</td>
<td>Nonliving matrix of bovine tendon collagen and chondroitin-6-sulfate</td>
</tr>
<tr>
<td>Epicel</td>
<td>Cultured autograft made of living keratinocytes with no dermal component</td>
</tr>
<tr>
<td>Biobrane</td>
<td>Nylon-meshed fabric embedded with peptides and adhered to thin silicone layer</td>
</tr>
<tr>
<td>OrCel</td>
<td>Cross-linked bovine collagen seeded with living human fibroblasts and keratinocytes on opposite sides of the matrix</td>
</tr>
<tr>
<td>TransCyte</td>
<td>Biobrane seeded with nonliving human fibroblasts</td>
</tr>
<tr>
<td>Laserskin and Vivoderm</td>
<td>Perforated hyaluronic acid seeded with human keratinocytes</td>
</tr>
<tr>
<td>EZDerm</td>
<td>Cross-linked porcine collagen</td>
</tr>
<tr>
<td>GraftJacket</td>
<td>Acellular collagen matrix made of human skin</td>
</tr>
<tr>
<td>Orth ADAPT</td>
<td>Acellular allograft derived from equine pericardium</td>
</tr>
</tbody>
</table>
Chapter 9  Surgical Management of Diabetic Foot Ulceration

Figure 9.3  A. Bilayered living human cell alternative tissue (Apligraf) preparation with aseptic technique and saline-moistened gauze to remove from shipping container. B. Fenestration of Apligraf with no. 15 surgical blade to prevent fluid collection under graft and to stimulate cellular activity and growth factor release. C. Apligraf cut to size of recipient wounds prior to removing from gauze sponge.

Figure 9.4  Clinical appearance of lateral ankle ulceration 1 week following Apligraf. Note hydrated graft material and collagen matrix over wound base.

fill large defects makes it ideal for deep wounds that may extend to deep fascia and bone (Figs. 9.6A,B and 9.7) (68,70,71). GraftJacket is an acellular collagen matrix derived from cadaveric skin. The allogenic human tissue is processed using technology that removes the epidermis and all cellular components while preserving the matrix and biochemical components (Fig. 9.8A,B). This product has been shown to be effective in the treatment of deep foot wounds in diabetic patients (72,73). Oasis is composed of porcine small intestine submucosa that provides a scaffold for the growth of new tissue. Oasis is an acellular product containing collagen and growth factors and has demonstrated positive effects in wound healing (74,75).

There are certain important considerations to make prior to the clinical application of BAT products. The first is timing, as it is not so much a matter of “That product should be used,” as it is “When is the appropriate time to use each product?” These products are not necessarily used in situations in which a wound has been making good progress in healing, but rather in situations in which a wound has become chronic in nature. The decision should be made based on the percent decrease in wound dimensions and/or the degree of granulation tissue noted in the wound bed. Prior to application, the wound should be free of infection, and an adequate blood supply must be confirmed or established. Each product may have
some subtle differences in application; however, a general protocol can be followed. Application should begin with débridement of the wound in the operating room or in an appropriate clinical setting. Some products require fenestration using a noncrushing skin mesher (Brennan Medical, St. Paul, MN) or using a no. 15 surgical blade to allow for drainage. The product is then applied to the wound and should be tacked down using sutures or staples. This keeps the BAT product in place and allows for full contact of the BAT to the wound base. A nonadherent dressing is applied on the wound followed by dressing materials (a silver-impregnated material may be helpful for infection control). The wound should be evaluated on a weekly basis, but the graft site should be left undisturbed and no débridements should be performed unless infection is suspected. Most products integrate into the wound within 3 to 4 weeks. It is of vital importance to leave the products undisturbed unless the area becomes grossly infected. The product in the wound bed may have a slimy, coagulum appearance with
mild to moderate drainage. This is part of the integration process and should not be misinterpreted as a graft failure.

Finally, these products can promote complete epithelialization of a wound. However, a split-thickness skin graft (STSG) may be more effective and efficient in achieving final closure (Fig. 9.9A–E). The product may also require sequential application of different BAT products or repeated applications of the same product may be necessary to ultimately close a wound (Fig. 9.10A–F).

NOVEL ALTERNATIVE TECHNOLOGIES

Many adjunctive technologies have demonstrated clinical success in improving the outcomes of BAT. These products can serve to increase the biologic viability of the wound base prior to application of the graft, or they may serve to optimize the wound healing once the BAT is in place.

PLATELET PREPARATIONS

Topical application of autologous blood products on chronic wounds has gained popularity. Specifically, the use of platelet-rich plasma (PRP) and other platelet preparations has been
increasing for bone and soft tissue applications. Platelets are involved in many steps of the wound-healing process. Their inherent function in the human body has spurred the advent of products that attempt to recreate, stimulate, and activate these processes. The following sections discuss the technology of topically applied platelet preparations in further detail.

There are currently multiple competing platelet preparation systems used for topical application on wounds in the lower extremity. Some of these include Symphony II PCS (DePuy Spine Inc., Raynham, MA), Vivo Stat System (Vivolution, Birkeroed, Denmark), SmartPrep (Harvest Tech Corp., Plymouth, MA), AutoloGel (Cytomedix Inc., Rockville, MD), Magellan (Medtronic, Minneapolis, MN), and Accelerate (ExacTech, Gainesville, FL). The differences in these systems are subtle and revolve around the centrifuge constructs and additive properties within the respective reagents. There is good evidence for the efficacy of these products in healing chronic wounds in the lower extremity (76–83).

Similar to the BAT products, proper assessment and preparation of the wound should be conducted prior to the application of the platelet preparations. This includes infection control, routine débridement, and adequate offloading through external devices or surgical removal of bony prominences. One may also consider obtaining laboratory studies, including a coagulation panel to ascertain the number of platelets in the circulating system. Although a clear platelet deficiency may dissuade the use of these products, no absolute threshold has been established.

There are different processing methods used for platelet preparations. Platelet preparations called platelet releasates require processing in a laboratory. This involves a process in which the autologous platelets are first separated from the other blood products. Then, growth factors, including PDGF and transforming growth factor-beta (TGF-β) are extracted from the platelets and placed into a solution with other reagents. Generally, multiple containers of this solution are produced for daily topical application. Platelet preparations that are produced in the office, wound care center, or operating room are growing in popularity. The patient’s whole blood is drawn (typically 5–60 mL) and centrifuged to separate the blood products: PRP, platelet poor products (PPP), and erythrocytes. The PRP is preserved, whereas the PPP and erythrocytes are generally discarded. The PRP is then activated using thrombin; additional reagents, including calcium chloride, are mixed into the solution. The now-activated PRP is then applied (sprayed) topically onto the wound surface using a handheld device similar to a syringe and needle. This platelet preparation should be applied within 10 to 30 seconds after activation for optimal results. The resultant viscous coagulum forms, and readily adheres to the surface of the wound. A nonadherent dressing is applied over this wound, followed by a bolster dressing (4 or other dressing material) and Coban (3M, St. Paul, MN), or other dressing material. This process is repeated every 4 to 7 days. The area is left undisturbed until the following visit, when sharp débridement may be necessary. Multiple applications may be necessary with typical treatments requiring >1 month (Fig. 9.11A–E).

NEGATIVE PRESSURE THERAPY

Negative pressure wound therapy (NPWT) has become a mainstay in the treatment of both acute and chronic diabetic wounds. Whether it is used as a technique for primary wound closure, as a precursor to delayed closure, or for preparation of the wound bed for other therapies, negative pressure therapy plays an important role.

Since its inception, negative pressure therapy has been reported with good success in the medical literature for the treatment of various wound types (84–92). Negative pressure therapy is thought to promote granulation through decreasing bacterial bioburden and increasing capillary budding at the wound site. However, the exact mechanism of action and its superiority over standard wound care protocols have yet to be established (93–95).
Figure 9.9  A. Problem plantar lateral midfoot wound after debridement of infection and placement of flexor digitorum brevis (FDB) local muscle flap. B. Debridement and Apligraf application to optimized wound bed. C. Note advancing wound margins and epithelialization following Apligraf. D. Continued wound base improvement following bioengineered alternative tissue (BAT) placement. E. Revision and final closure with a split thickness skin graft (STSG).
Current negative pressure treatment protocols are based almost exclusively on animal studies performed by Morykwas (87,96). The standard protocol includes the setting of 125 mm Hg of negative pressure with oscillation between continuous and intermittent suction. Examples of a portable negative pressure wound therapy devices include the vacuum assisted closure or VAC (Kinetic Concepts International, San Antonio, TX) and VISTA (Smith & Nephew, Cambridge, UK). These apparatuses essentially contain a motorized “suction” unit connected to a plastic tubing, which is then inserted into an open-cell foam sponge (VAC) or gauze dressing (VISTA) that is cut to the shape of the wound and placed onto the wound bed. Multiple wounds in multiple locations can be linked and serviced by a single tubing. Interface dressings (e.g., Mepitel) are often used to prevent adherence of the wound bed to the sponge dressing in an attempt to decrease pain and bleeding during dressing changes, to prevent adhesion of new granulation tissue to the sponge, and to prevent granulation tissue in-growth into the sponge itself. The sponge is covered by a transparent occlusive dressing. The negative pressure is set at an intermittent or continuous pattern and can easily be adjusted for the strength of suction. A new sponge and dressing is reapplied every 3 to 4 days.

Figure 9.10  A. Chronic dorsal ankle wound with exposed extensor tendons and ankle retinaculum. B. Viable pinpoint bleeding following sharp surgical débridement. C. Placement of Integra for deep tissue coverage. D. Negative pressure wound therapy (NPWT) dressing to control exudate and to maximize graft contact to wound bed and vascular supply. E. Wound base optimized with continued local care and application of Apligraf. F. Final wound closure with application of a split thickness skin graft (STSG) and external fixation for stabilization.
Figure 9.11 Platelet gel application. A. Nonhealing plantar heel ulceration. B. Preparation of autologous blood following centrifuge. C. Platelet gel concentrate ready for application following preparation and activation with reagents. D. Platelet gel application and dressing. E. Viable wound base with decreased size and depth following two applications of autologous platelet gel.
As negative pressure therapy becomes increasingly prevalent, various adjunctive techniques and modifications have been adopted into the therapy guidelines. These include the use of the combination of STSGs or BAT products with negative pressure therapy (97–101) (Fig. 9.12A–F). Negative pressure therapy for chronic diabetic wounds has quickly become a cornerstone in the armamentarium of wound care treatment and will continue to be so in the future.

**HYPERBARIC OXYGEN THERAPY**

Hyperbaric oxygen therapy (HBOT) has been demonstrated to be effective as an adjunctive therapy in diabetic wound management (102–104). This wound care modality should be used in conjunction with other wound care modalities, and it specifically may be beneficial in patients with microvascular disease causing an ischemic wound. Transcutaneous oximetry may be beneficial in assessing local tissue perfusion prior to using HBOT. HBOT involves the administration of 100% oxygen that is inhaled while the patient sits or lies in a compression chamber. The compression chamber is set at an ambient pressure of greater than one atmosphere absolute (typically 2.0–2.5 atmosphere absolute). Each treatment session lasts 60 to 120 minutes and is conducted one to two times daily for 15 to 30 treatments. HBOT essentially attempts to increase oxygenation at wound sites by increasing the partial pressure of oxygen in the arterial circulation, which then increases the diffusion of oxygen into the tissues. This increased level of oxygenation at wound sites has been purported to have positive effects, including enhancement of antibacterial components, increasing fibroblast activation, upregulation of growth factors, promotion of collagen synthesis, and angiogenesis (105–109).

There are some important factors when considering HBOT for chronic diabetic wounds. As with all wound care modalities, peripheral vascular disease must be addressed. Particularly, large vessel disease limits the oxygenated blood from reaching the target tissues. Adverse effects of HBOT have been also been reported, including barotrauma to the tympanic membrane and sinususes in addition to transient myopia. Further, elevated levels of oxygen can be toxic to brain and lung tissues. HBOT is an expensive wound care modality and is time consuming for the patient. Hence, a careful assessment of the cost-benefit analysis should be conducted prior to use.

A discussion of topical oxygen therapy concludes this section on HBOT. Topical oxygen therapy involves the application of an airtight chamber sealed around the lower extremity encompassing the site of the wound. Oxygen is then pumped into this chamber. Topical oxygen therapy should not be confused with systemic HBOT. The atmosphere absolute created within the topical oxygen therapy chamber is around 1.0. The mechanism of action of topical oxygen therapy is unclear, and there are limited data that supports the use of this treatment modality (110). Further studies are needed to validate this form of wound-healing modality.

**SURGICAL INTERVENTION**

Surgical treatment for a diabetic foot is discussed in depth in another chapter. Hence, this discussion is limited to address some important points. Surgical management can be done in conjunction with conservative measures. If the underlying etiology is a structural deformity, a reconstructive procedure, tendon lengthening procedure, or an exostectomy is absolutely critical. Without surgical intervention, the best efforts for local wound care will fail.

**ALTERNATIVE TECHNOLOGIES**

This chapter encompasses the more commonly used wound care modalities. However, other technologies are not routinely used in the care of a diabetic wound. One of these technologies is ultrasound. A low-frequency, low-intensity ultrasound machine converts electrical energy into sound waves. At low frequencies (25–120 kHz), ultrasound creates cavitation and streaming that may be effective for wound débridement; and potentially independent of the débridement effect, low-frequency ultrasound may directly promote wound healing (111–113). Another wound care technology is electrostimulation. Electrostimulation uses a high-voltage pulsed current passing through the wound site. The exact mechanism of wound healing via electrostimulation in a chronic wound environment has yet to be clearly elucidated; however, there have been reports of the positive effects on healing of diabetic wounds (114,115). Lasers have also been used in the treatment of diabetic wounds. These are low-energy lasers using helium-neon, CO₂ (carbon dioxide), or KTP (potassium-titanyl-phosphate). However, there is limited evidence to support the use of lasers in the treatment of diabetic wounds (116,117). Finally, other technologies, including electrocorporal shockwave therapy (ESWT), also have been used, although further studies are necessary to support their efficacy.

**THE FUTURE OF DIABETIC WOUND CARE**

As we look into the future of diabetic wound care, the gap between basic science and clinical application becomes narrower. A fundamental understanding of the complex interactions among the myriad of different physiologic components involved in wound healing is necessary. It is unrealistic and improbable to think that we will find a single element that will heal all diabetic wounds. Advances in new biotechnology will continue to occur, while innovations of old technologies will continue to evolve. One potential future area of development is in “smart dressings.” This field will likely produce biological dressing materials that respond to the needs of the wound. Currently, it is difficult for the clinician to assess the stage the wound is in. Smart dressings would release factors and other components as needed, when needed. Stem cells also show promise as a potentiator of wound healing by replacing or activating senescent cells around the wound site. Gene therapy could be used to activate quiescent cells and suppress inhibitors of wound healing. The future of wound care is bright, and advances are occurring at a rapid pace.

The chronic diabetic foot wound is a challenge to any wound care specialist. As outlined in this chapter, multiple factors are at play when evaluating and treating a chronic wound. It is important to have a working knowledge of the wound healing process and the available treatment options. A wound care specialist must adapt to the wound.
Chapter 9 Surgical Management of Diabetic Foot Ulceration

Figure 9.12  
A. Dermagraft applied to deep plantar heel wound site. 
B. Dressing with negative pressure wound therapy (NPWT) to control exudate and to maintain graft contact to wound bed. 
C. Second application of Dermagraft to wound base. 
D. Viable wound base with decreased depth and 100% granulation to surface. 
E. Continued improvement following biologic stimulation with Dermagraft. 
F. Surgical revision and closure of wound site to complete reconstruction and healing with full thickness coverage of the heel.
REFERENCES


RECOMMENDED READINGS


INTRODUCTION

With nearly one in three Americans at risk for developing diabetes mellitus, the U.S. healthcare system is confronting a potentially devastating epidemic. The number of Americans diagnosed with diabetes has doubled in the past 15 years and, given current trends, 40 million Americans will be diagnosed with diabetes by 2050. With over 20 million Americans currently suffering from diabetes—6 million of whom are as yet undiagnosed—and another 54 million prediabetics, the future medical, economic, and social burden imposed by chronic hyperglycemia and its consequences is difficult to imagine. The direct and indirect costs associated with diabetes in 2002, according to the Centers for Disease Control and Prevention (CDC), was $132 billion. The average annual healthcare costs for diabetics is more than five times the average for nondiabetics. Over 60% of all nontraumatic lower extremity amputations occur in diabetic patients. In absolute numbers, diabetics underwent 82,000 lower extremity amputations in 2002 (1). In nearly 85% of cases, lower extremity amputations occur in the setting of a chronic open wound. It is in this context that the need for effective wound healing modalities has become urgent. Negative pressure wound therapy is one of the latest modalities brought to bear in the fight to preserve the diabetic lower extremity.

The nomenclature of this therapy can be confusing and is variously referred to as subatmospheric pressure (SP), topical negative pressure (TNP), vacuum-sealing technique (VST), vacuum-assisted closure (VAC), vacuum-assisted wound therapy (NPWT), all of which are more or less synonymous. The VAC Therapy System® itself consists of a reticulated open cell foam, a semipermeable adhesive drape, an evacuation tubing, and a negative pressure therapy unit. The foam material is made from polyurethane ether foam with pore sizes measuring 400 to 600 micrometers. The foam is fashioned to conform to the dimensions and shape of the soft tissue defect. An adhesive, semipermeable dressing is then placed over the foam. Negative pressure is then applied through a tube attached at one end to the foam and the vacuum therapy unit at the other. The therapy unit is set to deliver negative pressure at a continuous or intermittent rate of variable pressures. Most of the evidence suggests that 125 mm Hg is most beneficial. In addition to factors related to patient morbidity, nutritional status, and smoking history, the duration of VAC Therapy and frequency of dressing changes depends on the size, location, and vascularity of the wound. Typically, the VAC dressing is changed every 2 to 3 days with the duration of therapy lasting for as long as several months. Adjunctive modalities including hyperbaric oxygen therapy can complement NPWT, dramatically increasing the rate of wound healing (2).

MECHANISMS

Considerable effort has been given to understand the physiology behind the apparent benefits of applied subatmospheric pressure to wound beds. Perhaps reflecting the complexity of the healing process and the work that remains to be done, no firm consensus exists on why NPWT works. The explanations proposed are, therefore, many and varied. The early work by Morykwas et al emphasized the effects of NPWT on blood flow, granulation tissue formation, and the reduction of bioburden (2,3). More current research has investigated the role played by the mechanical effects of negative pressure and the clearing of mediators—both inhibitory and up-regulatory—in involved in the healing process (4,5).

Briefly, the improved local perfusion rates to tissue treated with NPWT appear to depend on edema control. As interstitial fluid is cleared, a gradient is set up in which the interstitial pressures fall below the capillary pressures in the wound bed, dilating the capillary bed and increasing local perfusion. The early published work by Morykwas et al reported increases in perfusion by 400% (5). Because the formation of granulation tissue is proportional to local perfusion, wound defects were noted to fill as blood flow increased.

The mechanical effects of NPWT are supported by recent, strong evidence suggesting that certain forms of mechanical...
shear stress can induce microscopic changes improving the wound environment (6,7). It is known that tissues subject to deformation stress respond by up-regulating mitosis and cellular production (5). Plastic surgeons have taken advantage of this property with the use of tissue expanders. Callus distraction represents the osseous analog to this principle (8). Mechanical stress has been shown to induce the vascular endothelial growth factor (VEGF) pathway, increase local concentrations of mediators involved in gene expression, and stimulate the molecular cascade in the healing process. At the moment, the deforming effects of NPWT appear to account for the clinical benefits of VAC Therapy more successfully than the clearance of interstitial fluids. However, it is likely that both mechanisms play a role in the clinical improvement of wounds.

The beneficial effects of reducing the bioburden in a wound are self-evident. The presence of infection is a known obstacle to wound healing, largely because of exaggerating the normal inflammatory response found in an open wound (9,10). A bioburden of 10^5 organisms per gram of tissue represents the threshold past which means healing is not likely to occur (10–12). Investigations by Morykwas et al suggest that NPWT can substantially decrease the wound inoculate, which contradicts subsequent work on this question (3). Recent studies suggest that the VAC Therapy may actually increase the bacterial count at the wound site (13,14). This finding notwithstanding, the study still noted the beneficial effects of NPWT.

The proposed mechanism put forward by those who support the antibacterial properties of NPWT centers on two effects of applied VAC Therapy. First, local immune function is considerably hampered by excess fluid accumulation. Edema decreases local oxygen tension and increases the diffusion distance among leukocytes, nutrient substrates, and the wound bed, impairing the immunologic response to biological contaminant and infection. Evacuating the wound bed of excess fluid removes this obstacle to effective levels of oxygen and nutrients. The second effect of VAC Therapy on bioburden depends on increased perfusion to the wound site. Because the capillary bed is the last stop in the delivery of oxygen and leukocytes, any increase in perfusion will increase the concentration of these substances, thereby improving local immune function.

The overall effect of increasing the clearance of inflammatory mediators and growth factors remains unclear. The interaction between the various mediators is the subject of intense investigation, with some researchers suggesting that the net effect of reducing inhibitory molecules improves the overall environment, despite the clearance of growth-promoting factors as well (15).

**APPLICATIONS**

NPWT is an appropriate treatment modality in the chronic and difficult wound setting. Venous, pressure and diabetic ulcers, and surgically and traumatically induced wounds are common pathologies managed with NPWT. The applications for NPWT now include the management of open wounds with exposed bone, severe burn injuries, split-thickness skin graft (STSG) recipient sites, and wound bed preparation (16). The number of applications often seems limited only by the imagination of the treating physician. Most commonly, NPWT is applied to wounds without any obviously available soft tissue coverage, created by open amputations or extensive incision and drainage procedures. After the débridement of infected tissue, NPWT is applied to facilitate wound bed preparations for a graft and/or definitive coverage. In summary, the wound VAC can be applied to nearly any open wound, provided that the wound bed is free of necrotic, nonviable tissue and is well perfused. Partial thickness and full thickness wounds with exposed tendon, bone, and hardware can be candidates for NPWT (16).

The efficacy of NPWT in both diabetic and nondiabetic wounds is well established, with numerous studies demonstrating favorable outcomes (16–20). In a comparison study of healing times between standard wet to dry dressings and VAC therapy, wound healing rates were noted to be double in the NPWT cohort versus those undergoing standard dressing changes (20). Studies focusing on diabetic wounds have demonstrated the same efficacy, with both the size of the lesion and time to healing substantially better compared with standard wet to dry dressing protocols (18,19). Additional studies have demonstrated the effectiveness of NPWT over advanced and expensive topical wound agents. Ford et al used the VAC Therapy system in a study comparing NPWT to the application of Accuzyme, Iodosorb, and Panafil. When measured by healing time, production of granulation tissue, and management of osteomyelitis, NPWT was the more effective modality (21). Taken together, these studies establish the superior efficacy of NPWT in the management of diabetic wounds as compared with more traditional treatment modalities.

**CONTRAINDICATIONS**

In general, NPWT is a very safe treatment modality with little risk of serious adverse events. Still, there are clear contraindications to the use of VAC Therapy and some caution is required when using NPWT. The contraindications to NPWT include sensitivity or allergy to the dressing material, psychological intolerance, an acutely ischemic wound, and malignancy in the wound. Wound VAC dressings and drapes are considered latex-free materials. Considerable care must be taken when applying the VAC Therapy over viscera or deep organs. The formation of a deep fistula was noted by Arpexa and Morykwas after the direct application of NPWT to an open abdominal wound with exposed gut (22). Also, toxic shock syndrome has been linked to the VAC Therapy and technique (23).

Untreated osteomyelitis or malignancies within the wound base are contraindications for NPWT. NPWT becomes effective once osteomyelitis and soft tissue infections are eradicated with aggressive débridements and antibiotics. Malignant lesions in the wound bed could potentially proliferate with NPWT and therefore cannot be treated with the VAC Therapy (24).

Poor wound hemostasis can be difficult with applied NPWT, especially in the anemic, volume depleted, and elderly patient. Caution should be taken when applying NPWT in cases of potential hemorrhage, such as bypass grafts, open fractures, or partial calcaneotomies. Bleeders should be tied or ligated appropriately before using NPWT. Applying NPWT 1 to 3 days postsurgical débridement is recommended when expecting significant postoperative bleeding. The nursing staff should monitor the patient and check for excessive bleeding or drainage after applying negative pressure on surgical wounds and discontinue therapy if needed until hemostasis is achieved (24).

Patients undergoing anticoagulant therapy or taking platelet aggregation inhibitors such as nonsteroidal anti-inflammatory drugs (NSAIDs), warfarin (Coumadin), heparin, and platelet aggregation inhibitors such as nonsteroidal anti-inflammatory drugs (NSAIDs), warfarin (Coumadin), heparin...
skin changes, such as wound necrosis, and/or gangrene should be closely monitored with laboratory studies, keeping antimicrobial values within therapeutic range. The patient should be carefully evaluated for surrounding ecchymosis, excessive blood drainage, and hematoma (24).

In the setting of severe ischemia, NPWT will only further desiccate the wound bed, increasing the size of the lesion. A complete vascular workup is imperative in these cases with appropriate intervention by a vascular surgeon, if indicated. Finally, patient compliance is important during NPWT. Patients must be willing to continue NPWT throughout the day and while sleeping. Proper patient selection is important. Patients with dementia need appropriate home settings and home health nursing to avoid complications.

PREOPERATIVE PLANNING

The medical status of the patient should be thoroughly evaluated before initiating NPWT. The initial assessment should include the history of the patient’s wound and its clinical presentation. NPWT is an adjunctive therapy for wound healing and the basic principles of wound care should be applied in conjunction with NPWT. A thorough examination of the wound is essential to determine its etiology and its chronicity. The physical exam should pay particular attention to the size, depth, base, margins, and location of the wound. The exam should also note any sinus tract formation, undermining exposed bone, tendons, ligament, open joints, and vital neurovascular structures. Most importantly, deep tissue infection and underlying osteomyelitis must be identified and treated if present. Clinical findings including the presence of purulence drainage, malodor, edema, erythema, and exposed bone are diagnostic of infection and mandate treatment. Serial radiographs may be necessary to demonstrate osteolytic changes when suspecting osteomyelitis (24–26).

Optimizing the patient is an important part of the preoperative planning to maximize treatment outcomes. Diabetic patients by definition are hyperglycemic, malnourished, and also immunosuppressed. A thorough workup of the patient’s metabolic state and nutritional status should be performed with proper laboratory studies such as complete blood count with differentials, serum chemistries, albumin, prealbumin, and hemoglobin A1C (26). Any abnormal findings and nutritional deficits must be addressed early and aggressively for effective treatment of the wound.

The psychosocial state of the patient should be addressed with timely consultation if there is evident self-negligence, noncompliance, depression, substance abuse, marital crisis, delirium, impaired cognition, or inadequate family support. Patients with unaddressed psychosocial issues, substance abuse, or severe depression are prone to unsuccessful outcomes (27). These patients need medical and social support with lay-term explanation to effectively clarify the treatment plan, reduce anxiety, and maintain compliance throughout the treatment course.

A comprehensive vascular workup is important to determine the efficacy of any adjunctive treatment. A thorough vascular assessment should include arterial palpation of femoral, popliteal and pedal pulses, capillary filling time, pallor changes on elevation, and dependent rubor. Clinical documentation of ischemic skin changes, such as wound necrosis, and/or gangrene should be identified to decide if further workup is necessary to enhance the healing potential of the wound. Lower extremity arterial noninvasive and invasive studies should determine if vascular consultation is necessary to revascularize the lower limb prior to NPWT initiation. Tobacco usage is strongly discouraged, and referring patients to a smoking cessation program will enhance healing outcomes.

Also, the management of the diabetic foot is best handled by a multidisciplinary team approach that specializes in diabetes mellitus. The team of specialists should include, but is not limited to, internists, physiatrists, physical therapists, psychiatrists, psychologists, social workers, wound care nurses, foot and ankle specialists, vascular surgeons, plastic surgeons, endocrinologists, infectious disease specialists, cardiologists, and nutritionists. Communication within these groups is paramount to establish a long-term treatment plan required for effective wound healing and wound prevention. The comorbidities commonly found in diabetic patients include but are not limited to, renal insufficiency, coronary artery disease, peripheral vascular disease, congestive heart failure, and immunosuppression; it is paramount that these issues be addressed to enhance the healing outcomes of the diabetic foot wound and salvage of the lower limb (26,28–30).

SURGICAL TECHNIQUE

Successful wound bed preparation must be obtained before initiating adjunctive NPWT. Serial débridements may be necessary to accomplish a clean, stable wound bed environment. The ideal pedal wound should have clean viable wound margins with possible epithelialization and a well-vascularized wound base devoid of devitalized tissue. Multiple débridement or resection modalities may be used in preparing a viable wound bed environment, ranging from sharp dissecting instrumentation to a hydrosurgical technique. The Versajet Hydrosurgery System (Smith & Nephew, Cambridge, UK) operates by directing a fine jet of sterile saline at variable speeds over the wound bed surface, while creating a localized vacuum effect (venturi effect) to allow both hydration of the wound and precise soft tissue débridement. This device prevents excessive tissue excision through a power regulator system. The Versajet hand piece is passed through the soft tissue defect until the wound bed is 100% viable (31,32).

It is important to convert a chronic wound to an acute wound through débridement before applying NPWT; enabling healing stages of wound healing to proceed (33,34). Infected wounds must be addressed with aggressive and adequate surgical débridement, saline irrigation, culture-based antibiotics, and open wound packing before NPWT is initiated. Exposed avascular structures such as tendons, plantar fascia, bone, or joints may need to be excised or covered by deep surrounding tissue prior to NPWT. Nonadherent dressings applied directly to the exposed avascular structures may expedite granulation tissue formation by keeping the wound moistened and preventing adherence of vital structures. Theoretically, tendons with intact paratenon or bone with intact periosteum are protected and may granulate with NPWT alone. Nevertheless, exposed avascular structures should be covered by granular tissue as soon as possible to prevent wound infection (Figs. 10.1–10.3) (25).

The VAC system (Kinetic Concepts, Inc., San Antonio, TX) is the most used mode of NPWT, consisting of open-celled foam, adhesive dressings (drapes), vacuum tube or TRAC (text continues on page 125)
Figure 10.1 A-B. Postoperative wound dehiscence and necrosis after a triple arthrodesis with a circular external fixation device in a patient with a history of diabetes mellitus. C-D. Clinical appearance of the wound at the lateral aspect of the foot upon frame removal 10 weeks after the reconstruction. E. NPWT was applied after an aggressive débridement at the time of frame removal. F-G. Clinical picture of the wound 2 and 4 weeks post-NPWT application. H-J. Final postoperative clinical and radiographic pictures 7 weeks post-NPWT application.
A preoperative picture of a septic ankle in a patient with diabetes mellitus (A) requiring extensive surgical débridement (B). The wound was left open with local moist to dry wound care for about 5 days. C–E. A revisional surgical débridement was performed with the application of the NPWT. (continued)
Figure 10.2 (Continued) F,G. Clinical appearance of the wound 3 and 8 weeks post-NPWT application. H. Please note the significant decrease of the wound size and the excellent wound bed preparation for the final application of the split-thickness skin graft.

Figure 10.3 A. A preoperative clinical picture of an unstable Charcot foot and ankle and chronic ulceration that was initially excised. A takedown with a tibial-calcaneal arthrodesis was achieved with the use of a multiplane circular external fixation device. B. Please note that NPWT was applied to the clean wound directly after the major reconstruction in addition to the external electrical bone stimulator. C. Clinical picture of the wound 4 weeks post-NPWT application. The wound was eventually closed with further postoperative manual compression of the external fixator at the arthrodesis site. D. Please note the final wound appearance 10 weeks after the arthrodesis procedure.
Pad™ connector, effluent collecting canister, and a microprocessor-controlled therapy unit. There are two types of open cell foams available for the VAC system. The open-cell nature of the foams permits uniform subatmospheric (negative) pressure throughout the wound base to generate granulation tissue formation and eliminate excessive fluid removal. Modifications such as the GranuFoam heel dressing is contoured to fit the heel and allow the therapeutic regulated accurate care (TRAC) pad™ bridge to be placed on the dorsal aspect of the foot for better comfort and faster dressing changes. The TRAC Pad™ is designed to monitor and maintain target pressure at the wound site via accurate pressure sensory devices impregnated within the pad. Also, the GranuFoam Silver® dressing has microbonded metallic silver impregnated throughout the foam, which is continuously delivered to the wound with negative pressure. The GranuFoam Silver® eliminates the need for adjunct silver dressings and provides a protective bacterial and fungal barrier to prevent infection within the wound (24,25,35).

The second type of open cell foam is a versatile, microporous white colored foam (Versa White Foam) made of polyvinyl alcohol. This foam is inherently denser, hydrophilic, and premoistened with sterile water prior to packaging. Its high tensile strength and nonadherent qualities makes the Versa White Foam useful in undermining areas and exposed vital areas where neurovascular structures, tendons, bones, and joints are localized (25,35).

Initially, the open cell foam is trimmed and fitted according to the dimensions of the wound and placed in direct contact with the wound bed. An adhesive drape is then applied over the sponge, extending about 3 to 5 cm beyond the margins to create an airtight seal. The adhesive drape may be applied in one sheet or in overlapping strips. Smaller strips are easier to handle and can be adjusted to the underlying contour of the wound. Multiple wounds may share a single VAC device by Y connectors or by through-the-bridging technique. The Y connectors will allow two separate wounds to share one common vacuum tube, whereas the bridging technique connects two wounds with a piece of foam overlying normal skin directly between the wounds. The normal skin is covered with adhesive drape prior to bridging to protect the skin from the vacuum forces and prevent cross-wound contamination. The tubing is placed directly into the foam and connected to the VAC unit. The effluent collecting canister should be in the VAC unit prior to vacuum tube placement to have wound debris stored and collected. The tube is then sealed to prevent leakage. The TRAC Pad™ connector has replaced the tubing for easier VAC dressing changes and to maintain target pressure at the wound site (25,35).

The soft tissue reconstructive ladder or elevator from the least complex to most complex steps begins with healing by secondary intention, primary wound closure, skin grafting, local random flaps, local muscle flaps, pedicled composite flaps, composite vascularized osteocutaneous flaps, and free tissue transfers (29). NPWT can be a useful adjunct in many of these settings. A healthy vascularized wound bed will improve an incorporated graft or flap regardless of the closure strategy used. It is the responsibility of the surgeon to decide which step on the reconstructive elevator is most appropriate. An efficient wound bed preparation is the key to the successful use of NPWT. A necrotic wound bed will not granulate and serial debridements may be necessary prior to VAC Therapy (33,34).

In addition, the modified Papineau technique with VAC Therapy has been described to address bone and soft tissue deficits with osteomyelitis after extensive and precise bone resections. The Papineau technique involves open cancellous bone grafting on a granulated wound base with osseous defects created after resecting chronic osteomyelitis or tibial nonunions. It is closed with reconstructive skin coverage or by secondary healing intention. The first stage requires complete resection of infected tissue and bone. The second stage involves open cancellous bone grafting within the osseous and soft tissue defect with VAC foam application at 48- to 96-hour intervals until healthy granulation tissue formulation in the wound bed is obtained. Autogenous bone graft and bone allograft may be packed within the osseous defect and covered with Adaptic gauze to prevent adhesion of the wound VAC foam. The final stage requires split thickness skin grafting for definitive wound closure. Other modifications include external fixation in combination with the Papineau technique (Fig. 10.4) (36).

**POSTOPERATIVE MANAGEMENT**

For the first 48 hours, 125 mm Hg of continuous negative pressure is applied. Thereafter, the device is programmed to intermittent pressure cycles with 5 minutes of applied negative pressure followed by a 2-minute rest period. The dressings are changed every 48 hours. Patients may require pain medication during dressing changes; however, most dressing care is well tolerated and can be managed without difficulty at the bedside. Outpatients treated with NPWT are given a portable mini-VAC Therapy device. Weekly or biweekly wound inspections allow clinicians to document the formation of granulation tissue and address any complications that might arise. Patients are mostly managed by a home health agency, skilled nurses in nursing homes, or wound care specialist in a wound care clinic (17,24,37).

**AVOIDING COMPLICATIONS**

Air leakage at the vacuum suction tube surface or within interdigital areas can be avoided with compound benzoin tincture or skip prep applied directly to the periwound environment, keeping the adhesive drape from detaching. Tegaderm and loban may be used to reinforce the adhesive drape around the tube.

Fragile or macerated skin may be protected by applying adhesive drapes over the periwound environment prior to VAC foam application. This will limit skin irritation and stagnant fluid buildup. Persistent maceration and direct vacuum tube pressure are known to cause further skin breakdown. Also, applying adhesive drapes over hydrocolloid dressings will protect underlying skin from macerating (25,35).

Granulation tissue “in-growths” into the foam can be avoided by changing sponges more frequently or using the VersaWhite Foam, which limits adherence with its polyvinyl alcohol property. Excessive or prolonged discomfort caused by the VAC Therapy
Figure 10.4  A. A preoperative clinical picture of an infected Charcot foot and ankle fracture-dislocation with multiple wounds and talus osteomyelitis. The patient underwent a talectomy with an insertion of antibiotic beads for a period of 7 weeks. B–D. The patient was eventually brought back to the operating room for a tibiocalcaneal arthrodesis with an autogenous and allogenic bone graft. At the same time, NPWT was applied directly to the wound (F) before the use of the multiplane circular external fixator (G). (continued)
**Figure 10.4** (Continued) Clinical appearance of the wound 14 weeks postoperatively (H) and before the external fixator removal and application of the split thickness skin graft (I). J, K. Final postoperative outcome at 19 weeks.
system can be alleviated by decreasing pressure settings in 25 mm Hg increments. Patients are able to tolerate VAC Therapy with a reduced rate of negative pressure (25,38).

Finally, veracious adhesive draping or tight dressings should be avoided to prevent skin tissue necrosis, especially at the digits. Pedal pulses or capillary filling time should be routinely evaluated for ischemic changes. Sensory loss or cyanosis should require an immediate dressing change or discontinuation of the VAC system for further evaluation (25).

CONCLUSION

This chapter describes the authors’ techniques of NPWT in complicated diabetic foot wounds. Surgical experience and knowledge of the most common indications of this magnificent wound care modality are necessary for successful patient outcome.

REFERENCES

INTRODUCTION

The goal of soft tissue coverage is to restore form and function. However, because of its anatomic complexity, soft tissue coverage of the foot often falls short of Sir Harold Gillies’ adage to “…replace like with like” (1,2). Regardless of etiology, foot wounds in patients with diabetes are difficult to close in a timely fashion and more difficult to maintain closed once they do heal (1–6). This is especially true of a plantar foot wound that represents a frequent location in the patient with diabetes (1,2).

Following a detailed analysis of the patient’s medical comorbidities, nutrition state, wound chronicity, presence of contamination or frank infection, and ambulation capabilities, soft tissue wound closure options can be entertained (1,7).

Soft tissue wound coverage employs various forms of conservative and surgical techniques aimed at creating rapid, durable, and functional closure using the simplest and least invasive modalities (4–9). Ideally, soft tissue coverage of the foot would involve primary repair without tension and involve use of neighboring sensate native tissue that are capable of withstanding the shear and tangential forces sustained during gait (1–3).

Most diabetic foot wounds are small in size and amenable to proper débridement and local wound care measures followed by correction of the underlying skeletal deformity (i.e., revision of a previous partial foot amputation, resection of an osseous prominence, release of an equinus contracture, etc.). However, larger wounds, especially those associated with exposure of underlying soft tissue and osseous structures, usually require more elaborate soft tissue wound coverage techniques. The so-called “reconstructive elevator” provides a concise list of the options available to perform wound closure. These include, from least to most invasive: (a) local wound care modalities and dressings intended to maintain a moist and aseptic environment that promotes autolysis with subsequent healing via secondary intent occasionally enhanced with various wound healing agents such as biologically active tissues; (b) delayed primary closure with or without continuous tension devices or tissue expansion; (c) split- or full-thickness skin grafting; (d) adjacent tissue re-arrangement or random-pattern local flaps; (e) distant (i.e., pedicled) composite flaps; and (f) free tissue transfer with microvascular anastomosis (7–9). This process should not be viewed as a linear treatment approach such as climbing a “ladder” (7), as each patient and his or her particular wound is not amenable to all potential options “climbed” in succession (8,9). To this end, skin grafting is regarded as the “work horse” of wound closure because it is simple to perform, reliable, minimally invasive, and cost-effective with the ability to be repeated as necessary to afford full soft tissue wound coverage.

From a historical perspective, the first use of free skin grafting dates back to the ancient Egyptians, as evidenced by the Ebers papyrus of 1500 BCE to cover traumatic wounds. The Hindu Tilemaker caste of 500 to 1000 BCE used skin grafts to replace noses that were amputated as punishment for theft and adultery (10,11). Since that time, the physiology and technique of skin grafting has evolved, and the process of skin graft “take” is well established (12–16). Even with the significant impact that biologically active tissue (17), negative pressure therapy (18), and plastic surgery flap techniques (19,20) have made on treating diabetes related ulcerations and traumatic wounds, skin grafting remains as the simplest and most commonly performed soft tissue wound coverage option within the “reconstructive elevator” (8,9).

PHYSIOLOGY OF SKIN GRAFT HEALING

Skin graft healing proceeds through a series of phases unique to transplantation of skin (12–16). The initial phase is termed the phase of serum imbibition or “plasmatic circulation” and is an ischemic phase that occurs during the first 24 hours following graft application (14). During this stage, fibrin glue anchors the graft to the recipient bed, allowing the graft to passively absorb plasmatic nutrients into the empty vascular channels. The graft subsequently becomes edematous and can gain up to 40% its weight. This creates a moist, nutrition-rich environment that maintains the patency of the graft vessels until host revascularization can occur (15). The fibrin glue is then replaced by robust granulation tissue that permanently attaches the skin graft to its underlying recipient bed. With secure apposition of the skin graft to the recipient bed, revascularization can proceed through the formation of anastomosis between the skin graft vascular channels and those within the host tissues. This represents the second phase of skin graft take, the phase of...
void of paratenon, and bone fragments with disrupted periosteal
tissue with careful preservation or reconstruction of vital soft
substance (23–28). Although there are important differences be-
tween the fourth and eighth post-transplant days (16).

HOST AND WOUND SITE PREPARATION

Review of the phases of skin graft incorporation reveals several
important factors that must be addressed to assure full take
and progression through the phases described above. First,
the patient must be primed for healing, and all underlying
medical comorbidities must be optimized prior to skin graft-
ing (7,18,20,21). It is critical to view the patient as a complete
individual and not simply a “wound on a foot.” In this regard,
a multidisciplinary approach is essential; therefore, consulta-
tion with internal medicine, endocrinology, infectious disease,
vascular or endovascular surgery, plastic surgery, nephrology,
nutritional services, physical and occupational therapy, social
work, and spiritual services are routinely obtained (22).
The role of each consulted service should be clearly stated so that
duplicate services are not obtained and the resultant unneces-
sary expense and confusion created are avoided.

Second, the “personality” and chronicity of the wound must be
determined (23,24). An acute wound usually results from a
single traumatic event, while a chronic wound usually forms
after repeated insults over time prior to healing and maturation
of the injured tissue (23,24). Specific to diabetic foot wounds,
an acute injury is most commonly associated with highly con-
centrated periods of ambulation in poorly constructed or ill-
fitting shoe gear, chemical, or thermal injury (i.e., “medicated
corn pads” and heating blankets, respectively), or self-inflicted
trauma (i.e., “bathroom surgery” on toenails and callus tissue)
(1–8). These wounds are early in the initial phases of healing
and are frequently associated with cardinal signs of an acute
infectious process (i.e., calor, dolor, rubor, drainage, malodor,
etc.) (21,23–26). Conversely, a chronic wound is usually the re-

tult of either neglect, poor host factors (i.e., tobacco abuse,
malnutrition, obesity, renal disease, immunosuppression ther-
apy, etc.), or patient noncompliance (21,23–26). These wounds
have “stalled” within the wound healing phases for any of several
potential reasons, but are usually contaminated with subacute
levels of bacterial burden, surrounded by a dense hyperkera-
totic rim, and possess nonviable fibrotic tissue throughout its
substance (25–28). Although there are important differences be-
tween the two, the initial approach for both wound types is the
same, namely, extensive débridement of all involved nonviable
tissue with careful preservation or reconstruction of vital soft
tissue and osseous structures (24–31). The initial débridement
should be performed under loupe magnification and full light-
ing to appropriately visualize the involved tissues (24,29–31).
This index débridement should be aggressive and completely ex-
cise all nonviable tissue, contused muscles, frayed tendons de-
void of paratenon, and bone fragments with disrupted periosteal
coverage, regardless of the volume of tissue removed, until all in-
volved tissues possess brisk and diffuse bleeding throughout
(24,29–31). Deep cultures are then obtained from several loca-
tions and labeled as the immediate post-débridement cultures
for culture-driven parenteral antibiotics over an appropriate pe-
riod of time, as indicated by the involvement of underlying soft
tissue and osseous components (24). The use of a power irriga-
tion system or “high-pressure pulsatile lavage” is commonly em-
ployed based on the general principles that the elastic recoil of
the wound contents between pulses will effectively dislodge bac-
teria (32). Although high-pressure (i.e., 70–100 psi) pulsatile
lavage has been shown to be more effective than hand-held bulb-
syringe lavage (32), several studies have demonstrated increased
edema within already traumatized soft tissues, thrusting bacteria
deeper within the wound interstices, and extensive aerosoliza-
tion (33,34). In this regard, it is helpful to place the foot, ankle,
and lower limb inside of an x-ray cassette cover during actual ir-
rigation to avoid inadvertently spraying operating room person-
nel and to limit aerosolizing the irrigation fluid (24,35). The
additional cost is negligible and since the x-ray cassette bag col-
lects the fluid, it can simply be placed inside the operating room
biohazard bags and discarded appropriately. However, a recent
study has shown that pulsatile lavage has a limited effect on re-
duction of Staphylococcus aureus in contaminated wounds (32).

Because this is the most common organism isolated from dia-
etic foot wounds (18,21,25,26), one should rely on pulsatile
lavage simply to rinse and hydrate already well-debrided diabetic
foot wounds, instead of expecting a therapeutic effect in the
presence of persistent bacterial contamination or frank infec-
tion. In this regard, a novel FDA-approved device for wound
débridement that affords the ability to perform wound débride-
ment, hydration, and irrigation with a single instrument was
designed (36,37). The Versajet Hydrosurgery System (Smith &
Nephew, Inc., Largo, FL) produces a high-velocity stream of ster-
el saline that crosses through a variable length hand piece and
into an evacuation container. This process creates a localized
vacuum effect (i.e., Venturi effect) that captures the tissue within
the handpiece and affords precise tissue ablation with con-
comitant debris aspiration, wound irrigation, and tissue hydra-
tion (36–38). The speed of débridement is altered through
varying the intensity of the saline traveling through the hand-
piece and the rate at that the handpiece is swept across the
wound (36–38). The depth of penetration is altered according to
the orientation of the handpiece either directly vertical or oblique
to the wound, as well as contact pressure applied by the
surgeon (37,38).

Third, once properly débrided, the recipient site must con-
tain a granular base or capillary bed capable of vascular in-growth
(11,16,24,29–31). It should be understood that a thorough vas-
cular assessment is essential and should include palpation of the
femoral, popliteal, dorsalis pedis, posterior tibial, and perforat-
ing peroneal arteries as well as appropriate noninvasive vascular
modalities (i.e., ankle-brachial index, Doppler waveform analy-
sis, toe pressures, transcutaneous oxygen tension, etc.) (18,39).
The venous system should be evaluated as well and any associ-
ated venous insufficiency and/or edema is either controlled with
pharmacologic and/or external compression therapy or cor-
corrected with appropriate level venous ligation by a vascular sur-
geon (18). Local wound care modalities including biologically
active tissue (17) or negative pressure therapy (18) can speed
the development and enhance the quality of granulation tissue.
Fourth, all bleeding should be meticulously controlled to limit the potential for hematoma or seroma formation between the skin graft and underlying recipient bed that would prohibit fibrin anchorage and subsequent vascular ingrowth (15–16, 24,29–31). In this regard, it is helpful to utilize autologous platelet-rich plasma (PRP) concentrate (Accelerate, Exactech, Inc., Gainesville, FL) or autologous bone marrow aspirate (BMA) harvested from the lateral calcaneus or proximal tibia applied to the recipient wound bed prior to and immediately following application of the skin graft (40–42). In addition, the autologous platelet-poor plasma can be applied to the graft donor or “ harvest” site to aid in adhering the surgical dressing and pain reduction (41,42). Since fibrin anchorage occurs in the initial phase of skin graft take (10–12), the application of PRP or BMA concentrate on the recipient site results in immediate adherence and therefore, when combined with a proper uniform compression or “bolster” dressing, limits shearing forces that can disrupt the developing vascular buds from growing into the skin graft (40–42). The application of additional PRP or BMA concentrate on top of the skin graft aids in filling the vascular channels and provides an enhanced wound-healing environment allowing the graft to imbibe the growth factor rich components of the PRP. Although several elaborate bolster dressings have been described in the literature (10,11,43–46), if the wound recipient site does not possess variable depth and irregularity, the author prefers to use a non-adherent silicone-impregnated dressing (Mepitel, Mölnlycke Health Care, Inc., Norcross, GA) that is stapled about the perimeter of the split-thickness skin graft (STSG) (41,42,47). Saline-soaked sterile cotton balls or cotton-cast paddings are then soaked in saline and applied over the skin graft site followed by folding of the silicone-impregnated dressing edges that are stapled to the saline-soaked padding underneath (41,42,47). This represents a simple, cost-effective bolster dressing that is both easier to apply and remove when compared with traditional multiple suture type dressings (47). However, if the wound is not of uniform depth or is highly irregular, the use of topical negative pressure wound therapy (Vacuum-Assisted Closure Advance Therapy System, VAC, Kinetic Concepts International, Inc., San Antonio, TX) has been shown to serve as an effective bolster with the added effect of improved exudate removal and prevention of shearing forces about the graft application site (48,49). However, because of the significant expense of this device, its routine use as a bolster dressing is appropriate only in specialized circumstances.

**TYPES OF SKIN GRAFTS**

Skin grafts can be harvested as either split-thickness skin grafts (STSGs), full-thickness skin grafts (FTSGs), or as pinch grafts (PGs) that are actually a variation of FTSGs (10–12,50). STSGs consist of the epidermis and a portion of the dermis (10–12,50). Depending on the needs of the graft, they can be harvested as thin (i.e., 0.005- to 0.012-in.), medium (i.e., 0.013- to 0.018-in.), or thick (i.e., 0.019- to 0.030-in.) grafts. These thicknesses vary only in the amount of dermis that is included (10–12). FTSGs consist of the entire thickness of the epidermis and dermis (10–12,50), whereas PGs consist of irregular segments of the epidermis and dermis harvested as a small cone of tissue (51). The donor site for STSG harvest has traditionally included the foot (10–12) or lower leg as viable options (10–12). Instead, the upper thigh (i.e., anterior, medial, or lateral portions), upper arm (i.e., lateral or medial aspects), and volar surface of the forearm have traditionally been considered the “ideal” sites since they are located in a broad area of tissue, allow the surgeon direct access during the procedure, and can usually be hidden under clothing (10–12). On occasion the author has utilized the medial arch (Fig. 11.1A), along the non–weight-bearing border of the foot (52), as well as, the posterior-lateral (Fig. 11.1B) and posterior-medial (Fig. 11.1C) proximal calf (41,42) as donor sites for harvesting STSGs of varying dimensions. Relatively large STSGs of up to 5 x 3 cm can be harvested from the foot with little difficulty, although nearly the same volume of tissue that can be harvested from the anterior-lateral thigh is possible from the calf. Some benefits of harvesting the STSG from the ipsilateral lower limb include: (a) enclosure within the same dressing as the recipient site; (b) ease of exposure during the surgery; (c) less pain compared to the thigh or buttock region; (d) ability to be performed under local anesthesia if necessary; and (e) conspicuous location allows the harvest site to be easily hidden from view within conventional sock and shoe gear (10–12,41,42).

FTSGs consist of the entire thickness of the epidermis and dermis (10–12). The donor site for FTSGs has traditionally included the lateral and medial arch, volar surface of the forearm, and inguinal fold area as the most likely sources for larger defects (11,50), although the foot has occasionally been mentioned (11,50). In the foot, the most common harvest sites include the redundant soft tissue folds about the lateral hindfoot (11,50) and from the dorsal intermetatarsal spaces where direct, tension-free closure is afforded. However, the close proximity to the cutaneous nerves is of concern, and great care should be taken to identify, protect, and retract these structures during harvest (11,50).

PGs consist of irregular segments of the epidermis and dermis harvested as a small cone of tissue (51). PGs have been described from almost every region of the body but the locations described for FTSG’s above are still the most commonly described (51). In the foot, they are most commonly harvested from the medial arch (53,54) or lateral hindfoot (55). Advantages of STSGs over FTSGs include: (a) better chance of survival under conditions of vascular compromise since they contain less tissue requiring revascularization; (b) more likely to be successfully incorporated onto the recipient bed; (c) can cover large defects including those not amenable to a flap or would otherwise heal slowly through secondary intent; and (d) are easier to obtain (10–12). Disadvantages of STSGs compared to FTSGs include: (a) presence of a granulating and universally painful donor site wound requiring postoperative care; (b) greater graft contraction; (c) special equipment required for larger grafts; and (d) poor cosmesis of the incorporated STSG (i.e., “tire patch” appearance) and donor site since the resultant scar is quite noticeable and should be hidden from plan site whenever possible (10–12). In this regard, a study of 20 plastic surgeons and 50 members of the public revealed that the most important factor affecting the choice of skin graft donor site location was the lack of visible scarring (56).

Regardless of what type of skin grafting is utilized, once harvested, the skin graft should be applied to the recipient site as expeditiously as possible and any unused portions should be wrapped in a moist gauze sponge soaked with sterile saline impregnated with antibiotic followed by placement
in a sterile specimen jar. The specimen jar is then labeled with the patient’s identification and date of harvest followed by refrigeration. The “scavenged” skin graft can be safely reapplied for up to 21 days in the clinical setting if any graft failure occurs as long as the reason for failure has been properly addressed (57).

SPLIT-THICKNESS SKIN GRAFT SURGICAL TECHNIQUE

The STSG harvest is usually performed under a regional field infiltrative anesthesia block and intravenous sedation when harvested from the foot (58) and under either spinal or general anesthesia when harvested from the calf or thigh region (41,42). The harvest site of choice is first cleansed with alcohol to remove any sticky residues from the routine sterile preparation. The size of the recipient site is measured with a sterile ruler, and the corresponding area of skin is marked on the harvest site with indelible ink. The blade guard width clip from a power dermatome (Electric Dermatome: Padgett Instruments, Integra, Plainsboro, NJ) set that most closely approximates the width of the harvest site is then selected. The sequence of events required to properly setup the power dermatome is very specific and results in severe injury to the patient or dysfunction of the device if not properly performed. First, the metallic piston in the handpiece must be positioned vertically to accept the attachment hole within the knife blade (Fig. 11.2A). Occasionally, this is difficult to perform manually and the device must be turned on and put through a few cycles to allow proper orientation. Next, the knife blade must be carefully held in both hands and bent slightly (Fig. 11.2B) to allow the flat, blunt side to rest within both catchment points adjacent to the metallic piston (Fig. 11.2C). The preselected blade width clip (Fig. 11.2D) is then placed on top of the knife blade and secured with a low-torque screw driver (Fig. 11.2E). Care should be taken not to over tighten the screws since they can easily be stripped making subsequent use difficult. If these steps have been followed properly, the interface between the blade guard width clip and knife blade will be intimate, and there will be no gap whatsoever between the knife blade and the body of the dermatome handpiece (Fig. 11.2F). The thickness of the STSG is then set by rotating the calibration gauge on the side of the dermatome handpiece and locking it in place by tightening a small nut. A thickness between 0.0012 to 0.018 in. is most commonly used (Fig. 11.2G). The thickness of the dermatome is checked by inserting a no. 15 scalpel blade between the knife blade and dermatome base (50). When the entire no. 15 blade fits, the depth is approximately 0.015 in. If only the sharpened edge fits, the depth is approximately 0.010 in. (10–12,50). The handpiece is activated and the setup is looked over one final time before actual use.
Figure 11.2  (A) The metallic piston in the handpiece (left) is shown properly positioned vertically and in the center of the piston channel ready to accept the attachment hole within the knife blade (right). The knife blade is shown being bent slightly (curved arrows) (B) to allow the flat, blunt side to rest within both catchment points adjacent to the metallic piston (straight arrows) (C). (D) Photograph demonstrating various width blade clips. (E) Photograph demonstrating proper use of the low-torque screw driver to secure the screws. (F) Photograph demonstrating proper interface between the blade guard width clip and knife blade that reveals no gap whatsoever between the knife blade and the body of the dermatome handpiece (blue arrows). (G) The calibrating gauge is shown set at a thickness of 0.015 inch with the nut fully tightened.
When the STSG is ready to be harvested, the surgical assistant first cleanses the skin with alcohol for the reasons mentioned previously and then lubricates the harvest site with sterile saline or mineral oil. Next, a tongue depressor or moistened gauze sponge is then applied both behind and in front of the intended path that the power dermatome is to traverse. This creates a smooth, taught, flat plane over which the dermatome can pass without catching wrinkled or bunched up skin and is a critical step in the harvest process. For this reason, the most experienced member of the surgical team should perform this task. Once adequate tension has been applied to the harvest site, the handpiece is held at a 30-degree angle relative to the harvest site and turned on full speed prior to contacting the skin surface (Fig. 11.3). In a single, smooth pass with steady, controlled pressure applied to the skin surface, the handpiece is advanced until the desired segment of skin has been harvested. Once this has occurred, with the hand piece still at full speed, the surgeon’s hands are dropped to the skin surface as the distal end of the handpiece is turned away from the skin surface at as close to a 90-degree angle as possible to cleanly transect the skin graft. The key points are to turn the power on full speed prior to contacting the skin surface, maintain steady pressure during actual contact, and to disengage the skin surface prior to turning the power off. Failure to follow this process will lead to irregularly shaped and variable depth STSG segments that are difficult to use as well as a noncosmetic harvest site (Fig. 11.4).

The harvested graft is then fenestrated manually with repeated passes of a surgical scalpel (i.e., “pie-crusting”) or meshed at a ratio of 1:1.5 or greater, using a commercially available mesher (Fig. 11.5) (10–12,50). The recipient site is coated with a layer of PRP or BMA concentrate (Fig. 11.6A) followed by stapling of the STSG about the perimeter of the wound (Fig. 11.6B) and additional coverage with a layer of PRP or BMA concentrate (Fig. 11.6C) (40–42). A bolster dressing is then applied using one of the techniques described above to firmly secure the STSG in place (Fig. 11.7). In addition, negative pressure therapy can be employed if the STSG application site is highly irregular or covers a large surface area that is not amenable to simple bolster application. Inosculations of STSGs by vascular buds usually begins by the fifth day post-application (13,14). Therefore, the STSG recipient site is left undisturbed for 5 to 7 days time and, at that point, the bolster dressing is removed and the graft is evaluated for proper take with the staples being removed at 10 to 14 days (10–12,40–42). Applying a hydrogel to the surface of the STSG followed by a nonadherent dressing is routinely performed to maintain a moist environment for progressive healing and maturation. If negative pressure therapy has been utilized, this is usually changed in 4 days to limit maceration about the surrounding tissues and can either be reapplied or discontinued with the above mentioned process followed.

The donor site is infiltrated in the dermal layer with 0.5% Bupivacaine with 1:200,000 epinephrine, as well as covered with the platelet-poor plasma to afford hemostasis and postoperative analgesia (41,42). A nonadherent or occlusive dressing followed by application of an absorptive gauze pad, and either a compression wrap or foam-type tape is applied to the harvest site. The outer dressing is changed in 5 days time with the deep dressing being left in place and gently trimmed as necessary over the ensuing weeks until it falls off on its own (Fig. 11.8A) (10–12,40–42). The donor site usually heals very rapidly over the next few weeks, and once fully mature in a few months’ time it is barely visible at all (Fig. 11.8B).

**FULL-THICKNESS SKIN GRAFT SURGICAL TECHNIQUE**

The harvest site of choice is cleansed with alcohol for the reasons mentioned previously, and then a sterile template is constructed approximately 5% larger than the actual recipient site to account for graft contraction after its removal from the donor site (10–12). The paper packaging from a sterile pair of gloves acts as an inexpensive and accurate template. First, the recipient site is outlined with indelible ink and, while the ink is still wet, the paper wrapping is placed onto the recipient site which
Figure 11.5  A. Photograph demonstrating a properly harvested split-thickness skin graft (STSG) that has been placed with the epidermis against the 1:1.5 mesh carrier and the dermis side exposed. Note that the STSG has been protected from desiccation by intermittent hydration with sterile saline and is devoid of wrinkles to allow smooth passage through the carrier. B. Photograph demonstrating the STSG and carrier placed on the manual mesher. Turning the handle (orange arrows) in clockwise fashion will advance the carrier through the mesher (blue arrow). It is important that the same person turning the handle secures the mesher to the table by pressing down on the metallic handle (lightning bolt), and a separate individual guides the mesher into the entrance and out of the exit side to prevent binding and damage to the STSG. C. Photograph demonstrating a properly meshed STSG as evidenced by the symmetrical mesh pattern and integrity with gentle handling.

Figure 11.6  A. Photograph demonstrating initial application of autologous platelet-rich (PRP) plasma to a wound about the dorsal aspect of the midfoot. Application of the split-thickness skin graft (STSG) is then performed with care taken to make certain the dermis side is in intimate contact with the wound bed, gently stretched to take advantage of the meshing that has been performed, and secure fixation most commonly performed with staples. B. Note the slight overlap of native skin and STSG that allows the surgeon the ability to clearly differentiate between healthy viable graft (pink, well-athered, and hydrated) on top of the wound bed and nonviable graft (black, loose, and desiccated) on top of the native skin. C. The STSG is again covered with autologous PRP to further enhance healing.
Chapter 11  Skin Grafting Techniques for Open Diabetic Foot Wounds

Figure 11.7  A. Following application of autologous platelet-rich plasma (PRP) and the split-thickness skin graft (STSG), a bolster dressing consists first of applying a large sheet of non-adherent dressing followed by application of sterile cotton balls or cast padding that has been soaked in sterile saline over the surgical site. The nonadherent dressing is then secured to the perimeter of the STSG with several staples.  
B. The nonadherent dressing is then folded over and stapled to the underlying cotton padding with gentle compression.  
C. Clinical photograph approximately 2 weeks following harvest of a thin STSG from the medial arch of the foot (orange arrow) that was applied to the dorsal aspect of the foot (blue arrow). Note the excellent incorporation of the STSG and the well-healed, cosmetic nature of the harvest site.

transfers the outline (42). The paper is then cut and placed on top of the FTSG harvest site that is either outlined with an indelible marking pen or scored with a syringe needle. The FTSG donor site is then incised to the level of subcutaneous adipose and excised with great care taken to try and remove all adhered adipose tissue at this time rather than after the graft is removed since this is an exceedingly tedious task (10–12). The FTSG harvest is usually performed under a regional field infiltrative anesthesia block and intravenous sedation (58) although this may distort the tissues, and a general or spinal anesthetic may be preferred with post-excision infiltration of local anesthetic if necessary (41,42). The harvested FTSG is then prepared by fenestrating the graft manually (i.e., pie-crusting) to allow for drainage to seep through the skin graft which limits the potential for postoperative hematoma formation and resultant skin graft failure (10–12). The recipient site is coated with a layer of
PRP, and the FTSG is usually stapled in place under some slight tension over a thin application of PRP or BMA concentrate as described above (42). A bolster dressing is then applied using one of the techniques previously described to firmly secure the FTSG in place. The donor site is infiltrated at the dermal layer with 0.5% Bupivacaine and the reapproximated skin edges are covered with platelet-poor plasma to afford hemostasis and postoperative analgesia after excising any “dog ear” formation. A nonadherent or occlusive dressing covers the harvest site and is removed at the first postoperative dressing change in 5 days (10–12). The donor site usually heals very rapidly over the next few weeks.

PINCH SKIN GRAFT SURGICAL TECHNIQUE

For PG harvest, a simple local infiltrative anesthetic block is usually sufficient allowing this to be performed in the clinical setting (51,53–55). The harvest site of choice is cleansed with alcohol for the reasons mentioned previously and the tip of an 18-gauge or similar sized needle is then placed through the skin and into the dermal layer to elevate a small cone of skin to be harvested. A no. 11 blade is then used to section the elevated skin at the base of the cone (54). These steps are repeated as necessary to collect the proper volume of PGs necessary to cover the recipient site, which is coated with PRP or BMA concentrate, leaving 2- to 3-mm distances between the grafts (53–55). A bolster dressing is then applied using one of the techniques described above to firmly secure the PGs in place. The donor site is infiltrated in the dermal layer with 0.5% Bupivacaine and each of the PG harvest sites is filled with autologous platelet-poor plasma (41,42) and covered with a nonadherent or occlusive dressing that is removed at the first postoperative dressing change in 5 days (53–55). The donor site usually heals very rapidly over the next few weeks and once fully mature, in a few months it is barely visible at all.

DISCUSSION

Soft tissue coverage of diabetic foot and ankle wounds is an ever-evolving process that involves an elaborate series of potential conservative and surgical techniques. Regardless of what technique is employed, the host must be medically prepared to maximize wound healing. A study of diabetic patients with soft tissue foot wounds revealed that the success rate for wound closure decreased significantly as the patient’s medical comorbidities increased (20). Proper and prompt referral to a vascular or endovascular surgeon is essential and should be viewed as a necessary component of the treatment of diabetic foot and ankle wounds (18). Once the patient has been evaluated by medical and vascular surgery services and their wound healing potential maximized by reversing any underlying medical or vascular issues, the recipient wound site must be properly and promptly débrided to develop a dense layer of granulation tissue in as “sterile” an environment as possible (24,29–31). Wound débridement strategies should involve complete excision of all nonviable soft tissue and osseous components with great attention to preventing dead-space formation, infection, and further trauma (24,29–31). The timeliness of proper and aggressive surgical débridement cannot be overemphasized (23,24,27–31). A study of diabetic patients with foot infections requiring hospitalization were stratified into one of two groups, those that received parenteral antibiosis for 3 days and those that received immediate surgical débridement and parenteral antibiosis (39). Those patients that received immediate surgical débridement and...
parenteral antibiotic required less above-ankle amputations than those who received parenteral antibiotic alone (59). This clearly solidifies the importance proper and aggressive surgical débridement plays in the management of diabetic foot and ankle wounds. Once the host and recipient wound site has been properly prepared, skin grafting using one of the techniques described here becomes possible. With careful attention to these strategies, the final result should be a viable, functional, sensate, and well-perfused lower extremity regardless of the initial severity of the wound (60). It is interesting to note that a study involving plastic surgeons as part of a multidisciplinary team caring for 38 patients with diabetic foot wounds requiring soft tissue coverage underwent skin grafting as the primary procedure for wound coverage in >50% of patients (20). These data rightfully place skin grafting techniques as the primary soft tissue wound coverage option of choice in the treatment of diabetic foot wounds that have failed appropriate local wound care measures (60). The closed, stable, noninfected wound should then be amenable to further protection in appropriate pressure dispersing shoe gear (18). Diabetic foot wounds should initially be properly protected through an off-loading device (i.e., appropriately lined gear (18)). Diabetic foot wounds should initially be properly protected through an off-loading device (i.e., appropriately lined and accommodated post-operative shoe or total contact cast) until the soft tissue coverage performed has been able to mature enough to accept the shearing and tangential forces associated with weight bearing (61). At this time, multidensity customized or appropriated prefabricated in-shoe orthoses and properly modified, extra-depth or custom molded shoe gear with or without outer sole modifications (i.e., rocker sole or bar, etc.) are employed for long-term protection of the soft tissue wound coverage site (18).

CONCLUSION

When properly performed, skin grafting of diabetic foot and ankle wounds represent simple, reliable, minimally invasive, and cost-effective techniques useful in the surgical management of diabetic wounds involving patients with well-controlled medical comorbidities. Further protection of the soft tissue wound coverage site through the use of proper in-shoe orthoses and shoe gear is essential and should be frequently monitored to avoid or at least minimize late return of the wound.

REFERENCES

Local Random Flaps for Soft Tissue Coverage of the Diabetic Foot

In the surgical treatment of diabetic foot ulcers, tumors, malignant lesions, callousities, or traumatic lesions, the reconstructive surgeon is faced with the challenge of repairing the tissue defect or deficit. Healing the wound can be achieved by secondary intention, direct primary closure, skin grafting, myocutaneous graft, local cutaneous skin flaps, or free tissue transfers. Local flap closure restricts to the isolated pathology without sacrificing healthy tissue.

Gillies once said, “The next best skin is the nearest skin” (1). A flap is defined as a mass or tongue of tissue for transplantation being vascularized by a pedicle or stem (2). Local flaps include the epidermis, dermis, and subcutaneous tissue. The local flap may also include underlying fascia, muscle, or both. Flaps can be categorized by their blood supply, shape, donor anatomic location, eponyms, tissue type, or movement. For the sake of simplicity, this chapter separates the various types of local flaps according to movement, as shown in Table 12.1. Local flaps have an intrinsic blood supply ideal for covering defects containing exposed bone or tendon in that the vascular supply may not be sufficient to support a skin graft (1,3–46).

GENERAL PRINCIPLES

Preplanning must be performed prior to an incision, including excision of the initial ulcer or defect. Considerations include an assessment of the general health of the patient, the source of blood supply to the flap, donor site selection, the recipient site, and the optimum positioning and design of the flap. Intraoperative handling of the flap, such as using atraumatic techniques and minimizing the amount of undermining are paramount in the success and viability of the flap. Postoperative care of the flap, especially prophylaxis against common postoperative complications, should be maximized. External factors, such as patient compliance, vascular status of the patient, and presence of an underlying bony prominence, must be evaluated and addressed for a successful postoperative result.

PATIENT HEALTH FACTORS

Factors such as diabetes mellitus, hypertension, peripheral vascular disease, venous insufficiency, anemia, neuropathy, malnutrition, renal disease, infection, history of abnormal scarring, bleeding abnormalities, protein S deficiency, age of the patient, musculoskeletal abnormalities, and use of tobacco should be addressed preoperatively and optimized if possible (47,48). Patients taking medications that affect coagulation, such as aspirin, clopidogrel (Plavix), warfarin, or heparin must be appropriately managed. Nutritional supplementation can be considered. Smoking cessation should be of utmost importance because of its adverse effect on wound healing.

The lower extremity risk factors such as peripheral vascular disease and peripheral neuropathy must be assessed preoperatively. Significant vascular insufficiency may require a vascular surgery consultation and workup. The indications for vascular consultation include an ankle brachial index (ABI) of $0.7$, toe blood pressure $<40$ mm Hg, or transcutaneous oxygen tension (TcPO$_2$) levels $<30$ mm Hg. These measurements of perfusion allow predictability for wound healing (49). Diabetic and chronic renal insufficiency patients often have nonocclusive calcified vessels with falsely elevated numbers, showing ABIs $>1.3$ and therefore limiting the utility of segmental limb pressures in the vascular evaluation of the extremity. It is often beneficial to evaluate toe pressure measurements, transcutaneous oximetry, or waveform analysis. The toe brachial index (TBI) is a more reliable indicator of foot perfusion in diabetic patients because the small vessels of the toes are spared medial calcification. The absolute toe pressures are valuable when estimating ulcer healing potential; pressure $>30$ mm Hg is favorable for wound healing (50–59). Noninvasive vascular studies including ABIs, toe pressures (pulse oximetric toe pressure), pulse Doppler waveforms, treadmill exercise testing, and TcPO$_2$ should be evaluated preoperatively. Functional photoplethysmography (fPPG) is a noninvasive automated device using a novel cuffless functional test for assessing mild or significant peripheral arterial disease (PAD) without the operator dependency issues associated with resting ankle brachial pressure index (RABPI). Functional PPG may prove to be superior to RABPI and may be useful as a simple screening tool for early detection of PAD (60). If inconclusive, then Duplex scanning, contrast arteriography, or gadofosveset-enhanced magnetic resonance angiography (MRA) may be necessary (61). If inadequate perfusion is found, a vascular surgery procedure may be performed to increase peripheral perfusion.
Infections must also be eliminated prior to flap reconstruction, bearing in mind the options for wound closure. Infected wounds should be packed open after débridements and incision and drainage procedures. With respect to the patient’s age, one analysis of patients undergoing insensate free flap coverage of weight-bearing portions of the foot found good results in 70% of all patients. In contrast, 92% had good or excellent results in patients who were ≤40 years (26). In addition to all of the preceding factors, the patient’s occupation and capacity to deal with lost time from work, including the economic impact, should be considered. The patient’s expectations regarding the outcome of the surgery, possibility of additional surgeries, and potential risks (e.g., amputation) should be considered.

**BLOOD SUPPLY**

Knowledge of the vascular anatomy allows the reconstructive foot and ankle surgeon to plan safe incisions providing sufficient blood flow for healing. This allows the surgeon to assess whether a given amputation will heal, the flap can be harvested successfully, or revascularization will give the best chance to heal existent ischemic ulcers (59).

The skin receives its blood supply from any one of three sources: (a) a cutaneous artery, (b) musculocutaneous perforating arteries, or (c) fasciocutaneous arteries. A composite block of skin, including a specific cutaneous territory, is supplied by an artery called an angiosome (62). Multiple angiosomes constitute the three-dimensional vascular territories of the body (62). A venosome is a three-dimensional territory drained by a named vein and is connected to neighboring venosomes by “oscillating” veins. Angiosomes and venosomes tend to overlap a territory known as an angiotome. Each angiosome covers a specific area, but can communicate with other nearby angiosomes via either true anastomoses of normal caliber vessels or “choke” vessels. Choke vessels are small, reduced-caliber connecting branches that are usually closed between the angiosomes (63).

Angiosomes are connected to one another by choke vessels that define the anatomic territory of each artery (62). When a particular angiosome becomes compromised, the choke vessels open to allow a neighboring angiosome to support the compromised area. An angiosome can only support an adjacent neighboring angiosome. For an angiosome to support another angiosome beyond its direct neighbor, a delay procedure must be performed to allow two consecutive sets of choke vessels to open (1,2,13–46,64–89).

Ian Taylor introduced the angiosome concept, understanding that angiosomes of the foot and ankle and the interaction among their source arteries are clinically useful in surgery of the foot and ankle. There are six angiosomes of the foot and ankle originating from the three main arteries and their branches to the foot and ankle. The three branches of the posterior tibial artery each supply distinct portions of the plantar foot. The two branches of the peroneal artery supply the anterolateral portion of the ankle and rear foot. The anterior tibial artery supplies the anterior ankle, and its continuation, the dorsalis pedis artery, supplies the dorsum of the foot. Blood flow to the foot and ankle is redundant, because the three major arteries feeding the foot have multiple arterial–arterial connections. By selectively performing a Doppler examination of these connections, it is possible to quickly map the existing vascular tree and the direction of flow (90).

The delay procedure is based on the theory of gradually exposing a flap of skin to an environment of decreased blood flow that enables the flap to survive in such an environment. It is performed by either severing the vessels beneath or around the perimeter of a proposed flap or by incising and elevating a flap of skin and suturing it back into its original position. The blood flow to the skin is disrupted and the flap undergoes ischemic changes. Metabolism is converted from aerobic to anaerobic, lactic acid and carbon dioxide are produced, and the tissue pH changes to a more acidic environment. Subsequently, the blood vessels in the flap dilate. The pre-existing choke vessels

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**TABLE 12.1** Types of Local Cutaneous Skin Flaps

<table>
<thead>
<tr>
<th>Advancement Flaps</th>
<th>Rotation Flaps</th>
<th>Transposition Flaps</th>
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</thead>
<tbody>
<tr>
<td>Single advancement</td>
<td>Single rotation</td>
<td>Single lobe</td>
</tr>
<tr>
<td>Double advancement</td>
<td>Double rotation</td>
<td>Bi lobe</td>
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<tr>
<td>M-plasty</td>
<td>Modified M-plasty</td>
<td>Modified Bi lobe</td>
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<tr>
<td>T-plasty</td>
<td>Classic rotation flap</td>
<td>Z-plasty</td>
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<tr>
<td>V-to-Y</td>
<td>Satterfield-Jolly</td>
<td>Double-Z rhomboid</td>
</tr>
<tr>
<td>Modified V-Y plasty or double reverse V-Y plasty</td>
<td>Catanzariti-Wehman rotation flap</td>
<td>Double opposing Z-plasty</td>
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<tr>
<td>Double V-to-V</td>
<td></td>
<td>Four-flap Z-plasty</td>
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<td>Crescentic advancement</td>
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<td>Double opposing semicircular</td>
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<tr>
<td>Oblique sigmoid island flap</td>
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<td>W-plasty</td>
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<tr>
<td>V-Y plasty</td>
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<td>Rhomboid or Limberg</td>
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<tr>
<td>V-V plasty</td>
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<td>Flap of Dufourmentel</td>
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<td>Extended V-Y island flap</td>
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<td>30-Degree transposition</td>
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<td></td>
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<td>flap (Webster flap)</td>
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<td></td>
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<td>Double or triple rhomboid</td>
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<td>Note flap</td>
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<td>Interpolation flap</td>
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between adjacent perforators dilate, especially along the axis of the flap (1,2,13–46,62,64–89). In addition to changes in blood flow, the delay technique creates a local sympathectomy that also causes vasodilation secondary to the decrease in sympathetic tone (44). After approximately 2 to 3 weeks, the major beneficial effects of the delay procedure are seen and the flap can either be transposed or another delay procedure can be performed (44). For the best results (i.e., maximal survival of a flap), it is best to progressively undermine and ligate perforators of a flap, while leaving the tip attached until the final elevation and relocation (1,2,13–46,64–89). At least one additional anatomic vascular territory can be added to the length of a flap with the use of surgical delay (89). The survival of a length of a flap is inversely proportional to the distance between the artery at the base of the flap and the next perforator territory (72). An alternative to using a surgical delay procedure is to perform soft tissue expansion that increases the size of the flap and augments the vascular territory (38).

Without the use of a surgical delay, the first territory in a random area of a flap can be captured with safety; however, necrosis tends to occur in a flap when an attempt is made to capture the next or subsequent angiosome (1,13–46,62,64–72,89). Necrosis may be caused by the decrease in pressure gradient as the blood flows across the choke vessels. The more choke vessels present in a particular flap, the less pressure there is available for flow at the distal aspect of the flap (62). Although the survival of more than one adjacent vascular territory may occur, it does so inconsistently (72).

For many years, flap designs, especially those on the plantar aspect of the foot, were based on the concept that the blood supply was from deep to superficial, through muscles and the plantar fascia. Most flaps on the plantar aspect of the foot were musculocutaneous or fasciocutaneous flaps. Hidalgo and Shaw showed that local plantar flaps could be designed to include sensation and abundant blood supply without the need for a subfascial dissection (31). Another misconception regarding blood flow was skin flap dimensions must be based on length to width ratio (69). The accepted ratios of length to width had been defined as 3:1 in the face, 2:1 on the trunk, and 1:1 on the extremities. Milton demonstrated that the presence of an artery at the base of a flap determined its success and not the length to width ratio (69).

Blood vessels follow the connective tissue framework down to the microscopic level. If the connective tissue is rigid, then the vessels hug its surface, whereas if the connective tissue is loose, the vessels travel within it (62). Blood vessels radiate from fixed areas where tissues are anchored to mobile areas (62). When there is mobility between tissue planes over a wide area, large flaps are available for transfer (62). The safest design of a flap is where the axis of the flap is placed along the direction of the greatest mobility or lines of maximum extensibility, (LME), as determined by the pinch test and toward the next dominant perforator (89). Blood vessels also radiate from concavities and converge on convexities (62).

Hidalgo and Shaw determined that from the base of the heel to the base of the metatarsals, there exists an extensive subcutaneous plexus that provides vascularization to the region (31). In this anatomic area, vessels run medial to lateral and are supplied by the dorsalis pedis and lateral plantar arteries. The lateral plantar artery branches and descends vertically toward the plantar fascia. The medial plantar artery contributes fewer branches. There are perforators coursing through the plantar fascia from the flexor digitorum brevis muscle (5). The peroneal artery contributes lateral calcaneal branches to the lateral aspect of the proximal heel, and the posterior tibial artery contributes medial calcaneal branches to the medial aspect of the proximal heel.

The area overlying the distal two thirds of the plantar fascia is defined by Hidalgo and Shaw (31) as the watershed area because it receives blood supplies from multiple sources, such as the proximal plantar subcutaneous plexus, the medial and lateral plantar arteries, and branches of the deep plantar artery. The instep or medial plantar midfoot receives the majority of its blood supply from the superficial branch of the medial plantar artery (5). If a large rotation flap is required in this region, it should be based medially (5). Hidalgo and Shaw also determined that the lateral plantar surface of the midfoot receives its blood supply from branches of the dorsalis pedis artery curving around the lateral aspect of the foot and branches of the lateral plantar artery (31). Other authors demonstrated a clear line of demarcation at the sole of the foot intersecting the lateral dorsal skin (5). The lateral plantar surface receives some blood supply proximally from the proximal plantar subcutaneous plexus (31).

The area of the plantar foot distal to the plantar fascia receives blood supply from an arch formed by the dorsalis pedis artery and lateral plantar artery. Moderate-sized cutaneous vessels arise between slips of plantar fascia. These vessels run vertically to a subdermal plexus without a subcutaneous plexus (15). In addition, there is a small contribution to the arch by the medial plantar artery. The dorsalis pedis artery and first dorsal metatarsal artery together form the arterial axis, providing the majority of the blood supply to the dorsum of the foot. The distal aspect of the tibialis anterior, anterior peroneal artery, dorsal arterial rete, and marginal anastomotic branches along the medial and lateral aspects of the foot may also provide supply to the dorsum (82). The skin covering the extensor digitorum brevis has the poorest blood supply (78).

In the sole, an intimate venous network is formed by branches of the great saphenous vein, small saphenous vein, and dorsal venous arch. Vascular arrangement of the venous network is not random but characteristic in each region of the sole. In the medial plantar arch, vessels are arranged toward the anterior margin of the medial malleolus. Venous drainage of the medial plantar flap is formed by two venous systems: the cutaneous veins visible through the skin draining into the great saphenous vein and the deep veins accompanying veins of the medial plantar artery. In planning the medial plantar flap, taking the vascular arrangement of both arterial and venous networks into consideration helps avoid venous congestion and also extends the flap (91).

**DONOR SITE CONSIDERATIONS**

The donor site for local skin flaps should be evaluated for tissue mobility and elasticity; otherwise, the flap could be under tension after relocation. The composition of the skin at the donor site should be equal or greater in durability than the recipient site. Weight-bearing plantar skin is ideally used to replace weight-bearing plantar deficits. Donor sites can be closed primarily, allowed to heal by secondary intention, or may be
Plastic techniques, with and without bone resection, are a part of the treatment of diabetic or noninsulin-dependent diabetic foot wounds. The vascularity of the donor site, especially the location of dominant cutaneous perforators, can be determined with the use of a Doppler probe and aids the planning of skin flaps (1,13–46,64–72). Safe dimensions of a flap can be predicted and at the same time reveal areas of possible future ischemia with the use of a Doppler probe (89). If a long flap is needed, a delay procedure should be considered to recruit adjacent vascular territories toward the tip of the flap (13). If the flap is not delayed, the success of the flap is dependent on the location of the next dominant perforator along the length of the flap (13).

The use of local previously burned skin as flaps in burn reconstruction is safe. Reconstruction with flaps should be considered as first choice in burn reconstruction regardless of the quality of the local tissue (93). Local flaps are also useful in repairing deeply burned wound of extremities with a survival. The vascularity of the donor site, especially the location of dominant cutaneous perforators, can be determined with the use of a Doppler probe and aids the planning of skin flaps (1,13–46,64–72). Safe dimensions of a flap can be predicted and at the same time reveal areas of possible future ischemia with the use of a Doppler probe (89). If a long flap is needed, a delay procedure should be considered to recruit adjacent vascular territories toward the tip of the flap (13). If the flap is not delayed, the success of the flap is dependent on the location of the next dominant perforator along the length of the flap (13).

The use of local previously burned skin as flaps in burn reconstruction is safe. Reconstruction with flaps should be considered as first choice in burn reconstruction regardless of the quality of the local tissue (93). Local flaps are also useful in repairing deeply burned wound of extremities with a survival rate of up to 93.2%. The method is simple and with satisfactory results that can decrease the rate of disability suffered from a burn (94).

**PLACEMENT OF FLAPS**

Incision lines for the flap and donor area should be parallel to the lines of minimal relaxed tension or relaxed skin tension lines (RSTL) if possible (7,95). When incisions are placed parallel to RSTL, they heal better because there is minimal transverse force on them (36). The LME that typically run perpendicular to RSTL must be taken into consideration when planning skin flaps. LME can be found by pinching the skin, using two fingers. Since skin flaps rely on the movement of skin, it is necessary to plan these flaps so that the direction of desired movement of the flap corresponds to the LME.

Flaps should also be positioned to maximize the vascularity of the flap. Flaps placed in the proximal plantar area of the foot should be based either medially or laterally and should be based medially if the heel sensation is intact (86). In addition, large rotation flaps on the plantar surface of the foot should be based medially to take advantage of the blood supply from the superficial branch of the medial plantar artery (5). Flap elevation and rotation can be designed in anticipation of the increased mobility achieved because of bone resection and osseous debulking. LME and RSTL may be partially or entirely ignored when concomitant bone surgery is performed.

**INTRAOPERATIVE CARE OF THE FLAP**

A single-stage approach to the treatment of noninfected, chronic, well-perfused diabetic foot wounds consists of total excision of the ulcer with broad exposure, correction of the underlying osseous deformity, and immediate primary closure using a local random flap. The single-stage approach eliminates the need for additional surgical procedures and their associated costs and risks. In addition, healing time is significantly reduced, resulting in decreased hospital stays and subsequent costs, and providing the patient with an expedient return to footwear and bipedal function. Most importantly, by addressing the underlying bony pathology, the recurrence rates are drastically reduced (96).

When dissecting and handling the skin flap, anatraumatic technique must be employed. This technique involves the use of bipolar cautery, sharp dissection rather than cautery dissec-
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-tion, the use of skin hooks or fine-toothed forceps to handle tis-

-sue, and delicate handling of the flap. Care should be taken to avoid compromising the flap’s blood supply by traumatizing the base or twisting or kinking the base during movement. Nonreactive suture should be used. Deep sutures should be avoided if possible. Pulse irrigation or jet lavage, in addition to redraping and glove changes, also may be used or employed by the surgical team.

Four factors have to be considered when choosing where to place an incision. The ultimate choice depends on a balance of all four. The first factor is that the incision has to provide adequate exposure. The second is adequate blood supply on either side of the incision for the incision and flap to heal normally. Third, the incision should attempt to spare the sensory and the motor nerves. Fourth and finally, the incision, when placed perpendicular to the skin tension lines, carries the risk of causing scar contracture (58). Skin flaps are raised by undermining below the subdermal plexus of vessels in the subcutaneous plane and releasing the tethering effect of this tissue (44). During the movement of skin flaps, cones of skin and subcutaneous fat may be created. Typically, when an angle is closed, a standing cone may be created. These cones may be inverted or everted. When inverted, they are commonly referred to as a “dog ear.” Dog ears should be corrected using Burrow’s triangles and excising the excess tissue. Burrow’s triangles allow for optimum mobility of the flap while correcting the buckling of the adjacent tissues. When an angle is opened, a lying cone may be created that also may be inverted or everted. This excess tissue must also be corrected. It is important not to back cut the flap when excising a dog ear, as it may compromise the blood flow to the flap.

Undermining the wound edges reduces tension on the flap margins (67), but can jeopardize blood flow to the flap and should be avoided. Meticulous hemostasis prior to suturing avoids hematoma formation. As much dead space as possible must be eliminated deep to the flap. Any dead space must be packed or a drain may be employed. Tacking sutures may be used sparingly to hold the flap to its bed, if necessary (90), in the nondiabetic population.

After final suturing, the flap should be evaluated for excessive tension and adequate vascularity. If a flap cannot be inset with 4-0 nylon suture or suture of lesser strength, then most likely there is too much tension on the flap and a delay procedure may be prudent. Ideally, the surgeon should wait 15 minutes prior to evaluating the tension to allow for normal skin relaxation (4). Various methods are employed to evaluate flap viability and include subjective assessments, such as observation of color, capillary blanching and refill, warmth of the flap, and bleeding from

-100% of the time.
stabilization of wounds (3). Objective tests include measurements of tissue pH, TcPO2, ultrasound Doppler or laser Doppler, surface temperature, differential thermometry, plethysmography, angiography, and intravenous (IV) fluorescein dye. Warmth of a flap is not considered to be a reliable method for assessing flap viability (3). For flaps >1:1, a Doppler or other technique should be employed to ensure adequate vascularity into the flap. Intravenous fluorescein dye is considered by some (65) to be most useful in assessing viability of the flap both preoperatively and postoperatively. It involves injecting 1.5 mg/kg fluorescein dye intravenously. Peak serum concentrations are usually obtained in 20 minutes. At that time, the flap may be examined with the use of a Wood’s lamp. Although an excellent method for evaluating flap circulation, it may underestimate flap survival (3). If the flap appears to be under too much tension, is dusky or white, or does not have an adequate capillary fill time, then sutures should be removed and the cause determined.

A recent topical treatment has been developed and proved to reduce ischemia in skin flaps (79). It involves the application of 60% dimethyl sulfoxide (DMSO) solution (60% DMSO, 10% urea, and 30% water), sprayed onto the entire flap intraoperatively, then every 2 hours for the first 48 hours postoperatively, and then every 4 hours during postoperative days 3 through 10. The mean area of ischemia was reduced by >36% using DMSO, with minimal side effects (e.g., erythema and warmth at the application site and garlic-like breath odor).

POSTOPERATIVE CARE OF THE FLAP

The postoperative care of each local flap is extremely important and requires close observation. Each patient who undergoes reconstruction heals at his or her own pace, so one should avoid premature suture removal (97). Bandages over skin flaps should be loose and well padded, and must allow for normal postoperative edema. Bandages that are too tight might alter blood flow within the flap. Venous congestion is a common sequela of tight bandages. Patients must be restricted to bed rest, non-weight bearing of the affected limb, and strict nondependency of the limb for 1 to 2 weeks. After that period of strict bed rest, dependency of the limb by sitting and dangling may be permitted.

Some authors (70) feel that compressive wraps, such as Unna boots or elastic stockings, are essential in the early ambulatory period. They may be replaced by fitted elastic stockings or ace bandages after the wounds are stable and the edema has been resolved. Proper footwear that redistributes weight away from the operative site should be used until the wound has healed completely, to avoid recurrent ulceration or dehiscence of the surgical site.

Wet-to-dry dressings, championed in the past and useful on initial debriement of the wound, impede normal healing by removing healthy neoepithelium and granulation tissue every time the cotton dressing is ripped off the wound (54). The use of moist dressings on clean, granulating wounds improves the wound environment. The dressings not only provide protection against further bacterial contamination but also maintain moisture balance, optimize the wound pH, absorb fibrinous fluids, and reduce local pain. A variety of dressings are currently available that can be targeted to specific characteristics of the wound. However, moist normal saline dressings are probably sufficient for the majority of wounds. These inexpensive dressings are highly absorbent of exudative drainage and maintain the moist environment (98).

Postoperative evaluation of the viability of a flap may be performed by assessing bleeding from stab wounds (19). Using an 18-gauge needle or a no. 11 scalpel blade, the flap is stabbed. Absence of bleeding from the stab wound may indicate arterial failure of the flap, whereas delayed bright red bleeding can indicate some degree of arterial spasm. Cyanotic bleeding that promptly converts to bright red blood can indicate some amount of venous congestion. Conversely, normal arterial perfusion will display brisk, bright red bleeding.

A novel copolymer (porcine gelatin, dextran, and stabilizers) is useful for treating diabetic foot ulcers. Copolymer and control treatment demonstrated a similar safety profile, more effective than control for larger (>2 cm2; 8/17, 47%, versus 4/14, 29%) and older (>17 weeks duration; 6/15, 40%, versus 3/15, 20%) wounds. Further trials are necessary to confirm these promising initial results (53).

COMPLICATIONS

Extrinsic postoperative complications are confirmations of both intraoperative suspicions and judgmental errors (19) and can be divided into preoperative, intraoperative, and postoperative causes.

Preoperative flap complications can include poor flap design, which may result in an inadequate donor–size or a flap that is not mobile enough to reach the defect. In addition, comorbidities can lead to indirect and direct flap complications. Diabetic patients are known to have a reduced healing capacity as do patients with poor nutritional status. Albumin levels and total lymphocyte counts are important parameters that must be evaluated prior to surgery. Patients who are active smokers are found to have an increased risk for complications in skin flap surgery (40). Hypertension, anemia, and the presence of an infection can also lead to flap complications.

Intraoperative flap complications are usually the result of poor technique or insufficient surgical skills. The use of traumatic techniques, such as improperly grasping or pinching the tissue, excessive retraction of skin and surrounding tissues, or the use of aggressive monopolar cautery dissection should be avoided. Incisions should be made with the blade perpendicular to the skin and the incision should be made with one single movement. Multiple strokes lead to small pockets of dead space and ischemia along the incision line. Care should be taken not to kink or twist the pedicle or base of the flap during the procedure. Undermining of the flap should only be used when it is necessary for flap mobility and must be kept to a minimum. Excessive undermining reduces the vascularity of the flap and may lead to flap failure.

Postoperative complications can be the result of many factors. Bandages that are too tight, tension on the flap because of hematomas, venous congestion, or edema, and kinking of the flap’s pedicle all result in compromised vascularity to the flap. The presence of a wound infection will likely hinder healing. Patient noncompliance, such as premature dependency of the limb or early weight-bearing, will most likely lead to a flap failure.

Intrinsic postoperative complications are functions of the physiology of flaps and are functions of metabolic, hemodynamic, and neurologic changes that occur during the elevation and transplantation of the flap. The ischemic insult occurring secondary to
with a staged approach, with frequent débridement and establishment of granulation base. The clean wounds can then be closed with healthy tissue, with the use of local or free-flap coverage and soft tissue repair. Any remaining extrinsic or intrinsic pressures can be reduced with the postoperative use of orthoses (156).

Vacuum assisted closure therapy (VAC) is a unique system that helps promote wound healing. The VAC device is, in large part, responsible for simplifying wound care because it rapidly stimulates the formation of granulation tissue so that the wound size becomes manageable much more easily. The wound then usually is closed primarily or skin grafted (57).

Negative pressure wound therapy (NPWT) delivered by the VAC device is useful for acute as well as chronic wounds (55,102). A multicenter randomized controlled trial for comparison of NPWT utilizing VAC to advanced moist wound therapy (AMWT) in the treatment of diabetic foot ulcers showed a greater proportion of foot ulcers achieved complete ulcer closure with NPWT (73/169, 43.2%) than AMWT (48/166, 28.9%) within the 112-day active treatment phase ($p = 0.007$). In assessing safety, no significant difference between the groups was observed in treatment-related complications such as infection, cellulitis, and osteomyelitis at 6 months. NPWT appears to be as safe as, and more efficacious, than AMWT for the treatment of diabetic foot ulcers (103).

**ADVANCEMENT FLAPS**

Advancement flaps move in one direction only, without any lateral or rotational components. They include single or double advancement flaps, M-plasty, T-plasty, V-to-Y or double V-to-Y plasty, crescentic advancement flaps, and oblique signoid island flaps. These flaps simply advance into the defect and are best suited for areas with good tissue laxity and elasticity. They allow for primary closure of both the donor and recipient sites at the same time. Advancement flaps rely on direct cutaneous perforators. Care must be taken to avoid extensive undermining that may lead to flap necrosis. Since advancement flaps do not redistribute tension, dog ears or resulting cutaneous defects may occur. These can often be selectively positioned (30) and may aid in relieving some of the tension from the flap (21).

Inelastic tissue may require large Burrow’s triangles (21). A simple halving technique allows closure of the flap without the use of Burrow’s triangles (41).

Advancement flaps should be placed so as to benefit from the elasticity of the surrounding skin, while bearing in mind the regional blood supply. They should be perpendicular to the RSTL and advance in a movement parallel to the LME. Although advancement flaps allow for closure of the donor and defect simultaneously, their use can be limited in the foot because of mobility restrictions and the need for broad exposure to underlying osseous pathology.

Cutaneous advancement flaps, such as the T-plasty or H-plasty are commonly used to relocate standing cones away from critical structures. Through the described “running pleated” suture technique excess tissue created by flap advancement is distributed equally along the entire length of the incision. The running pleated suture technique obviates the need for large, laterally displaced Burrow’s triangles that are normally created during the construction of flaps such as the T- and H-plasty (104).
SINGLE ADVANCEMENT FLAP

The single advancement flap advances skin from a single side, into the area of the defect. Therefore, the major movement of the flap is in the direction of advancement, although a minor movement may also occur in the reverse direction on the opposing side of the defect. Two incisions are made, extending away from the defect, creating a flap with its apex adjacent to the defect. The incisions should be made perpendicular to the RSTL or parallel to the LME. The length of the incisions should be adequate to provide enough mobility for the flap to advance into the defect, while minimizing tension. The flap is lifted, at a minimum, below the subcutaneous layer. Burrow’s triangles can occur at any position along the line of advancement, but are typically found at the base of the flap. Burrow’s triangles should be positioned so that they do not compromise the width (base) of the flap. Burrow’s triangles should be positioned so that they do not compromise the width (base) of the flap (4). Pantographic expansion is a modification of the advancement flap that aids in relieving the tension of the graft, without the use of Burrow’s triangles. This modification is not recommended because of the potential to jeopardize the vascularity of the flap (21). As an alternative to Burrow’s triangles, small Z-plasties can be added to the base of the flap (19). Key sutures that bear the greatest tension and align the flap are placed at the tip of the flap. Sutures should also be placed obliquely away from the flap, to offset some of the tension along the tip of the flap.

This flap works well on the plantar aspect of the foot, especially beneath metatarsal heads, after structural correction of the metatarsal head with excision of a fibrous lesion (25). If a simple elliptical excision were carried out, the resulting incision line would lie directly under the metatarsal head, which may result in further breakdown because of a weight-bearing scar. With the use of a single advancement flap, the resulting incision line lies outside of the weight-bearing region. On the plantar aspect of the foot, the single advancement flap should have its flap based medially or laterally, to avoid venous congestion (25). This flap can be used for up to 1cm in diameter defects on the plantar aspect of the heel.

DOUBLE ADVANCEMENT FLAP

The double advancement flap, also known as an H-plasty, advances skin from two opposite sides, into the area of the defect and is used when the defect is too large to be covered by a single advancement flap. The incisions are made so that the flaps advance along the LME. The two flaps do not need to be the same length. At a minimum, the flaps include skin and subcutaneous tissue. The major movement of the flap is in the direction of advancement of each flap. There should be no minor movements associated with these flaps. Key sutures, which bear the greatest tension and help to align the flaps, are found at the tips of the flaps, and the peripheral sutures should be oriented obliquely to help advance the flap. As with the single advancement flaps, Burrow’s triangles can occur at any position along the line of advancement, but are typically found at the bases of the flaps. They should be positioned so that the width of the flap is not compromised (4).

M-PLASTY

A variation of a double advancement flap is the M-plasty. It is useful when shortening the length of an excision or when the standard elliptical excision cannot be performed secondary to anatomic constraints (41). Instead of designing the usual fusiform incision, the ends of the ellipse are incised inward, toward the center of the ellipse, creating a small “M” on either side of the excision. The larger sides of the excision are then advanced toward the center of the excision in the same fashion as a double advancement flap. When closing this incision, it is often useful to use a corner stitch “of Gilleys” to pull the tip of the M-plasty toward the center of the defect.

MODIFIED M-PLASTY

A modification of the M-plasty uses all of the principles of traditional M-plasty, but it shortens the length of the excision by the length of the triangular flaps present in the conventional M-plasty (105). The procedure is done by eliminating the initial creation of the two triangular flaps at the two ends of the excision. After the skin is excised in a short fusiform shape, with the shortest possible long axis, a triangular flap is created at each end by an incision parallel to its long axis and lateral to it on opposite ends. Actually, the flaps can be fashioned on either side of the excision and on either or both ends, depending on the position of the excision and its relationship to bordering anatomic structures or skin planes. A comparison of the M-plasty and the modified M-plasty will show that the final length of the scar is shorter for each subsequent procedure by the length of the triangular flap that would have been created (106).

T-PLASTY

The T-plasty, also known as A-to-T and O-to-T flaps, is a modification of the double advancement flap and consists of bilateral advancing flaps. It may be used as an alternative to the standard elliptical excision of small defects. If the defect is a circle, then the flap is an O-to-T. If the defect is a triangle, then the flap is an A-to-T. An incision is made extending from the base of a triangular defect or as a tangent to a circular defect, parallel to the LME. Ideally this incision should be placed along a natural skin crease or anatomic border. Upon advancement of the flaps, this incision forms the top of the “T.” For the O-to-T flap, it may be necessary to convert the circular defect into an ellipse to facilitate closure. The lateral skin flaps should be undermining to facilitate approximation. The major movement is in the direction of the flap movement and no minor movements should occur. Key sutures, as with other advancement flaps, are found at the tips of the flaps. The base limbs or flaps do not need to be of equal length. One of the advantages of these flaps is that they reduce the amount of healthy tissue that would normally be excised if an elliptical excision was performed (35).

V-TO-Y FLAPS

V-to-Y flaps have been used for defects in the posterior heel and ankle (66), and on the plantar aspect of the foot (1,15–46,64–76). They are also useful as an adjunct for closure of open toe amputation sites. They have been advocated for the closure of a newly formed web space during the correction of syndactyly (87). Hand surgeons have routinely used V-to-Y flaps for digital reconstruction following traumatically amputated terminal phalanges (107), and their long-term viability has been proved. V-to-Y has the direction of the LME. The width of the extended V-to-Y flap is greater.
than the width of the defect, because of the presence of an extension of the flap on one or both sides of the defect. If the extension is only on one side of the defect, then the length of the extension is equal to the width of the defect. If the extension is made on both sides of the defect, then the length of the extensions is equal to half the width of the defect. As the flap is advanced, the extension is hinged down into the distal aspect of the defect as a small transposition flap (Fig. 12.1).

For larger defects, double V-to-Y flaps should be used (15). However, if the necessary advancement needed to close the defect is not sufficient, then a second or even a third flap may be used (91). If additional flaps are not available, then scrupulous dissection with the aid of loupe magnification may be performed to dissect the fibrous bands that limit motion, while sparing the perforating vessels (91). One advantage of a V-to-Y flap is it eliminates the need for further procedures to excise dog ears that are often necessary with direct approximation (91). It also offsets the need for skin grafting of the donor site. V-Y flaps suffer from design problems of the advancing edge, which is usually concave, trying to match another concave edge on the opposite side of the defect. The flap-in-flap technique uses a second V-Y flap at the advancing edge of the main flap to overcome this mismatch, and also improves the amount of advancement possible (108).

MODIFIED V-Y FLAP

The V-Y advancement flap has been widely used for the reconstruction of cutaneous defects for decades; however, the movement of a V-Y flap is sometimes limited, allowing only for rotation or advancement movement. To overcome this limitation, one study introduced a transposition movement of the V-Y flap and assessed its clinical outcome for facial reconstruction. A modified V-Y flap was designed with a single laterally based pedicle and transferred to the defect through a transposition movement. This modified transposition V-Y flap is reliable and robust, and could be moved easily with less tension and serve as an alternative option for aesthetic reconstruction (109).

DOUBLE V-TO-Y FLAPS

A double V-to-Y flap, also known as a double kite flap, is useful when a defect is >2 cm and may be used to close defects as large as 3 to 4 cm (3). Double V-to-Y fasciocutaneous flaps have been recommended for coverage of small (up to 4 cm in diameter) lesions plantar to the metatarsal heads (1,15–46,64–80) and heel regions. Double V-to-Y flaps are designed in the same fashion as the single V-to-Y flap; however, a second identical flap is designed on the opposite side of the defect. Each flap is elevated in the same manner and advanced toward each other to cover the defect. Use of the double V-to-Y (contiguous island flaps) technique avoids tissue distortion, cosmetic defects, grafting, and later reconstructive surgery (Fig. 12.2) (51).

DOUBLE REVERSE V-Y PLASTY

A new modification of V-Y plasty called “double reverse V-Y plasty” is useful for postburn scar contractures. The postoperative results represent the versatility of this technique in the surgical treatment of postburn scar contractures, especially neck and extremities. Double reverse V-Y plasty is effective and alternative to the...
current techniques in surgical treatment of every kind of postburn scar contractures with one or more contracture lines and without any surgical knack. Some of the advantages include the following: (a) it is safely used when skin tension across the contracture line is too great to use any local flaps; (b) when superficial scarring is localized in the contracture site, it is superior to other local flaps because of rich vascularity and mobility; (c) it is advised for the inexperienced surgeon, since it is easy to use; (d) color and texture matches are cosmetically acceptable, and the resultant contracture is as much as with other techniques; (e) it can be used under local anesthesia almost in all cases; and (f) it requires a shorter period of operation and hospitalization (110).

**Y-V PLASTY**

The Y-V plasty is the opposite of the V-Y flap by increasing tension in line with the Y to V and releasing tension perpendicular to the flap. The procedure is usually performed as series of multiple Y-V incisions. These flaps are done in a series to release a contracture over the dorsum of the forefoot, in areas of burn scar contracture, or in contracted digits. The incisions of the Y-V plasty are carried deep into the subcutaneous tissue layer with gentle undermining of the surrounding tissue. The subcutaneous tip of the flap should be gently held in position with a skin hook, with care taken not to damage the skin layer of the tip. When the contracture is released, the Y incisions are closed with simple interrupted sutures at the base to release tension on the apex. The closure is comparable to that of a Z-plasty flap (Fig. 12.3) (106).

**V-Y-S PLASTY**

This skin plasty combines the V-Y plasty technique with the rotation flaps of the S-plasty. This combination maximizes tissue conservation and reduces the need for undermining the wound edges. Circular defects lend themselves to this procedure, and it is effective in areas on the extremities where the skin is taut.

Once the lesion has been outlined with a skin marker, an ellipse or fusiform drawing in the typical 3-to-1 pattern further encompasses the circular mark. The long axis of this marking lies parallel to the maximal skin tension lines, along the relaxed skin tension lines or skin folds. The circular defect is excised, leaving two triangular sections on either side of the defect. An intact side of one of the triangles is incised along its entire length and a back cut is made along approximately 30% to 50% of the remaining side. This produces a flap that hinges on one partially intact side. When creating the back cut on each side, it is important not to exceed cutting >50% of one side. Back cuts that exceed 50% greatly increase the risks of vascular compromise to the flap and enhance possible flap necrosis. This is even more of a possibility in skin that is under significant tension. The V-Y-S-plasty closure of circular defects conserves tissue and it also eliminates the need for undermining of wound edges (111).
V-Y-S Plasty

V-Y-S plasty is also useful for the extremities in which skin is under considerable tension (111).

CRESCENTIC ADVANCEMENT FLAP

The crescentic advancement flap can be used to close a triangular defect. As described by Jackson (36), a crescent-shaped incision is made extending from the base of the triangle and the resulting skin excised. The outer edge of the crescent should be equal to or slightly less than the combined length of the base of the triangle and the length of the inner edge of the crescent. The flap created between the triangular defect and the crescent-shaped donor site is widely undermined and advanced into the triangular defect.

OBLIQUE SIGMOID ISLAND FLAP

The oblique sigmoid island flap is a variation of a V-to-Y flap and is used to close small circular defects (73). After the lesion is excised in a circular fashion, two small 1- to 2-mm triangles are excised from opposite sides of the defect. The triangles should be positioned such that their apices are pointing along the RSTL. Next, a line should be drawn tangent to the circular defect and parallel to the RSTL. A flap is then designed using the tangent line as an axis. The width of the flap should be equal to the diameter of the defect. The side of the flap closest to the defect has an S-shaped edge and the side away from the defect has a spindle-shaped edge. The flap is then advanced obliquely into the defect and the remaining incision line is closed directly. This technique has been performed successfully on defects up to 10 mm in diameter (73). Skin plasties for congenital fifth digit contractures can also be included in this category. V-to-Y flaps create a functional and cosmetically pleasing outcome.

The extended V-to-Y flap, one variation of the standard V-to-Y flap, may be used for large defects and in regions with decreased mobility (77). As with the standard V-to-Y flap, the length of this flap measures one and a half to two times the diameter of the defect. One of the advantages of this flap is that it reduces the occurrence of trap doors, dog ears, and unnatural depressions at the sutured site (73). Disadvantages include a somewhat complicated operative technique that often includes delicate flap trimming and a slightly long scar (73).
Rotation flaps are those that pivot around a point and move through an arc. These flaps include single rotation flaps, double rotation flaps, and the Satterfield-Jolly flaps. Rotation flaps provide redistribution and redirection of tension from the primary defect to the donor site (30). They are frequently used in areas with convex surfaces or where tension lines are curved (30). Rotation flaps can be subfascial or suprafascial, as described by Shaw and Hidalgo (86). They can also be fasciocutaneous, myocutaneous, or a combination of both. Rotation flaps can be axial or random, depending on the level of dissection and angiosome involved.

Rotation flaps can be elevated from the non–weight-bearing arch to areas of pathologic weight-bearing surfaces. They allow for movement of premorbid tissue for coverage in areas that require durable and mobile tissues. They can be used to correct defects on the plantar aspect of the heel by including the heel pad (29). They can also be used to cover large defects in the foot; however, they often require a skin grafting component for closure of the donor site.

Rotation flaps are an excellent adjunct in Charcot foot reconstruction. Because of their inherent design, they can yield a wide-based exposure to the plantar osseous structures that are often subluxed or dislocated in neuropathic arthropathies. Fasciocutaneous rotation flaps can be rotated from medial to lateral to provide adequate coverage of plantar hardware used for the Charcot foot or for unstable midfoot and rearfoot pathologies (92). Because of the required skin grafting component, strict elevation and bed rest must be enforced for 5 to 7 days, therefore increasing hospitalization and cost.

**CLASSIC ROTATION FLAP**

The rotation flap consists of a triangle or two radii or wedges from a portion of a circle. If the rotation flap does not cover the entire defect it may be designed larger or the length of the curved incision may be extended to free more tissue. Additionally, if even more movement is needed, a back cut may be employed to the arc of the flap. The rotation flap used to close a circular defect is usually a combination of both primary and secondary movements. The primary movement is the rotation and advancement of the flap itself over the defect and the line of the greatest tension extends from the pivot point toward the defect site. This distal tension point is the area of greatest vascular compromise. The secondary movement is the movement of the adjacent or surrounding skin in the opposite direction of the flap movement. The skin from the side of the defect opposite to the flap moves over the defect more than the flap itself moves over the defect. This requires less rotation of the flap and creates less puckering at the flap pedicle. When puckers occur they may be eliminated by cutting a Burrow’s triangle at the end of the incision (106).

**SINGLE ROTATION FLAP**

A single rotation flap may be used to close either a triangular or circular defect. For closure of a triangular defect, the flap is shaped semicircular and rotates about a pivot point.

For a triangular defect, the base of the defect becomes part of the circumference of a semicircle (Fig. 12.4). An arch-shaped flap is then designed so that the leading tip of the flap will rotate around the circumference of the circle on which the defect lies. To enable primary closure of the donor site, the flap should have a circumference five to eight times the width of the defect (19) or an area of three to four times the area of the defect (30). The major movement is in the direction of the arc of rotation of the flap. Secondary movements of the adjacent or surrounding skin in the opposite direction of the flap movement also occur. Key sutures are placed along the closing edge or shorter side of the flap. Burrow’s triangles may be used at any point along the arc or longer incision, but are typically found at the base of the flap. The narrower the triangular defect, the less distance the flap will need to move (22); therefore, the defect should be excised with as narrow a triangle as possible.

The use of a back cut, incised at the pivot point of the flap, is controversial. Some (3,30,36,44) feel that back cuts allow for additional mobility of the flap, allowing it to be inset into the defect with little tension. Others feel that back cuts into the base should be avoided. If a back cut is used, it should be cut away from the base if possible or its length should be minimized to avoid jeopardizing the perfusion of the flap. To avoid potentially compromising the vascularity of the flap when using a back cut, perforators into the flap should be evaluated with the use of a Doppler (3).

If the flap will not close without excessive tension, then a maneuver described by Jackson (36) should be used. In this technique, the circumference of the rotation flap is increased, thereby lengthening the leading edge of the flap and allowing closure with decreased tension.

For a circular defect, an arc is created that is tangent to the circle, having a greater radius than the defect. The resulting flap is then rotated into the defect. In this case, there is usually a combination of both primary and secondary movements, in varying degrees depending on the elasticity of the surrounding skin. The primary movement is the rotation of the flap into the defect. The secondary movement is the movement of the surrounding tissue in the opposite direction of the flap movement. If puckering of the flap occurs, then a Burrow’s triangle may need to be excised from the end of the defect (Fig. 12.5).

**DOUBLE ROTATION FLAP**

The double rotation flap, also known as O-to-Z flap, S-plasty, bi-winged flap, and V-Y-S plasty is a variation of the standard fusiform incision for closing circular wounds. It disperses the tension of closure along three lines, as opposed to just one line when a simple elliptical closure is used. It also preserves premorbid and nonpathologic tissues.

With the O-to-Z flap, two arc-like incisions are made tangential to a circular defect. The radii of the arcs are greater than that of the original defect. The incisions are made on opposing sides of the defect and do not need to be of equal
The V-Y-S plasty is a variation of the O-to-Z flap and involves placing V-to-Y advancement flaps on the ends of the arcs, resulting in an S-shaped incision. It controls the amount of tissue displacement that occurs at the ends of a double rotation flap and minimizes asymmetry.

SATTERFIELD-JOLLY ROTATION FLAP

The Satterfield-Jolly flap (83) is a variation of a single rotation flap, which is used to close excisions of painful plantar forefoot lesions. First, a medial to lateral transverse incision is made along the plantar margin of the sulcus, following its natural arc. Then, a triangular portion of skin, containing the lesion, is excised. This triangle is designed so that its base is formed by the initial transverse incision and its apex is proximal. The triangle is typically four to five times as long as it is wide. The underlying plantar fat is left intact. The leading edge of the flap is undermined at the fascial plane. The amount of undermining should be kept at a minimum, performing only the amount necessary to allow tension-free movement of the flap. Burrow’s triangles are typically necessary along the length of

length. Burrow’s triangles may be used where needed. The sides of the defect are approximated and sutured in place, creating the central line of the “Z.” These are key sutures and are under the greatest tension. The arc-like incisions are then closed, creating the final two lines of the “Z.”

With the biwinged flap, the lesion is bisected with a line that runs parallel to the RSTL. The line should be approximately three times the length of the diameter of the lesion. Two equal triangles are then excised on each side of the bisector, such that the base of the triangles is one fourth to one half the diameter of the lesion. When the skin edges are re-approximated, the resulting incision resembles a rounded step or a lazy “S.” It should be noted that the central arm of the “S” is placed under increased tension and care must be taken when suturing to ensure adequate wound approximation (14). It was determined that the biwinged flap used minimal amounts of surrounding tissue to close a defect, when compared with a standard fusiform incision (32). Lesions on all areas of the foot, including plantar and medial lesions, can be excised using the biwinged flap, and for some authors (20) this flap has replaced the use of elliptical closure for circular defects.

The V-Y-S plasty is a variation of the O-to-Z flap and involves placing V-to-Y advancement flaps on the ends of the arcs, resulting in an S-shaped incision. It controls the amount of tissue displacement that occurs at the ends of a double rotation flap and minimizes asymmetry.

Figure 12.5 A delayed single rotation flap at the initial heel ulcer débridement (A), followed by a delayed closure (B). A final clinical postoperative outcome (C).
Figure 12.6  The Catanzariti-Wehman rotation flap for complete closure of plantar defects without the need for Burrow’s triangles.

Figure 12.7  A transposition flap that moves over adjacent intact skin to close a defect and combines the use of both rotation and advancement techniques.

Figure 12.8  A transposition flap created to close a plantar defect (A), followed by insetting the flap to the original defect (B), and close of the donor site with a split-thickness skin graft harvested from the plantar aspect of the same foot (C). A final clinical postoperative outcome (D).
the transverse incision, interdigitally, high in the sulcus. The flap is then sutured into place, without tension.

Advantages of this flap include a non-weight-bearing scar, primary closure of the donor site and flap simultaneously, and a broad-based exposure to underlying structures of the metatarsal parabola.

**CATANZARITI-WEHMAN ROTATION FLAP**

A very similar approach using a modified rotation flap was described by Catanzariti and Wehman in 1988. The wedge is much smaller and the incision along the arc is much longer. This provides for complete closure without the need for Burrow’s triangles, but the design places more of the incision on the ball of the foot. The curved incision is brought down across the plantar ball, trying to avoid the weight-bearing surfaces as much as possible. They are especially useful in the removal of hypertrophic scars or triangular lesions on the plantar aspect of the foot (Fig. 12.6) (106).

**TRANSPOSITION FLAPS**

Transposition flaps are similar to rotation flaps except these flaps are tongue-like in shape and generally have narrower bases than rotation flaps. The surface area of a transposition flap is less than the surface area of a rotation flap covering a defect of the same size. Transposition flaps are also more likely than rotation flaps to require split-thickness skin grafts to close their donor sites, especially in the plantar arch. Transposition flaps are more capable than rotation flaps of covering large wounds in the plantar hindfoot because the coverage of the donor site by a split-thickness skin graft augments the total surface area. A number of modifications to the standard transposition flap have been described and many have been used in the foot. These modifications include rhomboid flaps, bilobed flaps, and Z-plasties (97).

Transposition flaps (Fig. 12.7) move over adjacent intact skin to close a defect and combine the use of both rotation and advancement. These flaps include the single lobe flap, the bilobed flap, Z-plasty, double-Z rhomboid, double opposing Z-plasty or two-flap Z-plasty, four-flap Z-plasty, double opposing semicircles, W-plasty, the rhomboid or Limberg flap, flap of Dufourmentel, the 30-degree transposition flap, double and triple rhomboid flaps, and the note flap. As with rotation flaps, these flaps redistribute and redirect tension from the primary defect to the donor site (30). It is critical that the flap extend beyond the defect, thereby ensuring adequate length after its transposition (19). If additional length is required, a back cut away from, or into, the base can be made; the latter option poses a risk of reducing the blood supply into the flap (19). Closure of the donor site may be primary, if the adjacent skin is elastic enough, but more likely a skin graft or another skin flap will be required (Fig. 12.8).

**SINGLE LOBE FLAP**

The single lobe flap, also known as the Schrudde slide-swing plasty (Fig. 12.9), may be used to close circular, oval, and semicircular defects (84). It has been used successfully for removal of small digital lesions, such as fibrous scars, intractable keratoses, and digital mucoid cysts (22) and to close a defect plantar to a metatarsal head (Fig. 12.10) (1,10–28).

To close a circular defect, a flap in the shape of a lobe is created. The rounded end of the flap is designed with a radius smaller than the circular defect and the flap as a whole is designed to be smaller in size than the original defect. The base of the flap is placed at a 90-degree angle to the defect (84). The length to width ratio is typically 3:1 (30). Key sutures are at the distal ends of the flap. The donor region is closed primarily.

To close an oval defect, a similar flap is designed, but the base of the flap is placed at a 60-degree angle to the defect (Fig. 12.11) (84). The advantages of a single lobe flap are that it can be used to close a large defect, its broad base ensures good vascularity, and it avoids a secondary defect (22). Because most lesions are circular and this flap was designed to close a circular defect, it does not involve additional excision of healthy tissue to produce a defect of a specific geometrical figure such as a rhombus (84). It should be noted that up to one third of the flap length may be lost during transposition of the tissue into the defect (30). The disadvantage of a single lobe flap may be that too much tension is created and closure is not possible without an additional lobe to disperse the tension.

**BILLOBED FLAP**

The bilobed flap consists of two flaps that are separated by an angle and that share a common pedicle (Fig. 12.12). It was originally described by Esser (24) and later revised by Zimany (95). It is designed to move more skin over a larger distance than is possible with a single lobe flap and it works well in regions in which skin mobility is limited (94). It has been described as using the Robin Hood principle of borrowing from the rich laxity of a neighboring area and transposing it to a relatively poor area of inelastic skin (88). This flap has been used to
close defects on the plantar aspect of the foot (10,68,81,93), where it is recommended for defects 1 to 3 cm in diameter (81).

The bilobed flap is very versatile and can be adapted for closure of defects throughout the foot. Its uses include closure of excisions for digital cysts, metatarsal head ulcerations, osteomyelitis, and plantar rearfoot ulcerations and heel defects (Fig. 12.13). Bilobed flap technique and arthroplastic resection is useful for excision of digital mucoid cysts. The use of bilobed flap allows for greater exposure than the traditional semieliptical incisions while it also permits the wide excisional defects to be closed primarily with no recurrence, flap failures, or other major complications as it was shown in a retrospective study of 15 patients with an average follow-up of 4.6 years (52).
Since two flaps are used, two adjacent donor sites are needed to close the defect. The first lobe closes the original defect, whereas the second lobe closes the first flap donor site. The second flap donor site is then closed primarily. Typically the lobes are designed to be 90 degrees from the defect and from each other, although this is not a necessity (30–46,64–68) and the angles may vary from 45 to 90 degrees (93). On the plantar aspect of the foot, it is recommended that the angles be no greater than 60 degrees (81). The first lobe can be up to 20% smaller than the defect, and the second lobe can be up to 20% smaller than the first lobe (88). Some authors (1,3–46,64–71,95,107) feel that the lobes can be up to half the size of the defect they close. A general rule for lobe creation includes the following parameters. The first lobe can be 75% of the width of the original defect, whereas the second lobe is 50% of the original defect. The rotating base should be the only area undermined (23), although some authors recommend wide undermining (88,94). Some authors have found it easier and quicker to suture the second lobe into the defect caused by the first lobe and then suture the first lobe into the original defect (99). The two apices should actually be closed first, followed by the circumferential sutures along the lobes.

An improvement in the design of bilobed flaps consists of rotating each lobe only 45 degrees, including a Burrow’s triangle in the original design of the flap, and extending the length of the second lobe (94). This results in a reduction of dog-ear formation, pincushioning, and distortion (94). A trilobed flap has been described (35) to reduce the dog ear often obtained with a bilobed flap, but at the expense of an enlarged incision.

The advantage of the bilobed flap is the ability to recruit large amounts of tissue by borrowing from different areas and opposing directions. The disadvantages are the length and varying directions of the incisions required (42). A modified

Figure 12.11  A preoperative picture of a heel ulcer (A), excised as an oval defect (B) and closure by a single lobe local flap (C–E).

Figure 12.12  The bilobed flap consists of two flaps that are separated by an angle and that share a common pedicle.
Chapter 12  Soft Tissue Coverage of the Diabetic Foot

Figure 12.13  A bilobed flap designed on the dorsal aspect of the foot (A), followed by a circular excision of the lesion (B) and final closure (C–E).

A modified bilobed flap from mastoid and lateral neck skin for reconstruction of complex defects of the posteromedial surface of the auricle and mastoid skin is described, with the preservation of the retroauricular sulcus and closure of the donor site. Scars were hidden along minimal tension lines and the possibilities of wearing spectacles along with sensitivity all over the reconstructed area were maintained (112).

Z-PLASTY

With the Z-plasty, two triangular flaps are transposed, using a Z-shaped incision. The Z-plasty is a useful technique for lengthening a linear scar contracture, dispersal of a scar by breaking up the scar, realigning a scar within the LME (67), and web space widening and construction (44). Z-plasties have many adaptations for foot surgery. They can be useful for correction of congenital fifth toe contractures, congenital overriding of the fifth toe, revisional bunion surgeries, and reconstruction of burn scar contractures to the dorsal and plantar regions of the foot (113). Also, a Z-plasty can be used to prevent a scar contraction, when an elective incision will cross a flexion crease (44), such as over the metatarsal phalangeal joints or over the joints on the digits. In addition, it can be used in conjunction with other flaps to improve cosmesis or flap movement (36).

Z-plasty should only be considered if there is sufficient skin laxity in the direction opposite to the direction of skin to be lengthened. Once it has been determined to use a Z-plasty, certain design parameters such as length of incisions and angles between incisions must be determined. Given the design of the Z-plasty, the amount of length that will be gained is determined by both the lengths of the incisions and the angle between the incisions (Figs. 12.14 and 12.15). Because length is gained at the expense of width, the longer the three incisions are, the more...
Figure 12.14  The Z-plasty with two triangular flaps being transposed by using a Z-shaped incision. The Z-plasty is a useful technique for lengthening a linear scar contracture and realigning a scar within the LME.

Figure 12.15  A Z-plasty is shown over a contracted second digit (A), followed by transposition of the flaps (B) and arthrodesis of the proximal interphalangeal joint (C,D).

The scar can be lengthened; however, this results in a narrower width with increased tension (44). Theoretically, the amount of length gained is equal to the length of the center diagonal incision minus the length of an imaginary line connecting the other two incisions. Similarly, the closer to 90 degrees the angles are, the more the length will be increased. Ninety-degree advancing tip angles, however, generally result in dog ears at the bases. When angles are too acute, the advancing tips may have compromised blood supply and may become ischemic. A 75-degree angle may theoretically result in 100% increase in length; however, it will also result in too large of a lateral tension on the flaps and will likely cause a failure of the flaps (16). A 30-degree angle will only result in a theoretical 25% increase in length and will not provide a sufficient amount of tension release (16). In general, angles between 45 and 60 degrees work best (44).

Some authors feel that it is more advantageous to use one large Z-plasty as compared with multiple smaller Z-plasties (Fig. 12.16), given the fact that larger Z-plasties have larger flaps that typically have better blood supply (44); other authors believe that multiple Z-plasties are preferred (67). In the digits, larger Z-plasties may constrict the digit horizontally and compromise the blood flow into the digit. In the digits, it is better to use multiple Z-plasties (44).
The initial incision, which will become the diagonal line of the Z, is made longitudinally along the length of the scar or along the direction to be lengthened. The other two incisions are then made off this central line at 45- to 60-degree angles and should parallel the RSTL. The three limbs of the Z-shaped incision should be of equal length. If the three incisions are not made of equal length, then puckering will occur (67). The incisions may be made of unequal length; however, if the skin on one side of the central incision is elastic and loose then the skin on the other side of the central incision is constricted (67).

The flaps should be fully elevated to slightly beyond their bases to allow for ease of rotation (36); however, care must be taken to avoid undermining the tip of the flaps. An imaginary line connecting the two noncentral incisions becomes the new central line or diagonal of the final Z after the flaps have been transposed. If the surrounding skin is extremely taut, then a smaller angle, such as 45 degrees, and a longer central incision should be used (16). By curving the top and bottom incisions of the Z-flap away from the diagonal incision, extra tissue can be included in the flap base that may help to increase flap vascularity (Fig. 12.17). (36).

A critical stitch or suture should first be placed in the midpoint of the new central arm, followed by other sutures at the base of the flaps. Apical sutures should be used at the tips of the flaps. Oblique sutures should be used to advance the tip of each Z-flap. If there is excess tension across the central limb of the final Z, then a mini Z-plasty can be performed along that limb (85). The technique involves incising two lines that are parallel to the outer limbs of the larger Z, less than half the length of the larger limbs, and are carried out just through to the dermal layer. The central limb of the mini-Z is contained within the central one third of the central limb of the larger Z. It is especially useful if the initial Z-plasty design was slightly larger than appropriate and can therefore repair problems that result from poor planning (85).

A Z-plasty is preferred over the W-plasty when there is either too much or too little skin tension (1,9–46,64–67). In comparison with the W-plasty, the Z-plasty uses all the available skin without increasing the overall tension in the area (9). The limbs are

![Figure 12.16](image1.png)

**Figure 12.16** A schematic diagram showing a large Z-plasty compared with multiple smaller Z-plasties.

![Figure 12.17](image2.png)

**Figure 12.17** A radiographic (A) and clinical picture (B) of the resected distal first metatarsal caused by osteomyelitis. Multiple small Z-plasties (C) for wound closure after the insertion of bone grafting with internal fixation at the first ray (D–F). (continued)
Figure 12.17 (Continued) A final clinical postoperative outcome (G).
lengthening and functional recovery was achieved in all cases. The technique was applied to 21 postburn scar contractures, both ensuring primary donor site closure and minimizing the need for skin grafts (114).

DOUBLE OPPOSING V-Y-Z PLASTY
This technique is a combination of V-Y plasty with Z-plasty in double opposing fashion, both ensuring primary donor site closure. The technique was applied to 21 postburn scar contractures in 14 patients. All flaps healed uneventfully with adequate lengthening and functional recovery was achieved in all cases.

DOUBLE Z RHOMBOID FLAP
The double-Z rhomboid flap uses the technique of two Z-plasties to correct a rhomboid-shaped defect. It may be used to create a non-weight-bearing incision because of the transposition of the two Z-flaps. Double-Z rhomboid flaps can be used for fifth metatarsal head pathologies, in addition to a variety of plantar forefoot and rearfoot conditions (Fig. 12.18).

The double-Z rhomboid flap was originally described as a rhomboid-to-W flap (6). The flap was later designed so that its long diagonal was parallel to the RSTL (17,18). This, however, was later redesigned (37). The recommended technique is to draw two parallel lines in the direction of the RSTL that will enclose the defect. Then a second set of parallel lines are drawn to complete a 60- and 120-degree rhombus. Two Z-plasties are then drawn on opposing sides of the rhombus, such that their central lines are continuations of the original two parallel lines of the rhombus. The flaps are then transposed in a similar fashion as a Z-plasty, resulting in an incision shaped like two Zs end-to-end.

DOUBLE OPPOSING Z-PLASTY
A double opposing Z-plasty, which is very similar to the five-flap Z-plasty (34), can be used when the anatomy or vascularity of the area does not permit the use of a large single Z-plasty and is as effective as the single Z-plasty in release of a scar contracture (67).

Two Z-plasties are designed so that their central incision or diagonal stem of the Z are along the same line. The two Z-plasties are then created such that one Z is backward and one is forward, in relation to each other. The flaps are then elevated and transposed in a manner similar to single Z-plasties. To facilitate closure, the double opposing Z-plasty may be converted to a five-flap Z-plasty by creating an additional incision to bisect the largest flap.

Double opposing Z-plasty is useful for syndactyly release, operating on only one side of the finger at any particular time to prevent ischemic compromise to the finger should one of the digital vessels be absent or be injured. The surgical division is individually tailored based on complexity and location of the syndactyly. Generally, the release is accomplished by dividing the fingers and resurfacing the surgical wound with a well-vascularized dorsal trapezoidal shaped flap, interdigitating fasciocutaneous flaps, and full-thickness skin grafts to resurface interdigital space. If the fingernail is involved, divide it longitudinally. Osteotomize and cover any bony exposure with local fasciocutaneous flaps for stable coverage. It is important that the local interdigitating flaps be designed well to minimize the need for skin grafts (114).

DOUBLE OPPOSING V-Y-Z PLASTY
Similar to the Z-plasty, the W-plasty can also be used to break up a scar into smaller components. Since it involves excising the scar tissue, it has the disadvantage of increasing the tension in the area of a scar secondary to the removal of tissue (9,67). It should be employed in areas with sufficient tissue and elasticity. The W-plasty produces a zigzag scar and is simpler than using multiple Z-plasties. The amount of lengthening that occurs, however, is minimal (36).
Figure 12.18 A double-Z rhomboid flap (A) uses the technique of two Z-plasties to correct a rhomboid-shaped defect (B). It may be used to create a non-weight-bearing incision because of the transposition of the two Z-flaps (C,D).
Two zigzag patterns are designed along the length of the scar, one on each side of the scar. As with a Z-plasty, the optimum angle between incisions should be 55 to 60 degrees (67). It is recommended that at the end of the W-plasty, the triangles be designed smaller in size, with a tapering of the length of the limbs of the W-plasty (67). Once one incision is made along one side of the scar, the other opposing incision is made so that the tip of one triangle on one side corresponds to the midpoint of the base of a triangle on the opposing side. The piece of skin containing the scar is then excised. On a curved scar, the angles of the triangles on the inner incision should be more acute than the angles of the triangles on the outer aspect of the curve.

A continuous subcuticular suture should be used to approximate the triangles between the two zigzag incisions and should be placed halfway between the apex and the base of each triangle (67). Additional approximation can then be obtained using interrupted sutures.

**RHOMBOID OR LIMBERG FLAP**

The rhomboid or Limberg flap (Fig. 12.19) is typically used to close a rhomboid-shaped defect, but may be used to close circular defects (30,43). A flap of exactly the same shape and size as the defect, is raised and transposed 60 degrees into the defect. Although the flap covers the original defect 100%, it only closes half of the total defect; the remaining defect is closed primarily (11). The flap redistributes and redirects tension from the donor site to the recipient site, in 90 degrees (Fig. 12.20) (30).

The rhomboid flap is one of the most versatile adjuncts for closure of foot wounds and pedal defects. It can be used for correction of isolated metatarsal head lesions, with simultaneous exposure for osseous corrections, such as a condylectomy, osteotomy, or metatarsal head resection. Rhomboid flaps may also be used to correct a plantar lesion. It has been adapted for dorsal lesions of the foot (4), although greater mobility is required for primary closure. Desyndactylization procedures can also employ a rhomboid flap in the foot for plantar closure (75) or in the hand (45).

Two parallel lines are drawn in the same direction as the LME or perpendicular to the RSTL. These are drawn tangential to the defect. Two additional lines are drawn that complete the design of an equilateral parallelogram or rhombus with 60- and 120-degree angles. Four possible rhomboid flaps can then be drawn (Fig. 12.21). Two of these possible rhomboid flaps will have their short axis parallel to the LME. In closing the donor site, choosing either of these two will result in the area of greatest tension to occur in the same direction as the LME (7,8,12,41,45). If the short axis of the flap is perpendicular to the LME, the design will result in immobile flaps (19). By using the pinch test to determine the orientation of the LME, the best flap for transposition can be chosen. Anatomic constraints or surgeon preference will result in the optimum choice from the two final possibilities.

An alternative way of viewing the design of a rhomboid flap is to first excise the lesion in the shape of a rhombus so that two of the sides are parallel to the LME. Next, extend the short diagonal of the rhombus, in either direction, by the same length as the sides of the rhombus. The final side of the flap is designed at a 60-degree angle to the end of the extended short diagonal and equal to the length of the sides of the rhombus. Once again, the short axis of the flap must lie parallel to the LME.

Although the complex geometry must be understood, it does not need to be strictly adhered to obtain satisfactory clinical results (11). Although the rhomboid flap was designed for use in areas in which skin extensibility is significant, the flaps may be used in regions of tense skin (95). In such cases, the entire area must be undermined, including the margins of the rhomboid defect and the base of the flap. Undermining of the donor site can be successfully achieved without compromising the surrounding subcutaneous perforators. Mobility can be increased with concomitant bone resection.

A major advantage of the rhomboid flap is that the surgeon can choose the ideal flap from four possibilities. Another advantage is that once the length of one of the sides of the rhomboid is determined, all other incisions are the same length and calipers can be used to facilitate the design (45). One disadvantage of the rhomboid flap is that in younger patients or when the skin is dense and thick, cosmetically significant bulges or dog ears may occur (104).

**FLAP OF DUFOURMENTEL**

The flap of Dufourmentel can be used for rhombic defects of any acute angle, not just those of 60 and 120 degrees (11).
Although more difficult than the classic Limberg flap, it is especially useful for rhombic defects with an acute angle of 60 to 90 degrees (11,41–45), or when excision of additional skin to create a more acute angle is undesirable (41). If the acute angle is $\leq 60$ degrees, then the flap becomes wider than the primary defect and the use of the flap is not advantageous (45).

First the defect is excised in the shape of a rhombus or an equilateral parallelogram. The short diagonal of the rhombus is extended from the tip of one of the less acute sides. From that same point, one of the sides of the defect is also extended. The angle formed by these two lines is then bisected by a line equal in length to the sides of the rhombus and the corresponding line forms one of the sides of the flap. The final side of the flap is incised equal in length to all the other sides of the rhombus, but parallel to the long axis of the defect. Once again, as with the Limberg flap, the use of calipers may facilitate the design, although the addition of a protractor may also be helpful (45).

Some authors (8) feel that since the flap of Dufourmentel does not take advantage of the LME to the extent that the Limberg flap does, then it is not as useful as the Limberg flap; however, this had been discounted previously (45).

**THIRTY-DEGREE TRANSPOSITION FLAP**

A variation of the rhomboid flap, the 30-degree transposition flap contains a 30-degree angle at the distal end of the typical rhomboid flap. It was found that a 30-degree angulation will not cause cosmetically significant bulges that plague the typical rhomboid flap (104). Since one drawback of using a
30-degree distal angle is a significantly increased incision length, the 30-degree angle is typically combined with an M-plasty, which shortens the rhomboid shape.

The distal end of the flap is designed parallel to the RSTL. The final edge of the flap is at a 30-degree angle to the distal end of the flap. The flap is transposed in a similar fashion to the rhomboid flap. The sides of the M-plasty are advanced into the side of the defect. Although more difficult than the classic Limberg flap, it has the advantages of dispersing tension more evenly around the flap (41), thereby closing with less tension.

**DOUBLE OR TRIPLE RHOMBOID**

Double or triple rhomboid flaps are useful in the closure of large rectangular or circular defects (41). Double rhomboid flaps may be used to close a 60-degree parallelogram with a 2:1 length to width ratio (1,12–42). Given the fact that a 2:1 parallelogram is actually two 60-degree rhombi, the closure with the use of double rhomboid flaps can be visualized easily. Triple rhomboid flaps may be used to close a larger defect, if the defect can be designed as a hexagon, or three 60-degree rhombi (45). The calipers are set to the length of the radius of the defect. The flaps should all have their limbs pointing in the same direction. Only in special circumstances should two of the flaps share a common base because in that instance, when they are rotated, a 120-degree angle is closed. This will likely cause a pronounced and probably permanent dog ear.

**NOTE FLAP**

Walike and Larrabee (115) designed this flap, which allows for closure of a circular defect with a triangular flap that maximizes use of surrounding tissues (41). A tangent is drawn on either side of a circular defect, parallel to the RSTL. The tangent should be approximately one and a half times the diameter of the circle. At the end of the tangent, a 50- to 60-degree flap is designed, having a length approximately equal to the diameter of the circle. The flap is then transposed into the circular defect and the tip is trimmed or de-epithelialized. The major movement is perpendicular to the tangent (41). Because the flap is approximately two thirds the size of the defect, clinical judgment is required when using the flap (41). The flap is recommended for smaller defects, 2 cm or less (41). The small dog ear that is created usually resolves, but may be revised at the time of the procedure (41).

**CONCLUSION**

Local flap reconstruction of pedal defects can be accomplished with a variety of techniques. Multiple geometric constructs have been described for closure of foot defects. Each has its own unique principles that can be adapted to certain locations and premorbid conditions. Local flaps considered for closure of foot defects should lie within the higher level of any algorithm, because of their versatility, reproducibility, and long-term functional outcomes. In addition, hospitalization, length of anesthesia, and perioperative care can be much less with the use of local flaps.

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INTRODUCTION

Local intrinsic muscle flaps of the foot are advantageous in covering full-thickness soft tissue defects among the diabetic foot and ankle, especially when there is exposed hardware, bone, joint capsule, and/or tendon. In addition, muscle flaps are particularly useful in the surgical treatment of osteomyelitis. In case scenarios in which diabetic foot or ankle wounds are further complicated with osteomyelitis, the use of a muscle flap can be advantageous in that it provides increased local blood flow to the area, thereby enhancing the delivery of antibiotics and white blood cells, and facilitating the healing process. Muscle flaps can be harvested to include the cutaneous portion supplied by the musculocutaneous perforating vessels; however, in the diabetic foot this is often difficult, and muscle flaps are often harvested in isolation followed by coverage with a split-thickness skin graft. The most used local intrinsic muscle flaps for soft tissue coverage of the diabetic foot is the abductor hallucis, extensor digitorum brevis, flexor digitorum brevis, and abductor digiti minimi. Muscle flaps that contain a dominant vascular pedicle and several more distal minor pedicles allow for easy mobilization, rotation, and various modifications to achieve soft tissue coverage about the foot and ankle. Muscle flaps have proved to be a powerful procedure in the surgeon’s armamentarium to obtain durable soft tissue coverage in difficult to heal diabetic foot and ankle wounds.

INDICATIONS AND CONTRAINDICATIONS

A local muscle flap is a useful procedure for obtaining soft tissue coverage of a complicated diabetic foot wound with either exposed bone and/or previous hardware. In the diabetic foot, a muscle flap is used predominantly for soft tissue closure over bone defects as a result of deformities associated with a Charcot foot and/or resected osteomyelitis (1,2). Exposed retained hardware that may not suitable for removal are best covered with a muscle flap and if a free tissue transfer is not feasible or indicated. The main advantage of a muscle flap is that extensive soft tissue coverage about all aspects of the foot can be provided without the microvascular anastomosis that is required of a free tissue transfer. Often, diabetic patients present with severely calcified vessels, making microvascular anastomosis daunting or impossible. Soft tissue coverage can be obtained with a muscle flap about the plantar, medial, lateral, and dorsal aspect of the foot (3).

Wounds with underlying osseous deformities may be managed with a muscle flap, depending on the size and anatomic location of the wound. Overall, the authors have experienced better durability when muscle flaps are used over bone defects rather than bony prominences from underlying deformities. For this reason, bony prominences should be managed either through surgical resection or deformity correction prior to insetting of a local muscle flap regardless of the muscle flap to be performed. The enhanced local vascularity provided by a well-perfused muscle flap is often advantageous to facilitate the healing process of arthrodesis procedures that are required to correct and provide stability to underlying deformities.

Surgical wound dehiscence with or without exposed hardware is an indication for consideration of a muscle flap for soft tissue coverage. Exposed hardware is not a contraindication for soft tissue coverage with a muscle flap. However, the surgeon must be certain that the proposed muscle flap does not display atrophy and is robust to provide adequate and durable soft tissue coverage. In addition, the surgeon needs to determine if eventual hardware removal and/or further reconstructive surgery to the area may be warranted in the future. In these case scenarios, a free tissue transfer or pedicle flap may be a preferable alternative because they can be easily raised, as opposed to the local muscle flap, which will interfere with the exposure and wound healing. Local muscle flaps can be raised if needed in future procedures; however, they tend to display a great deal of fibrosis and wound complications are commonly encountered with resetting of the muscle flap. A common example is wound complications associated with the lateral extensile incision for operatively treated calcaneal fractures among the diabetic population (4). These wounds need close monitoring to prevent secondary or further infection prior to osseous healing of the associated fractures. As a result, retained hardware cannot be removed at the
time of soft tissue coverage. In addition, it is not uncommon for these patients to require subsequent subtalar joint arthrodesis and/or realignment calcaneal osteotomies. As a result, muscle flaps can be employed to salvage small wounds, particularly at the apex or along the horizontal limb of the incision as long as procedures in the future, if required, can be performed through safe alternative incisions. Larger wounds in this region that involve extensive hardware exposure or a large portion of the calcaneal body may be surgically managed with a free tissue transfer that can be easily raised if needed in the future to remove hardware and perform additional osseous procedures.

Diabetic plantar wounds that have not responded to offloading and other conservative modalities or wounds that display exposed joint capsule, tendon, and/or bone with or without underlying osteomyelitis are other indications for consideration of a muscle flap (1,2). We use muscle flaps to obtain closure of weight-bearing plantar wounds that are not amenable to closure via a local pedicle flap as a result of scar contracture, or are small and involve areas that would not be affected by shear forces across the overlying split-thickness skin graft that is applied over the muscle flap.

The abductor hallucis muscle flap is considered for soft tissue coverage about the plantar, medial, and at times the dorsal aspect of the foot. The abductor hallucis muscle flap is versatile in that it can be considered for surgical management of soft tissue defects about the metatarsal region, but can also be extended as far proximal as the medial malleolus if needed. The abductor hallucis muscle flap is often performed for bone defects about the first and central metatarsals. This muscle flap is very useful for coverage of central metatarsal defects as a result of traumatic injuries or previous infection in which the wound is complicated with extensive bone and soft tissue loss. In addition, the abductor hallucis muscle flap is useful for covering exposed joints and tendon structures about the medial aspect of the foot.

The flexor digitorum brevis muscle flap is used to obtain soft tissue coverage about the plantar central aspect of the foot. It is often utilized to cover and to salvage plantar central ulceration as a result from an underlying Charcot deformity. In addition, associated midtarsal fractures and/or dislocations will need to be addressed in conjunction. The authors favor on the side of using a local pedicle flap in lieu of the flexor digitorum brevis muscle flap if the skin integrity permits and there is no evidence of underlying osteomyelitis. In the face of skin contracture and/or underlying osteomyelitis, the authors favor the use of a flexor digitorum muscle flap for closure of atypical plantar central ulcerations. This is often apparent in patients who had a history of previous surgeries with extensive plantar soft tissue loss and required previous split-thickness skin grafting and/or a local flap for closure. The flexor digitorum brevis muscle flap is perfused through multiple perforating arterial branches providing a well-vascularized and robust muscle to provide extensive soft tissue coverage about the plantar aspect of the foot. Caution should be employed when previous surgical débridements were performed to manage a diabetic plantar central space infection. In these circumstances, the musculature could have been excised or severely compromised and should be evaluated by a magnetic resonance imaging (MRI), or another method of closure should be considered. The main advantage of this muscle flap is that it can be raised, rotated, and positioned in a direction that permits the donor site to be closed primarily. The donor site for a medial or lateral planter artery flap usually requires a split-thickness skin graft, and in the presence of an underlying deformity that needs correction, the authors favor a muscle flap to prevent donor site complications. Rarely are diabetic plantar midfoot ulcers present without underlying skeletal deformity and/or osteomyelitis. Charcot neuropathopathy is often the main causative factor that leads to the development of a plantar midfoot ulceration in the diabetic patient (5–7). The flexor digitorum brevis muscle flap is an excellent alternative to obtain soft tissue coverage when a medial or lateral planter artery flap cannot be performed in conjunction with the skeletal reconstruction of a Charcot foot. The flexor digitorum brevis muscle flap is useful for salvaging failed medial or lateral planter artery flaps.

The abductor digiti minimi muscle flap is used for soft tissue coverage about the lateral aspect of midfoot and rearfoot. The flap is useful for soft tissue coverage about the base of the fifth metatarsal, cuboid, and calcaneal region. The flap can be extended as far proximal in selected cases to the lateral malleolus. The abductor digiti minimi muscle flap is used for plantar lateral ulcerations that accompany cavovarus foot deformities. This flap is only useful if deformity correction can be obtained through osseous reconstruction or tendon balancing to unload the lateral column of the foot. The abductor digiti minimi is not very bulky and cannot be placed over high pressure regions of the foot. The close proximity of the abductor digiti minimi is advantageous in providing adequate soft tissue coverage after extensive bone resection such as a cuneiformectomy and resection about the lateral column as a result of osteomyelitis. In addition, the abductor digiti minimi flap is very useful to obtain soft tissue coverage in diabetic patients who have exposed hardware as a result of wound healing complications after open reduction and internal fixation of intra-articular calcaneal fractures, as discussed previously (4).

Virtually all patients who suffer from diabetic associated foot complications have multiple comorbidities. In addition, chronic wounds that require surgical closure are often associated with underlying osteomyelitis, vascular insufficiency, and/or severe skeletal deformities that need to be addressed prior to closure. Muscle flaps are typically performed in a delayed fashion after adequate wound débridement, control of infection, revascularization, and optimization of the patient’s diabetes and other associated comorbidities. The timing of surgery is paramount in deciding when a muscle flap is indicated. A muscle flap can be performed after an osseous reconstruction in the same operative setting if not complicated by infection, vascular insufficiency, or a chronic draining wound. However, in the presence of infection or heavy bacterial colonization, serial débridements and parenteral antibiotics are needed prior to surgery, and this can range from days to weeks before a muscle flap can be performed and is usually based on the clinical appearance of the wound (8,9). Chronic wounds, even if drainage is not apparent, are typically managed with simple excision and deep intraoperative cultures prior to definitive closure. The authors have found that by surgically creating an “acute” and “clean” wound prior to de-
to determine if underlying osteomyelitis and skeletal deformities are present. The surgeon needs to be aware that the lag period is about 10 to 14 days before osteomyelitis can be detected through plain radiographs. Other studies are useful, such as technetium bone scan, bone marrow scan, indium scan, and MRI to determine the presence and extent of deep infection. However, the sensitivity and specificity for diagnosing osteomyelitis diminishes in the presence of Charcot neuroarthropathy. The authors' preference is that if there is any suspicion for infection or osteomyelitis, then deep intraoperative tissue and bone cultures may be warranted (11). The authors have also found this approach to be more accurate, and guide appropriate treatment while minimizing the risk from contrast materials, particularly in diabetic patients with renal impairment.

The lower extremity should be evaluated for palpable pedal pulses. After a thorough vascular examination for the presence of palpable pedal pulses, the arterial Doppler ultrasound can also be used as a great screening test to determine the need for more invasive vascular imaging or angiography. The ankle-brachial index (ABI) is determined by measuring the ankle systolic pressure and dividing it by the brachial systolic pressure using Doppler detection of the pulse. This is best performed in a certified noninvasive laboratory. Severity of arterial disease is relative to decreasing values of an ABI, and a value <0.70 is considered abnormal in the diabetic patient. The ABI is only a screening test, and there is controversy regarding the sensitivity and specificity of the test. The ABI may be falsely elevated, underestimating the severity of arterial insufficiency secondary to stiff calcified vessels common among the diabetic population. Perforators for the planned muscle flap are assessed with a Doppler ultrasound. Often, when a muscle flap is considered for the diabetic foot with the presence of arterial insufficiency, a vascular surgery consultation is obtained to be certain that invasive angiography or revascularization will not be needed prior to soft tissue reconstruction.

It is important to correlate the lower extremity examination with radiographs to determine if there is a musculoskeletal deformity present that may be the causative factor or have an effect on the proposed muscle flap postoperatively. The patient should also be evaluated for a preoperative equinus contracture. A contracted Achilles tendon is suspected in patients who present with foot ulcerations, previous amputations, acquired pes planovalgus or acquired cavovarus deformities, Charcot neuroarthropathy involving the midfoot, and those who have been non-weight-bearing for long periods of time. Testing for an equinus must be performed with the knee in flexion and extension, which determines if the contracture is solely the gastrocnemius or a combination of the gastrocnemius and soleus. This can help the surgeon decide if an Achilles tendon lengthening or gastrocnemius recession is needed.

If a Charcot deformity is present, it should be clinically assessed to determine if the deformity is stable or unstable. Computed tomography scans are useful preoperatively to better visualize and evaluate the deformity. Often, deformities of the midfoot are managed with a simple exostectomy if the deformity is stable. The surgeon should also be aware that a stable deformity preoperatively may become unstable after a simple exostectomy is performed. The rationale is that bone

**PREOPERATIVE PLANNING**

The most important determining factor for a successful muscle flap is appropriate patient selection, wound selection, and medical optimization prior to surgery. Associated diabetic comorbidities such as arterial insufficiency, venous stasis, heart failure, hypertension, anemia, renal disease, and peripheral neuropathy increase the risk of postoperative complications significantly. Unfortunately, as mentioned, the diabetic patient who is in need of a muscle flap for soft tissue coverage to achieve limb salvage often is affected with a multitude of comorbidities that increase the risk for surgical complications and presents with a wound that needs definitive closure to prevent major limb loss. For this reason, it is important to have a candid discussion with your patient concerning the rationale behind performing a muscle flap, the alternatives, complications, and how those complications will be managed. The flap is often used as an alternative to a pedicle flap, free tissue transfer, or major limb amputation. However, if the muscle flap fails, the patient may need a pedicle flap, free tissue transfer; and if a free tissue transfer is not feasible, then major limb amputation may be required. The surgeon needs to consider the existence of any psychosocial issues that may need to be addressed or considered in the overall decision-making process (10). The authors typically do not exclude a diabetic patient from receiving a muscle flap if other comorbidities are present. However, medically optimizing the high-risk diabetic patient is paramount prior to performing a muscle flap. A multidisciplinary team approach is executed and the timing of surgery is coordinated among the various services needed to prevent complications (3).

In diabetic patients, it is essential to identify those with a wound that warrants a muscle flap for soft tissue coverage. The wound should be thoroughly examined to determine the size, depth, anatomic location, geometry, presence of superficial and deep infection, underlying skeletal deformities, exposed hardware, tissue perfusion, skin contractures, edema, and sensation to the surrounding soft tissues. The surgeon must evaluate the area closely, as previous surgeries in the vicinity of the proposed muscle may have involved excision or scarring of the muscle intended for transfer. This is usually seen when previous incisions were placed over the proposed muscle flap to manage previous infections. In addition, the diabetic foot needs to be assessed for intrinsic musculature atrophy, which is commonly seen in the presence of diabetic peripheral neuropathy. In this case scenario, a muscle flap may not be a valid surgical option, as atrophied muscle does not provide durable and extensive wound coverage.

Radiographs are important in the preoperative planning to determine if underlying osteomyelitis and skeletal deformities are present. Patients who require revascularization prior to soft tissue reconstruction are delayed an additional 24 to 72 hours after the revascularization and prior to performing a muscle flap.

Absolute contraindications to muscle flaps include vascular insufficiency despite endovascular or vascular surgery and active infection.

In diabetic patients, it is essential to identify those with a wound that needs definitive closure to prevent major limb loss. For this reason, it is important to correlate the lower extremity examination with radiographs to determine if there is a musculoskeletal deformity present that may be the causative factor or have an effect on the proposed muscle flap postoperatively. The patient should also be evaluated for a preoperative equinus contracture. A contracted Achilles tendon is suspected in patients who present with foot ulcerations, previous amputations, acquired pes planovalgus or acquired cavovarus deformities, Charcot neuroarthropathy involving the midfoot, and those who have been non-weight-bearing for long periods of time. Testing for an equinus must be performed with the knee in flexion and extension, which determines if the contracture is solely the gastrocnemius or a combination of the gastrocnemius and soleus. This can help the surgeon decide if an Achilles tendon lengthening or gastrocnemius recession is needed.

If a Charcot deformity is present, it should be clinically assessed to determine if the deformity is stable or unstable. Computed tomography scans are useful preoperatively to better visualize and evaluate the deformity. Often, deformities of the midfoot are managed with a simple exostectomy if the deformity is stable. The surgeon should also be aware that a stable deformity preoperatively may become unstable after a simple exostectomy is performed. The rationale is that bone

**PREOPERATIVE PLANNING**

The most important determining factor for a successful muscle flap is appropriate patient selection, wound selection, and medical optimization prior to surgery. Associated diabetic comorbidities such as arterial insufficiency, venous stasis, heart failure, hypertension, anemia, renal disease, and peripheral neuropathy increase the risk of postoperative complications significantly. Unfortunately, as mentioned, the diabetic patient who is in need of a muscle flap for soft tissue coverage to achieve limb salvage often is affected with a multitude of comorbidities that increase the risk for surgical complications and presents with a wound that needs definitive closure to prevent major limb loss. For this reason, it is important to have a candid discussion with your patient concerning the rationale behind performing a muscle flap, the alternatives, complications, and how those complications will be managed. The flap is often used as an alternative to a pedicle flap, free tissue transfer, or major limb amputation. However, if the muscle flap fails, the patient may need a pedicle flap, free tissue transfer; and if a free tissue transfer is not feasible, then major limb amputation may be required. The surgeon needs to consider the existence of any psychosocial issues that may need to be addressed or considered in the overall decision-making process (10). The authors typically do not exclude a diabetic patient from receiving a muscle flap if other comorbidities are present. However, medically optimizing the high-risk diabetic patient is paramount prior to performing a muscle flap. A multidisciplinary team approach is executed and the timing of surgery is coordinated among the various services needed to prevent complications (3).

In diabetic patients, it is essential to identify those with a wound that warrants a muscle flap for soft tissue coverage. The wound should be thoroughly examined to determine the size, depth, anatomic location, geometry, presence of superficial and deep infection, underlying skeletal deformities, exposed hardware, tissue perfusion, skin contractures, edema, and sensation to the surrounding soft tissues. The surgeon must evaluate the area closely, as previous surgeries in the vicinity of the proposed muscle may have involved excision or scarring of the muscle intended for transfer. This is usually seen when previous incisions were placed over the proposed muscle flap to manage previous infections. In addition, the diabetic foot needs to be assessed for intrinsic musculature atrophy, which is commonly seen in the presence of diabetic peripheral neuropathy. In this case scenario, a muscle flap may not be a valid surgical option, as atrophied muscle does not provide durable and extensive wound coverage.

Radiographs are important in the preoperative planning to determine if underlying osteomyelitis and skeletal deformities are present. Patients who require revascularization prior to soft tissue reconstruction are delayed an additional 24 to 72 hours after the revascularization and prior to performing a muscle flap.

Absolute contraindications to muscle flaps include vascular insufficiency despite endovascular or vascular surgery and active infection.
bridging across a joint may be removed when performing an
exostectomy permitting unwanted motion. For this reason, we
favor arthrodesis procedures to correct midfoot deformities
with soft tissue loss and reserve exostectomy procedures for
elderly patients, those who are medically unstable for major
ossseous reconstruction, or in situations in which performing
the exostectomy will not compromise stability to the foot
(5–7). The authors feel that deformities about the rearfoot
and ankle are also best managed with major and extended
joint arthrodesis procedures to achieve correction and long-
term stability.

If underlying osteomyelitis is present, this does not present
as a contraindication for a muscle flap. However, attempts at
surgical débridement and excision of all infected bone should
be performed prior to inserting of the muscle flap. Bone
defects after surgical resection for infection are best managed
with antibiotic cement beads or spacers until culture-specific
long-term parenteral antibiotics can be initiated and finally
followed by bone grafting and closure via a muscle flap.
Muscle flaps can enhance arterial perfusion and as a result in-
crease the deliverance of antibiotics. This is very useful in
the management of osteomyelitis in the diabetic foot. Relying on
the notion that the use of a muscle flap and parenteral antibi-
otics alone is sufficient to treat osteomyelitis in the diabetic
foot is likely to result in failure. A muscle flap is a useful ad-
juvant procedure in the management of osteomyelitis, but
should not replace adequate surgical débridement of the in-
fected bone. Surgical débridement cannot be overempha-
sized in these cases, as this is the single most important factor
in the patient’s overall successful outcome.

**SURGICAL TECHNIQUE**

Incision placement for the abductor hallucis muscle flap is
started just proximal to the first metatarsal phalangeal joint
on the medial aspect of the foot and extends proximal to the
plantar aspect of the navicular tuberosity. The incision can be
modified and extended as far proximal as the medial malleo-
lus if needed. The incision should not be placed through the
thick plantar skin that extends slightly dorsal, particularly
along the medial longitudinal arch of the foot. Rather, the in-
cision should be placed at or just above the junction of the
plantar and dorsal skin crease. After the skin incision is per-
formed, commonly encountered perforating veins extending
from the great saphenous vein need to be ligated along the
proximal aspect of the muscle belly and as the incision is
deepened down to the fascia level. Once the fascia overlying
the muscle is identified, attention is then directed to the
tendinous insertion of the abductor hallucis muscle along the
medial aspect of the first proximal phalanx. Limited dissec-
tion superior and inferior to the tendinous slip is performed
and a small malleable retractor or curved hemostat is placed
on the undersurface of the tendon as it is transected with a
tenotomy scissor. The tendon is then tagged with a 2-0 non-
absorbable suture. Grasping the suture is preferred to direct
handling of the muscle, as this allows easy control of the
muscle belly as it is raised, while avoiding trauma to the un-
dersurface of the muscle flap. A self-retaining retractor is
then applied and is directed just superior to the deep fascia of
the abductor hallucis muscle and inferior to the first
metatarsal to expose the distal perforating arterial branches
of the medial plantar artery. Elevation of the muscle is per-
formed by applying gradual tension in a proximal direction
through the tendinous portion of the muscle flap as the mus-
cle is folded onto itself. The muscle flap itself should not be
manipulated with forceps or sharp retractors. The surgeon or
assistant should use finger or blunt retraction when needed
on the muscle to prevent inadvertent trauma and fraying of
the muscle, which can easily occur. The distal perforating ar-
teries that arise from the medial plantar artery are identified
and ligated as they pierce the deep fascia to supply the abduc-
tor hallucis muscle. The muscle is then rotated in one fluent
direction and once the proximal perforating arteries are
identified off the medial plantar artery. The direction of rota-
tion tends to be toward the medial malleolus. Rotation in this
manner minimizes tension across the last perforating artery.
The last perforator from the medial plantar artery is com-
monly encountered 0.5 to 1 cm distal to the plantar aspect of
the navicular tuberosity. If further mobility is required, as in
the case for soft tissue coverage about the medial malleolus,
dissection is then continued proximal through the tarsal tun-
el. The flexor retinaculum is transected and the medial
plantar and the posterior tibial arteries are mobilized facilitat-
ing extensibility to the abductor hallucis muscle flap (Figs.
13.1 and 13.2).

Incision placement for harvest of a flexor digitorum brevis
muscle flap is usually placed through a midline plantar inci-
sion. The authors have modified this incision to a “Z” shaped
incision to facilitate dissection for this broad based muscle
flap. The flexor digitorum brevis muscle flap is supplied by
perforators from of the lateral plantar artery and to a lesser
extent by the medial plantar artery. Dissection can be facili-
tated by marking out the perforators with a Doppler ultra-
sound probe. The lateral plantar artery is oriented oblique to
the muscle flap, and identification of the perforators are diffi-
cult as one elevates the muscle from distal to proximal as op-
oposed to the abductor hallucis or abductor digit minimi mus-
cle flap in which the perforators are oriented in a linear path.
After the skin incision is made, the skin flaps are tagged and
retracted with suture to expose the underlying plantar fascia.
Tethering ligaments are released with blunt finger dissection.
The plantar fascia is then incised at midline, exposing the
flexor digitorum brevis muscle and tendinous structures. The
plantar fascia can be reflected medially and laterally with a
freer elevator. Sharp dissection and handling the muscle
should be avoided, as fraying of the muscle will occur. The
four flexor tendons that arise from the flexor digitorum bre-
vis muscle are then identified, clamped, and transected 1 cm
proximal to the plantar aspect of the metatarsal neck and
tagged with a 2-0 nonabsorbable suture. The distal stump of
the flexor digitorum brevis tendon can be sutured to the
flexor digitorum longus tendon if desired, but it is not usually
required and is rarely performed by the authors. The flexor
digitorum brevis muscle belly is then gradually raised while
proximal tension is applied on the tendinous portion and
until the surgeon encounters the perforating vessels that were
previously marked out. The distal perforating vessels are lig-
ated only if needed for mobility of the muscle flap to rotate
into the defect. If additional rotation or proximal extension is
Figure 13.1 An exposed medial cuneiform with osteomyelitis after the use of a uniplane monolateral external fixator to address instability of a Charcot foot (A), followed by large bone and joint resections (B) and utilization of an abductor hallucis muscle flap (C–E). Please note the distal dissection and rotation of the vascularized muscle flap to cover the proximal prepared joints for arthrodesis. The muscle flap was then covered by a split-thickness skin graft (F) and followed by an external fixation technique (G) for arthrodesis and stability of the medial column of the foot. Final appearance of the Charcot foot with adequate soft tissue coverage (H).
needed, the muscle can be elevated at the plantar aspect of the calcaneus while preserving the arterial supply from the last perforators from the lateral plantar artery and at times from the medial plantar artery (Fig. 13.3).

The abductor digiti minimi muscle flap is performed by placing a lateral incision along the junction of the plantar lateral and dorsal lateral skin crease. The incision is carried distal to the level of the fifth metatarsophalangeal joint and proximal to the fifth metatarsal base. At times, the incision can extend as far proximal as the lateral malleolus if needed. Dissection is similar to the abductor hallucis muscle flap and is initially carried down to the fascia overlying the abductor digiti minimi. The tendinous insertion is then identified just lateral and distal to the fifth metatarsophalangeal joint, transected and tagged with a 2-0 non-absorbable suture. The muscle flap is then raised and reflected back onto itself as the distal perforators are identified. The last perforator is usually located at the fifth metatarsal base or up to 1 cm proximal to the fifth metatarsal base (Fig. 13.4).

(text continues on page 176)
Figure 13.3  A chronic Charcot deformity with a plantar lateral ulceration (A), followed by an initial ulcer excision and intraoperative bone and soft tissue cultures (B). Harvesting of the flexor digitorum brevis muscle to cover the bone and soft tissue defect proximally (C–E) and covering with a split-thickness skin graft (F). (continued)
Figure 13.3 (Continued) A medial incision for the Charcot midfoot reconstruction (G) followed by an arthrodesis (H) with a multiplane circular external fixator (I).
Figure 13.4 A large bone and soft tissue defect at the proximal lateral aspect of the foot and ankle (A), covered by an abductor digiti minimi muscle flap (B–D) and split-thickness skin graft from the ipsilateral extremity (E). A hybrid offloading external fixator was also applied for the flap protection and lower extremity stabilization (F).
is released to facilitate hemostasis of the area. Muscles flaps must be handled delicately, especially in diabetic patients with calcified vessels and muscle atrophy. Topical thrombin is commonly used on the donor site along with the application of cement beads or spacers are first applied, followed by bone grafting and insetting of the muscle flap in a delayed fashion. If a graft when possible to prevent further drainage. If drainage appears excessive, then a surgical drain is placed for 24 to 48 hours.

Negative pressure wound therapy can be used in conjunction with a muscle flap. We have found that when a muscle flap is raised and vascular inflow appears compromised or questionable, then the muscle flap can be inset and followed by a nonadherent dressing and negative pressure therapy to further increase arterial perfusion and eliminate wound drainage. The muscle flap is then assessed every 24 hours and when muscle viability is confirmed, a definitive split-thickness skin graft can be applied in a delayed fashion. If a muscle flap is raised and is not well perfused, which can occur particularly in a diabetic patient with peripheral arterial disease and calcified vessels, the muscle belly is resected and negative pressure wound therapy is initiated while the wound is reassessed to determine future options to obtain closure.

POSTOPERATIVE MANAGEMENT

Initially, a stent dressing or negative pressure wound therapy overlying the split-thickness skin graft can be covered with dry soft dressings and a well-padded splint or short leg cast if an external fixator is not used. If an external fixator is used, the stent dressing can be covered in soft dressings permitting easy exposure for inspection of the surrounding tissues. The patient is typically admitted to the hospital for 3 to 5 days for close observation. Surgical drains if used are typically removed after 24 to 48 hours. The patient is instructed on elevation of the extremity and strict bed rest for the first 24 to 48 hours. During this period deep vein thrombosis prophylaxis with compression stockings on the contralateral extremity is enforced along with pharmacological therapy as consuded with the medical team.

The muscle flap with overlying split thickness skin graft is inspected every 2 weeks on discharge from the hospital if a stent dressing was placed. We typically inspect the soft tissue around the periphery of the stent dressing for drainage, edema, and signs of infection. If erythema, edema, purulent drainage, or foul odor is detected, the stent dressing is then removed prematurely to inspect the viability of the muscle flap and incorporation of the split-thickness skin graft. If the stent dressing is well maintained and displays no clinical signs for early removal, we elect to remove the stent dressing at 4 to 6 weeks postoperatively to prevent iatrogenic removal to portions of the split-thickness skin graft. After removal of the stent dressings or after removal of an external fixator if used, the authors place the patient in a below the knee cast non-weight-bearing for an additional 4 to 6 weeks. The patient is then progressed into a walking cast or fracture boot for an additional 4 to 6 weeks, during which time custom made shoes and appropriate bracing is fabricated by a pedorthotist. The cast changes are performed every 2 weeks to prevent skin irritation and breakdown.

Physical therapy is initiated 48 to 72 hours after surgery to instruct the patient on proper technique for transfers and non-weight bearing gait with crutches or a walker. Often, the diabetic patient with peripheral neuropathy needs additional bracing or specific shoe gear on the contralateral extremity during this postoperative period to prevent further diabetic foot complications.

TECHNIQUE TIPS AND ADJUNCTIVE PROCEDURES

Detailed knowledge of the muscle vasculature expedites its harvest and permits modifications while minimizing complications. An example of a modification would be to harvest the muscle from proximal (i.e., origin) to distal (i.e., insertion), relying on the distal perforators and collateral circulation through retrograde flow to maintain muscle viability. Muscle flaps must be handled delicately, especially in diabetic patients with calcified vessels and muscle atrophy. Intraoperative use of a Doppler ultrasound probe and loupe magnification is required to minimize complications associated with disruption or failure to include the dominant vascular pedicle. Insetting the muscle should be done without excessive tension or torsion on the dominant vascular pedicle so that blood flow and muscle viability are not compromised. For this reason the muscle is rotated in one fluent motion, and the amount of time that it is handled is kept to a minimum. Frequent irrigation with warmed normal saline prevents desiccation and vasospasm from occurring. The muscle is then sutured to the dermis and fascia at the perimeter of the defect with a 2-0 monofilament absorbable suture such as polydioxanone. The vascular inflow should be assessed with a Doppler ultrasound probe after insetting the muscle. If inflow is compromised, the muscle must be repositioned to ensure adequate blood flow. A split-thickness skin graft that is 18 thousandths of an inch and meshed in a 1:1.5 ratio is then applied to the muscle flap.

Muscle flaps often require adjunctive procedures for a successful outcome. In most cases, an osseous reconstruction is required and external fixation is used to achieve deformity correction and successful arthrodesis. The authors have found that even when local muscle flaps are performed without underlying osseous reconstruction the use of an external fixator is paramount to offload the muscle flap, facilitate daily inspections, and continuously elevate for edema control. In addition, the external fixator can be employed to facilitate minimal weight bearing if indicated while preventing inadvertent trauma to the muscle flap.

The appropriate management of dead space is important to prevent hematoma, seroma, and infection. Robust muscle flaps can provide adequate management of dead space. However, bone defects may still be packed with either autogenous or allogenic bone graft prior to insetting of the muscle flap if possible. In the presence of osteomyelitis, antibiotic cement beads or spacers are first applied, followed by bone grafting and insetting of the muscle flap in a delayed fashion. Defects from hardware removal may be back-filled with bone graft when possible to prevent further drainage. If drainage appears excessive, then a surgical drain is placed for 24 to 48 hours.

In addition, achieving adequate hemostasis is paramount to prevent hematoma formation and muscle flap failure. If a pneumatic tourniquet is used, it should be released prior to insetting the muscle flap to ensure flap viability, arterial patency, and achievement of adequate hemostasis. Topical thrombin is commonly used on the donor site along with the application of a compressive dressing for 3 to 5 minutes while the tourniquet is released to facilitate hemostasis of the area.

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Initially, a stent dressing or negative pressure wound therapy overlying the split-thickness skin graft can be covered with dry soft dressings and a well-padded splint or short leg cast if an external fixator is not used. If an external fixator is used, the stent dressing can be covered in soft dressings permitting easy exposure for inspection of the surrounding tissues. The patient is typically admitted to the hospital for 3 to 5 days for close observation. Surgical drains if used are typically removed after 24 to 48 hours. The patient is instructed on elevation of the extremity and strict bed rest for the first 24 to 48 hours. During this period deep vein thrombosis prophylaxis with compression stockings on the contralateral extremity is enforced along with pharmacological therapy as consulted with the medical team.

The muscle flap with overlying split thickness skin graft is inspected every 2 weeks on discharge from the hospital if a stent dressing was placed. We typically inspect the soft tissue around the periphery of the stent dressing for drainage, edema, and signs of infection. If erythema, edema, purulent drainage, or foul odor is detected, the stent dressing is then removed prematurely to inspect the viability of the muscle flap and incorporation of the split-thickness skin graft. If the stent dressing is well maintained and displays no clinical signs for early removal, we elect to remove the stent dressing at 4 to 6 weeks postoperatively to prevent iatrogenic removal to portions of the split-thickness skin graft. After removal of the stent dressings or after removal of an external fixator if used, the authors place the patient in a below the knee cast non-weight-bearing for an additional 4 to 6 weeks. The patient is then progressed into a walking cast or fracture boot for an additional 4 to 6 weeks, during which time custom made shoes and appropriate bracing is fabricated by a pedorthotist. The cast changes are performed every 2 weeks to prevent skin irritation and breakdown.

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COMPLICATIONS

Muscle flaps provide an excellent tool to a surgeon’s armamentarium in soft tissue reconstruction of the diabetic foot and ankle. Complications associated with muscle flaps are delayed soft tissue healing, vascular insufficiency, and infection that can lead to subsequent muscle necrosis. Muscle necrosis is often the result of arterial insufficiency and/or iatrogenic insult intraoperatively. Its presence can serve as a nidus for the development of a secondary wound infection. Unfortunately, close observation of the muscle flap for necrosis is difficult in the immediate postoperative period, since it is typically obscured by stent dressings that were applied to the overlying split-thickness skin graft. Malodor is usually apparent with muscle necrosis and if present, the stent dressing may need to be removed prematurely to assess the muscle viability. If muscle necrosis is evident, débridement and excision of the nonviable muscle should be performed as soon as possible as nonviable tissue is detrimental to wound healing and can lead to further infection.

Late skin breakdown of a muscle flap can be the result of infection, underlying skeletal deformity, and/or ill-fitting shoe gear. It is important for the clinician to inspect the fitting of orthosis, braces, and shoe gear to determine if this is the causative factor. In addition, radiographs should be obtained to examine for underlying skeletal deformity, which can account for the ulcerative lesion. If infection and/or osteomyelitis are suspected, then appropriate laboratory and medical imaging studies are performed. In addition, it is important to discuss with the patient any changes in daily activities that may have preceded the skin breakdown. Regardless of the cause it is best to offload the area as soon as possible. Delay in offloading with the presumption that the skin breakdown is minor will result in more extensive skin breakdown, flap necrosis, and further complications. If an underlying osseous deformity is the causative factor, then revisional surgery may be indicated if offloading cannot be achieved through bracing and/or orthotic management to prevent further skin breakdown and flap failure. The presence of infection must be managed with antibiotics and/or possible surgical débridement if indicated.

CONCLUSION

This chapter has reviewed the most common intrinsic muscle flaps for soft tissue coverage of the diabetic foot. Knowledge of the vascular anatomy is paramount to these reconstruction procedures along with a vast experience in plastic surgery and external fixation.

REFERENCES

INTRODUCTION

A commonly performed and useful procedure for closing a complicated wound in a diabetic foot is a local or distant pedicle flap. The pedicle flap is used predominantly for durable soft tissue closure to the weight-bearing aspect of the foot and becomes very useful when performed in conjunction with an osseous reconstruction. The main advantage of a pedicle flap is that extensive soft tissue coverage to the plantar aspect of the foot can be provided without the microvascular anastomosis that is required with a free tissue transfer. In addition, the authors have experienced better durability and fewer complications with pedicle flaps when compared to free flaps for the plantar soft tissue reconstruction of the diabetic foot.

INDICATIONS AND CONTRAINDICATIONS

Diabetic plantar wounds that have not responded to off loading modalities or wounds that healed with an unstable scar and re-ulcerate periodically after conservative care are indications for consideration of a pedicle flap. The authors use pedicle flaps to obtain closure of weight-bearing wounds that are not amenable to closure via a random local flap or when closure of a plantar wound is needed in conjunction with skeletal reconstruction to address the underlying deformity. The local pedicle flaps that can be used in the diabetic foot are the great toe fibular flap, medial plantar artery flap, and lateral plantar artery flap.

The great toe fibular flap is considered for soft tissue coverage of the plantar forefoot primarily over prominent metatarsal heads. The use of the great toe fibular flap is sparse secondary to the wound often being amendable to closure via a local random flap after a metatarsal head resection, ray resection, osteotomy, sesamoidectomy, and/or exostectomy. The great toe pedicle flap is often performed for revisions of a failed primary closure, local random flap, or if the surrounding soft tissues are not amendable to other closure techniques (1).

The medial or lateral plantar artery flap is used to obtain soft tissue coverage over the plantar midfoot and distal rearfoot (2). Of these two, the medial plantar artery flap is the most commonly used to obtain closure of a complicated plantar midfoot ulcer. The medial plantar artery has many perforating superficial branches contributing to a large angiosome allowing for extensive soft tissue coverage. The main advantage of this flap is that it can be raised and rotated in a direction that permits the non-weight-bearing donor site (medial longitudinal arch) to be skin grafted. Rarely are diabetic plantar midfoot ulcers present without underlying skeletal deformity. Charcot neuroarthropathy is often the main causative factor that leads to the development of a plantar midfoot ulceration in the diabetic patient (3). The medial plantar artery flap is the “work horse” to obtain soft tissue coverage in conjunction with the skeletal reconstruction of a Charcot foot (3,4).

The distant pedicle flap that is most commonly used in the diabetic foot is the reverse flow sural artery neurofasciocutaneous flap (5). A diabetic wound located in the plantar or posterior aspect of the calcaneus is associated with a high morbidity and incidence of major limb amputation (6). The reverse flow sural artery neurofasciocutaneous flap is beneficial to obtain soft tissue coverage about the lower leg and heel and further prevent a major limb amputation.

Virtually all patients who suffer from diabetic-associated foot complications have multiple comorbidities. In addition, chronic wounds that require surgical closure are often associated with underlying osteomyelitis, vascular insufficiency, and/or severe skeletal deformities that need to be addressed prior to closure via a pedicle flap. Pedicle flaps are typically performed in a delay fashion after adequate wound débridement, treatment of infection, revascularization, and optimization of the patient’s diabetes and other associated comorbidities (7). The timing of surgery is paramount in deciding when a pedicle flap is indicated. A pedicle flap can be performed after an osseous reconstruction in the same operative setting if not complicated by infection, vascular
insufficiency, or a chronic draining wound. However, in the presence of infection or heavy bacterial colonization, serial debridements and parenteral antibiotics are needed prior to reconstructive surgery, and this can range from days to weeks before a pedicle flap will be indicated for wound closure (8). After successful revascularization, the authors typically wait a minimum of 72 hours prior to performing a pedicle flap.

Absolute contraindications to pedicle flaps include vascular insufficiency despite endovascular or vascular surgery, complicated renal and cardiac issues, nonambulatory patient, severe infection, unsalvageable foot, and a noncompliant patient.

**PREOPERATIVE PLANNING**

The first and most important determining factor for a successful pedicle flap, as in many surgeries, is proper patient selection. Associated comorbidities such as diabetes, arterial insufficiency, venous stasis, heart failure, hypertension, renal disease, and older individuals increase the risk of postoperative complications significantly. Unfortunately, the diabetic patient who is in need of a pedicle flap to achieve limb salvage is often affected with a multitude of these associated comorbidities that increase the risk for surgical complications. For this reason, it is important to have a candid discussion with your patient regarding the risks and benefits of performing a pedicle flap versus a major amputation. The surgeon should keep in mind the existence of any psychosocial issues that may need to be addressed or considered in the overall decision-making process (9). The authors typically do not exclude a diabetic patient from receiving a pedicle flap if other comorbidities are present. However, medically optimizing the high-risk diabetic patient is paramount prior to performing a pedicle flap. A multidisciplinary approach is taken and the timing of surgery is coordinated among the various services needed to prevent complications.

In diabetic patients, it is essential to identify those with a wound that warrants a pedicle flap for soft tissue coverage. The wound should be thoroughly examined to determine the size, depth, location, presence of superficial and deep infection, underlying skeletal deformities, tissue perfusion, skin contractures, edema, and sensation to the surrounding soft tissues. If the wound is small, noninfected, well perfused, and the surrounding soft tissues demonstrate good elasticity with a pinch test, then primary wound closure or a local random flap may be performed instead of a pedicle flap.

Radiographs are important in the preoperative planning to rule out osteomyelitis and any underlying skeletal deformity that may be present. The surgeon should keep in mind that the lag period is 10 to 14 days before osteomyelitis is apparent on plain radiographs. Other studies are useful, such as technetium bone scan, bone marrow scan, indium scan, and magnetic resonance imaging to determine the presence and extent of deep infection. However, the sensitivity and specificity for diagnosing osteomyelitis diminishes in the presence of Charcot neuroarthropathy. If there is any suspicion for infection or osteomyelitis, then deep intraoperative tissue and bone cultures, along with histopathological analysis, should be performed after antibiotics are stopped for three drug half-lives (10).

Evaluation of the vascular status is paramount in the preoperative planning. Pedicle flap necrosis is significantly increased in the presence of limb ischemia and venous insufficiency. The lower extremity should be evaluated for palpable pulses. After evaluation for the presence of palpable pedal pulses, the arterial Doppler ultrasound is widely available and serves as a great screening test to determine the need for more invasive vascular imaging or angiography. The ankle brachial index (ABI) is determined by measuring the ankle systolic pressure and dividing it by the brachial systolic pressure using Doppler detection of the pulse. This is best performed in a certified noninvasive laboratory. Severity of arterial disease is relative to decreasing values of an ABI, and a value <0.70 is considered abnormal in the diabetic patient. The ABI is only a screening test, and there is controversy regarding the sensitivity and specificity of the test. The ABI may be falsely elevated, underestimating the severity of arterial insufficiency secondary to stiff calcified vessels that are common among the diabetic population. The Doppler ultrasound should also be used to determine patency along the course of the proposed artery to be included in the pedicle, and the direction of flow should be determined as well.

Often, when a pedicle flap is considered for the diabetic foot with marginal circulation, a vascular surgery consultation is obtained to be certain that invasive angiography or revascularization will not be needed prior to soft tissue reconstruction. In addition, angiography allows the surgeon to adequately evaluate arterial patency of the proposed artery to be included in the pedicle. In addition, venous mapping is performed when a reverse flow sural artery neurofasciocutaneous flap is planned. Vein mapping is also performed in a noninvasive vascular laboratory in the same manner that the great saphenous vein is mapped preoperatively for a cardiac bypass. In the case of a reverse flow sural artery neurofasciocutaneous flap, the lesser saphenous vein is marked out preoperatively, as this will be the vein included among the pedicle components. The diameter of the vein is also taken into consideration preoperatively. The authors prefer a diameter ≥2 mm to ensure patency of the vein after the pedicle flap is inset to prevent venous congestion. In addition, the marking of the vein on the posterior aspect of the lower leg facilitates incision placement and surgical dissection of the pedicle components.

It is important to correlate the lower extremity examination with radiographs to determine if a musculoskeletal deformity is present that may be the causative factor or have an effect on the proposed pedicle flap postoperatively. The patient should be evaluated for a preoperative equinus contracture. A contracted Achilles tendon is suspected in patients who present with forefoot ulcerations, previous amputations, acquired pes plano valgus deformity, acquired cavovarus deformities, Charcot neuroarthropathy involving the midfoot, and those who have been non-weight-bearing for long periods of time. Testing for an equinus needs to be performed with the knee in flexion and extension, which determines if the contracture is solely the gastrocnemius or a combination of the gastrocnemius and soleus. This can help the surgeon decide if an Achilles tendon lengthening or gastrocnemius recession is needed. However, caution should be made in performing an Achilles tendon lengthening or gastrocnemius recession in patients who are undergoing a reverse flow sural artery flap. The authors do not recommend correcting an equinus contracture in the same operative setting, as this can lead to tension across the pedicle components and ischemia to this flap. In these cases, it is beneficial and recommended to apply external fixation to gradually correct the equinus deformity after the reverse flow sural artery neurofasciocutaneous flap has healed.
If a Charcot deformity is present, it should be evaluated to determine if the deformity is stable or unstable. Computed tomography scans are useful preoperatively to better visualize and evaluate the deformity. Often, deformities of the midfoot are managed with a simple exostectomy if the deformity is stable. The surgeon should also be aware that a stable deformity preoperatively may become unstable after a simple exostectomy is performed. The rationale is that bone bridging across a joint may be removed when performing an exostectomy, permitting unwanted motion. For this reason, we favor arthrodesis procedures to correct midfoot deformities with soft tissue loss and reserve exostectomy procedures for elderly patients, those who are medically unstable for major osseous reconstruction, or for situations in which performing the exostectomy will not compromise stability to the foot (3). The authors feel that deformities about the rearfoot and ankle are also best managed with major and extended joint arthrodesis procedures to achieve correction and long-term stability.

**GREAT TOE FIBULAR ARTERY FLAP: SURGICAL TECHNIQUE**

Once the recipient wound has been extensively débrided and appropriate cultures have been taken, the lateral aspect of the great toe is identified and marked over the vascular pedicle flap that is determined by a Doppler device. The use of a tourniquet has been used safely for better visualizing the pedicle flap and speeding the operative procedure. A large portion of a full-thickness skin can be raised from the lateral aspect of the great toe, including the pedicle, adipofascial, and/or periosteum structures. A skin incision is then performed to communicate the recipient wound bed and donor site. The authors rarely isolate the very delicate lateral plantar digital neurovascular bundle and place the pedicle without any tension into the first web space. It is essential that hemostasis has been achieved throughout the procedure and before the adipofascial-cutaneous flap is rotated into the wound and sutured to the deep tissues with simple interrupted nonabsorbable sutures. The donor defect is closed primarily or covered with a split-thickness skin graft or other skin graft substitutes. A lateral toe exostectomy can be performed also to facilitate wound closure at the donor defect (Fig. 14.1).

**MEDIAL PLANTAR ARTERY FLAP: SURGICAL TECHNIQUE**

The first step in performing a medial plantar artery flap is to adequately excise the previous ulcer. The tourniquet is not used initially during ulcer excision. The ulcer should be excised in a triangular fashion with its base positioned laterally. Excision of the ulcer is full thickness, including any granulation tissue and underlying adipose tissue that may be present. At this point the wound is irrigated with normal saline via bulb syringe or pulsed lavage technique. After the wound is adequately irrigated and hemostasis is achieved, the outer edges of the operative team are changed, and any previously used instrumentation is removed from the operative field, eliminating any form of cross-contamination. This technique to avoid contamination by changing the outer edges and instrumentation is employed by the authors for all types of pedicle flaps that need to be performed. A hand-held Doppler is then used on the field to mark out the course of the medial plantar artery. After this is performed, the incision is then marked out, keeping in mind that flaps raised from the instep of the foot are supplied by two vessels: (a) the collateral flow from the dorsalis pedis, and (b) perforators of the superficial branch of the medial plantar artery. When the medial plantar artery flap is raised with a medially based peninsula (i.e., skin island), both angiosomes are preserved. If the medial plantar artery flap is designed as an island to increase mobility of the flap, the blood supply is solely from the medial plantar artery. It is important when marking out the skin incision for the medial plantar artery flap to (a) create as large of a radius as possible; (b) maintain the medial skin island if possible; and (c) avoid placing the incision over the weight-bearing aspect of the metatarsal heads.

The tourniquet can then be elevated prior to dissection, but is not required. Dissection under loupe magnification begins laterally at the apex of the flap. The flap can either contain the plantar fascia or be raised just above the plantar fascia. Gentle retraction and minimal handling of the soft tissue edges with atraumatic forceps is especially important. Dissection begins laterally and proceeds distally toward the metatarsal heads. This establishes the correct depth of the pedicle flap with no undermining. Dissection is then carried medially toward the medial plantar artery so that it is identified and isolated. Blunt dissection using the index finger is an excellent technique to separate any tethering ligaments of plantar fascial bands while preserving any superficial perforators that are supplying the pedicle. After the medial plantar artery and nerve are identified and isolated, the flap is covered with a saline-soaked gauze and retraction is maintained with a couple of simple sutures through the lateral edge of the flap. The dissection required for raising a medial plantar artery flap offers the surgeon a direct approach from the plantar aspect of the foot to address any underlying osseous deformities for an exostectomy or arthrodesis if needed. After osseous reconstruction is performed, the tourniquet if elevated is released and hemostasis is achieved. Adequate hemostasis and assurance of flap viability at this point is essential and cannot be overlooked. The flap is assessed for the next 5 to 10 minutes to ensure good tissue perfusion while the tourniquet is released. After release of the tourniquet, it can take 3 to 5 minutes before tissue perfusion is evident. If tissue perfusion is not adequate after 10 minutes, a strong consideration should be made to “delay” the flap for 5 to 7 days. Insetting the flap is performed with minimal deep sutures to prevent necrosis of the wound edges. A 2-0 or 3-0 nonabsorbable monofilament suture and/or skin staples are then used to inset the flap. At no point should tension be placed on the pedicle components or the skin edges. If any signs of tissue ischemia occur while suturing, then the sutures are removed and replaced after reassurance that the flap is well perfused. The donor site is then covered with a split-thickness skin graft and a bolster dressing is applied in a typical fashion (Fig. 14.2).

**REVERSE FLOW SURAL ARTERY NEUROFASCIOCUTANEOUS FLAP: SURGICAL TECHNIQUE**

The reverse flow sural artery neurofasciocutaneous flap is a very useful distant pedicle flap for soft tissue coverage of various size
defects around the heel, ankle, and lower leg. The flap can be raised as large as $12 \times 15$ cm, offering soft tissue coverage to areas that previously needed free tissue transfer with microvascular anastomosis. As in preparation for the medial plantar artery flap, the first step is to adequately excise the previous ulcer or wound without a tourniquet. Not using a tourniquet at this point allows the surgeon the ability to debride the recipient bed to viable bleeding tissue while decreasing overall tourniquet time. The shape of the defect around the heel, ankle, and lower leg can range from circular, ellipse, square, rectangular, or diamond. After the wound or ulcer at the recipient site is adequately excised, debrided, irrigated, and hemostasis is achieved, the surgeon then uses the sterile paper wrapping from the surgical gloves to trace out the defect with a surgical marker.

(text continues on page 185)
Figure 14.2  A. Intraoperative picture showing the medial plantar artery design, excision of ulcer in a triangular fashion, and direct approach of the lateral column arthrodesis. Intraoperative picture showing the neurovascular pedicle flap dissection (B), followed by joint preparation (C), and application of allogenic bone grafting at the lateral column arthrodesis site (D).  (continued)
Figure 14.2  (Continued) Closure of the pedicle flap (E), and application of a bioengineered alternative tissue at the donor site (F). Picture of the donor site and stent composed of a nonadherent dressing and sterile sponges soaked in saline and application of a circular external fixation for the lateral column arthrodesis site (G). Four weeks postoperative picture of the stent removal and circular external fixation of the skeletal reconstruction (H). (continued)
Figure 14.2  (Continued) Followed by moist to dry dressings at the donor site (I) and postoperative circular fixation dressings (J). Intraoperative picture 10 weeks postoperatively after external fixation removal and application of split-thickness skin grafting (K), and final clinical picture 14 weeks since the initial surgery (L).
With the surgical marker the distal peroneal perforating artery is marked on the distal posterolateral lower leg and with the assistance of a hand-held Doppler. The location of the distal perforating artery is approximately 5 to 6 cm from the distal tip of the fibula. The wound defect previously traced on the paper is cut out and retracted onto the proximal posterolateral aspect of the leg. The authors also try to incorporate the mapping of the lesser saphenous vein, which was performed preoperatively within the midline of the dissected flap. A cutaneous tail or extension over the pedicle can be used, and has been shown to decrease complications resulting from tension over the pedicle components (7,11). In addition, the authors design the flap further from the popliteal crease, ensuring that the pedicle components are contained in their entirety throughout the flap and allowing for harvest of a split-thickness skin graft just superior to the donor site. A "Z" incision with each arm of equal length is marked from the pedicle flap over the distal perforating peroneal artery to the recipient site. The authors feel that incision placement is paramount to successful dissection of the pedicle components and should not be overlooked at the start of the procedure. Meticulous dissection under loupe magnification begins midline at the most superior aspect of the outlined flap. Starting in this direction, it permits direct visualization of the pedicle components at the start of the surgical dissection while allowing the width of the flap to be altered if necessary to ensure that the pedicle components lie central to the flap.

After the incision is made, blunt dissection with minimal handling of the flap edge is carried down to the fascia overlying the gastrocnemius muscle belly. It is important to avoid undermining of the flap, as this will result in flap necrosis postoperatively. After identification of the medial sural nerve, median superficial sural artery, and lesser saphenous vein, each is ligated with two closely placed medium-size hemoclips as superiorly as possible. The pedicle components superiorly are then isolated after being transected between the junction of the closely placed hemoclips. At this point, a pocket is then created with blunt dissection deep to the pedicle components and superficial to the fascia overlying the gastrocnemius muscle. Dissection is then directed over the "Z" incision to identify and isolate the pedicle components inferiorly. After isolation of the pedicle components, dissection of the medial and lateral aspect of the flap is performed, completing the harvest of the reverse flow sural artery neurofasciocutaneous flap. The tourniquet if used is released and the flap is assessed for perfusion over the next 5 to 10 minutes. If there is question of flap viability, then a "delay" procedure is performed over the next 5 to 7 days (12). The flap is inset into the recipient site and the closure is typically obtained with simple sutures that are placed full thickness using a 2-0 or 3-0 nonabsorbable monofilament suture or skin staples. However, deep absorbable sutures may be needed if there is a loss of the surrounding tissues that will need a split-thickness skin graft. The "Z" incision and donor site of the reverse flow sural artery neurofasciocutaneous flap, if <5 cm, can be closed primarily. If the donor site of the pedicle flap is >5 cm, soft tissue coverage is obtained with a meshed split-thickness skin graft harvested just inferior to the popliteal crease and superior to the donor site of the pedicle flap. The donor site can also be reduced in size prior to split-thickness skin grafting by applying deep buried sutures at the periphery of the wound edges and underlying muscle belly. This technique reduces the depth of the surgical wound and permits better contouring of the split-thickness skin graft. Finally, flow through the pedicle can be confirmed with a hand-held Doppler, but the color of the flap is more revealing as to the successful outcome of insetting of the flap (Fig. 14.3).

**OFFLOADING EXTERNAL FIXATION AND SURGICAL TECHNIQUE**

Offloading a pedicle flap while allowing for minimal weight-bearing across the affected extremity is a critical part to the overall success of the flap procedure. Offloading pedicle flaps to the foot and ankle region is notoriously difficult and numerous techniques have been documented in the literature (7,11). Postoperative techniques used to limit pressure over pedicle flaps and donor sites have included awkward positions in bed until fully healed, use of pillows, and use of posterior splints and casting modifications. The authors do not recommend casting techniques because they do not allow easy access to the pedicle flap and donor site for observation and management in the critical portion of the postoperative period. In addition, cast applications require frequent changes to prevent skin breakdown, which can be time consuming and painful for the patient. Furthermore, none of these techniques provides complete pressure relief, stable immobilization, elevation, and proper positioning of the foot and ankle, and do not offer the ability of direct visualization of the flap and donor site throughout the postoperative course.

External fixation to offload pedicle flaps of the foot and ankle allows for quick and repeated evaluation of the flap while maintaining the alignment of the foot and leg to prevent "kinking" of the pedicle components. Several publications have described the use of various external fixation devices to immobilize the foot and ankle and offload compromised areas of the foot, ankle, and/or leg (7,11). Commonly used for ease of application is a hybrid "kickstand" external fixator to provide immobilization, complete pressure relief, elevation of the lower limb, and the ability to observe repeatedly the flap while allowing for easy dressing changes (13). This external frame is very useful in patients who do not require concomitant osseous procedures, are not obese, or do not require any weight-bearing across the involved extremity. The device can be constructed with a circular ring and two to three smooth wires 45 degrees to each other in the anatomic safe zones of the lower leg. The ring is then secured to either a threaded Steinman pin or transfusion pin in the calcaneus. The apparatus is then elevated from the bed with a simple bar to clamp configuration or an additional circular ring. An additional threaded Steinman pin can be placed safely in the midfoot, allowing control of the foot position and enhancement further stability. Construct of this device is very simplistic and can be applied within minimal operative time (Stryker Orthopaedics, Mahwah, NJ) (Fig. 14.4).

The authors have also used the stacked Taylor Spatial Frame foot plate technique in larger individuals where osseous procedures or deformity correction needed to be performed across the lower extremity (Smith and Nephew Orthopaedics, Memphis, TN) (Fig. 14.3). Two to three Taylor Spatial foot plates of the same size are connected to each other with threaded connecting rods and secured with threaded nuts. The flat surface of the foot plate offers the advantage of eliminating rotational forces that occur with a typical circular ring. Another advantage is that osseous procedures can be performed easily if needed at the (text continues on page 191)
Figure 14.3  Intraoperative pictures showing severe degloving injury (A–C), followed by the application of a negative pressure therapy (D), and after serial débridements (E,F). (continued)
Figure 14.3  (Continued) Intraoperative appearance of the foot after 6 weeks of negative pressure therapy. Marking of the donor site on the posterolateral aspect of the leg (G), followed by careful dissection of the neurovascular pedicle, and most distal peroneal perforator (H). Insetting of the pedicle flap on the recipient site (I), followed by releasing the tourniquet and reapproximating the donor site with deep sutures (J).

(continued)
Figure 14.3  (Continued) Immediate postoperative pictures showing the stacked Taylor spatial foot plate offloading external fixation system and split-thickness skin grafting to the donor and non-weight-bearing surfaces followed by our preferred stenting technique (K,L). Final clinical pictures of the healed lower extremity 13 weeks after the initial surgery and proper offloading techniques (M–O).
Figure 14.4  A. Intraoperative picture showing the marking of the donor site as well as the lesser saphenous vein mapping performed preoperatively at the vascular lab. Careful pedicle dissection starting proximally (B), rotated (C), and placed into the defect heel area (D). E. Note that the tourniquet is then released and split-thickness skin graft is applied over the donor as well as over the pedicle sites if necessary to minimize skin tension. F–H. Offloading hybrid external fixation device consisted of a combination of threaded pins and transosseous wires for daily visualization of the pedicle flap. I. Final clinical outcome at 10 months follow-up. (continued)
Figure 14.4 (Continued)
intervals between the foot plates, which can be modified later to either compress or distract if needed. Although the system can be visualized as very bulky and intimidating, it is fairly light because the foot plates are made of high-grade aluminum. The frame is applied after transposition and insettting of the pedicle flap. The frame can be applied while the patient is in a supine or prone position, eliminating movement and inadvertent damage to the pedicle components that can take place when a patient is repositioned. The authors typically use crossed smooth wires in the location of the foot, ankle, and lower leg anatomic safe zones and while the foot and leg are appropriately positioned. Positioning of the lower extremity is paramount and care needs to be taken as to the amount of tension applied to the pedicle components. For example, the foot should be held in a slight plantarflexed position when performing a reverse flow sural artery neurofasciocutaneous flap in order to reduce the length in which the pedicle components have to be stretched. The use of the Taylor spatial rings and foot plates allow for the easy substitution of threaded rods for Taylor spatial struts to correct any residual deformity. Once completed, the limb remains suspended within the external fixation system allowing complete offloading, immobilization, limb positioning, elevation, minimal weight-bearing if needed, concomitant osseous procedures, and adequate access for flap observation and other necessary local wound care modalities that may need to be performed.

**POSTOPERATIVE MANAGEMENT**

Initially, soft dressings are avoided over the pedicle flap. This allows the flap to be easily inspected without unwanted motion and discomfort to the patient. The patient is typically admitted to the hospital for 5 to 7 days for close observation and frequent vascular checks. Surgical drapes if used are typically removed after 24 to 48 hours. The patient is instructed on elevation of the extremity and strict bed rest for the first 24 to 48 hours. During this period deep vein thrombosis prophylaxis with compression stockings on the contralateral extremity is enforced along with pharmacological therapy as directed by the medical team.

The pedicle flap is inspected every 2 to 4 hours for the first 24 hours, and then every 4 to 6 hours for the next 48 hours. It is important to educate the ancillary staff on signs of pedicle flap ischemia and venous congestion. Venous congestion is a commonly seen postoperative complication. Any signs of venous engorgement or congestion mandate immediate application of medicinal leeches. For this reason, medicinal leeches should be readily available in the hospital for application.

Patients undergoing leech therapy should be administered a broad-spectrum antibiotic such as an aminoglycoside or third-generation cephalosporin to prevent infection by *Aeromonas hydrophilia*, which is a symbiotic bacterium that inhabits leech intestines. Caution should be used in immunocompromised patients. Infection caused by *Aeromonas hydrophilia* can be devastating, resulting in extensive soft tissue loss and sepsis. For this reason prophylactic antibiotics with gram-negative coverage are recommended at the time of leech application.

Leeches are typically applied to the pedicle flap after pie crusting of the area is performed to allow bleeding for the leech to attach. A basin filled with alcohol is typically applied below the leeches to collect them after being detached from the operative site. The typical feeding time for a leech is 15 to 20 minutes. Application of the leeches can be applied up to every 6 hours for up to 7 days. Leeches may draw up to 50 mL of blood per feeding. Repeated leeching may decrease hemoglobin levels dramatically. For this reason, the hemoglobin and hematocrit need to be checked routinely while applying leeches.

Physical therapy is instituted 48 to 72 hours after surgery to instruct the patient on proper technique for transfers and non-weight-bearing gait with crutches or a walker. Often, the diabetic patient with peripheral neuropathy needs additional bracing or specific shoe gear on the contralateral extremity during this postoperative period to prevent further diabetic foot complications.

The removal of skin sutures and staples may be delayed until 6 to 8 weeks or longer after surgery if needed. The stent dressing applied to a split-thickness skin graft at the pedicle flap donor site is typically removed 4 to 6 weeks after surgery. It is not uncommon, to see small areas of wound dehiscence. In these cases, the authors typically deal with the wound dehiscence if there are no signs of infection at the time of external fixation removal, which is usually 6 to 8 weeks postoperatively but can be as long as 12 to 16 weeks, depending on the concomitant osseous procedures that were performed. Most frequently, the authors perform any ancillary procedures at the time of external fixation removal. These procedures might include removing any remaining sutures, staples, stents, or debridement of any calcareous wound dehiscence and proceed with primary closure, and additional split-thickness skin grafting or randomized local flap closure. This is a very important step in the proper management of a common surgical complication, and needs to be addressed for the overall patient's successful outcome. After external fixation removal, the authors typically apply a below the knee cast with non-weight-bearing for an additional 4 to 6 weeks. Cast changes are performed every 2 weeks to prevent skin irritation and ulceration. The patient is then slowly advanced into a walking boot device with partial to full weight-bearing activities. The patient is typically seen by a certified pedorthist 4 to 6 months postoperatively after complete healing has occurred to begin appropriate bracing, orthosis, and/or custom shoe modification. Finally, the patient is then followed to the surgeon's outpatient clinic every 3 to 4 months for the first year and every 6 months following the first year unless problems arise sooner.

**COMPLICATIONS**

Most common complications associated with the usage of pedicle flaps include delayed healing, wound dehiscence, flap necrosis, and late skin breakdown. Delayed wound healing is commonly seen with scant amounts of noninfected serous drainage at the wound edges, indicating that a longer healing time will be needed. Frequently, local wound care consisting of silver products and dry dressing may be needed along with a few additional sutures to prevent further wound dehiscence. Preventing the risk of postoperative complications usually starts in the operating room by a meticulous handling of the soft tissues and avoidance of undermining the skin edges. The patient should be closely observed postoperatively and suture removal may be delayed until good coaptation and healing of the wound edges are evident.

If wound dehiscence develops, it can be the result of skin tension, edema, inadequate vascularity, and/or infection. The diabetic patient should be placed on empirical antibiotics to prevent secondary infection. Nontiable tissue is debrided and
local wound care is instituted. At times, local wound care is not sufficient and the patient may require negative pressure therapy after serial débridements along with the use of adjunctive hyperbaric oxygen therapy. Negative pressure therapy promotes granulation tissue and eliminates further surgical drainage. Deep intraoperative tissue cultures should be obtained and antibiotics need to be adjusted accordingly. Clinical swab cultures should be avoided as they are misleading and have no clinical relevance. Definitive closure can be obtained through healing by secondary intention or with the application of a split thickness skin graft if the area permits.

Flap necrosis is another common complication associated with local and distant pedicle flaps. Flap necrosis is usually the result of a venous congestion, but can also be associated with arterial insufficiency to the flap. The presence of flap necrosis does not imply complete surgical failure and major limb loss. In the presence of partial flap necrosis the area can be precisely débrided by using different modalities of hydrosurgery. This surgical technique offers the advantage of meticulous soft tissue excision while avoiding further trauma to the surrounding wound margins. Often, the adipofascial component of the pedicle flap is viable and this offers durable soft tissue coverage if a split thickness skin graft needs to be reapplied. In rare circumstances, the entire pedicle flap can become necrotic. In these situations, it is best to excise the entire pedicle flap, adequately débride the area to prevent infection, and consider further negative pressure therapy followed by skin grafting or free flap coverage versus major limb amputation as a salvage option.

Late skin breakdown of a pedicle flap can be the result of poor-fitting shoe gear or an underlying skeletal deformity. It is important for the clinician to inspect the fitting of orthosis, braces, and shoe gear to determine if this is the causative factor. In addition, radiographs should be obtained to evaluate for any underlying skeletal deformity that can account for the ulcerative lesion. Furthermore, it is important to discuss with the patient changes in their daily activities that may have preceded the skin breakdown. Regardless of the cause, it is best to offload the area as soon as possible through a total contact casting or other available offloading devices. Delay in offloading with the presumption that the skin breakdown is minor will result in more extensive skin breakdown and further complications. If an underlying osseous deformity is the causative factor, then revisional surgery may be warranted to prevent skin reulceration and flap failure.

CONCLUSION

In this chapter, the authors have described the most common pedicle flaps performed for soft tissue coverage of the diabetic foot. It is important to note that these plastic surgery techniques require a vast knowledge and experience and the participation of all medical and surgical disciplines with an interest in the management of the diabetic foot and lower extremity.

REFERENCES

INTRODUCTION

Gangrenous wounds of the leg and foot are common expressions of arterial insufficiency. In diabetic patients, these lesions frequently become infected with subsequent exposure of critical structures. The wounds frequently require operative débridement, leaving wounds that are large and expose vital structures. Because of arterial insufficiency local flaps may not be large enough, and/or may be unreliable even if the extremity is revascularized, essentially placing the involved limb at risk for subsequent amputation. It has been well demonstrated that the diabetic population with lower extremity wounds has a higher rate of lower extremity amputation when compared with the normal population.

Lower extremity amputation carries significant postoperative morbidity, and societal costs associated with this procedure are not necessarily less when comparing amputation versus limb salvage (1,2). It is well known that soon after lower extremity amputation in diabetic patients, the contralateral limb may be threatened with the same fate (3,4). These patients are less likely to ambulate (5), and overall postamputation mortality is higher in this group of patients than in nondiabetics (6). With an amputation the patient’s oxygen requirement is increased. As a group, diabetic patients with multiple comorbidities are ill equipped to tolerate the increased physical demands that come with one amputation, and are even less able to tolerate bilateral amputations. Thus, all reasonable efforts should be made to salvage the leg.

Revascularization may be required to bring in a new blood supply and accomplish limb salvage (7). Because of the size of some wounds, even with adequate arterial inflow they may not heal without some type of soft tissue procedure, and the extremity may still be at risk for amputation. Until the 1980s, reconstruction of large foot wounds in diabetics was uncommon. Free tissue transfer can cover vital structures, achieve wound closure of large defects, and bring in a reliable source of vascularized tissue that introduces antibiotics and immune cells that can combat infection. A multidisciplinary team approach is required to perform these procedures and maximize the chance for a successful outcome in the diabetic patient with peripheral vascular disease.

That team should include a podiatrist, orthopedist, or plastic surgeon with an interest in foot and ankle conditions, at least one internist who is capable of managing a patient with multisystemic diseases, a vascular surgeon, a microsurgeon with experience in free tissue transfer in the diabetic population, and a physiatrist.

This chapter reviews the indications, contraindications, preoperative planning, some of the surgical techniques that will maximize the chance for a successful outcome, as well as postoperative monitoring.

FREE TISSUE TRANSFER IN THE DIABETIC PATIENT

Free tissue transfer is a commonly performed procedure that has been demonstrated to have a high rate of success (8,9). However, the success rate decreases and morbidity increases in diabetic patients (10,11).

Free tissue transfer is technically difficult and requires specialized training on the part of the operating surgeon for selection of appropriate surgical candidates and the technical execution of the operation. Also needed are nursing staff who have specialized training in the postoperative monitoring of the flap and clinical evaluation of the patient. Because free tissue transfer is physiologically taxing for the patient, and diabetic patients with lower extremity wounds frequently have multiple systemic illnesses (including coronary artery disease, renal insufficiency, and peripheral vascular disease), close postoperative monitoring should not be overlooked. These patients are at risk for significant postoperative complications exclusive of operative failure.

Specialized imaging for radiographs and equipment (e.g., an operating binocular microscope that permits two surgeons to work simultaneously, microscopic instruments and sutures for the operation, and postoperative monitoring) are required. Although not necessary, these procedures ideally should be performed at a tertiary referral center that has access to appropriately trained staff, consultants, equipment, and resources for the required successful outcome of the procedure and safety of the patient.
FREE TISSUE TRANSFER

A thorough history and physical examination is crucial to exclude patients who are not candidates for both medical and surgical reasons. A suggested format for evaluation is provided in Table 15.1. This format provides information on the etiology of the wound, its progression, and any interventions that have been performed up to the time of consultation. The medical and surgical history alerts the reconstructive surgeon to the possible need for additional consultants and possibly eliminates patients who do not have the physiological reserve to undergo an operative procedure that may lead to their demise (4). Additionally, the surgical history provides insight into any postoperative complications that may have been experienced by the patient as well as the donor flaps that may be available. Finally, the psychiatric history may exclude patients who are unable to adhere to strict postoperative instructions.

The physical examination provides information about potential donor flaps. Examination of the lower extremity may alter the choice of flap. Very large wounds may prevent the use of a forearm flap, whereas the converse may sway the choice toward a forearm flap. Furthermore, the presence or absence of lower extremity palpable pulses or Doppler signals may dictate the need for vascular studies, whether invasive or noninvasive studies are required, and whether radiographic studies are needed to eliminate the possibility of osteomyelitis. Given that diabetic patients may have calcified vessels, ankle brachial measurements are inaccurate and pulse volume recordings may provide information about arterial inflow in these patients. The input of a vascular and/or endovascular surgeon is invaluable in patients who have questionable or poor arterial inflow. Good communication with the vascular surgery team is important if arterial reconstruction is required, because the conduit may serve as the arterial inflow for a free flap.

Once the decision is made to proceed with free tissue transfer, the wound should be appropriately prepared. This may require serial débridements of the wound and appropriate cultures if the wound is infected. Antibiotic therapy should be modified based on culture sensitivities and/or bone biopsies. The patient’s medical comorbidities should be maximized to decrease the possibility of intraoperative and postoperative complications.

TECHNICAL ASPECTS OF THE FREE TISSUE PROCEDURE

Before beginning the operative procedure, we ask the anesthesiologist to avoid pressors if possible during the procedure because this could cause arterial constriction. If using a rectus flap, we ask the anesthesiologist to avoid nitrous oxide because...
this may cause distention of the intestines and may make abdominal wall closure more difficult.

Unfortunately, diabetic patients frequently have peripheral vascular disease with poor arterial inflow. Thus, a working relationship with a vascular surgeon may be required to provide inflow into the leg. This conduit can serve as the arterial source for the free flap or can revascularize the leg so that another vessel can be used to provide arterial inflow to the flap. Technically, the former is easier to sew to in view of the fact that the graft is unlikely to be calcified, as the patient’s native leg arteries are likely to be.

When performing free tissue transfer, a multi-team approach is ideal if feasible. This decreases operative times, costs, and surgeon fatigue. While the recipient site is prepared either for arterial bypass (if necessary), the vessels are exposed and the wound is appropriately débrided. To facilitate vascular anastomosis when possible, a noncalcified soft spot in the arterial recipient site should be chosen. Any arterial branches that may serve as arterial inflow for the flap should be preserved; this may permit an end-to-end anastomosis for the flap’s artery, which some surgeons may find easier; otherwise an end-to-side anastomosis between the flap and the donor artery will be required.

To minimize a size discrepancy between the flap and the native venous system, the deep venous system, venae comitantes, can be used for outflow, and an end-to-end anastomosis can be performed (instead of the greater saphenous vein, which is typically larger than the flap’s vein). Otherwise, the greater or lesser saphenous system can be used for drainage of the flap. If the decision is made that arterial reconstruction is not required, although the local environment is hostile for arterial inflow, the greater or lesser saphenous system can be used for drainage of the flap. If the decision is made that arterial reconstruction is not required or feasible, although the local environment is hostile for arterial inflow for the free flap, but attempts will be made for free tissue transfer, arterial inflow may be facilitated by using an in situ vein graft connecting proximally into an artery. Doing this minimizes the size discrepancy between the arterial inflow vessel and the flap’s artery.

Once the donor artery is dissected out, an arteriotomy should be performed to ensure pulsatile flow. If there is no pulsatile flow, then efforts should be made to correct the cause for this or find an alternative inflow vessel with pulsatile flow.

If using a donor artery with a calcified wall, then the surgeon should try to find a “soft spot” for anastomosis. If none is available, then the surgeon should use a suture needle that is able to pass through the calcified vessel wall. When passing the needle a concerted effort should be made to tack up the intimal wall; this can be done by passing the needle from inside the calcified lumen to the adventitial surface of the vessel.

**CHOICE OF DONOR FLAPS**

Because of peripheral vascular disease, choosing lower extremity donor flaps may not be prudent, as the donor vessels may be calcified (12), and inflicting a wound on an extremity with already compromised circulation may cause wound healing problems.

Donor flaps that fulfill the above criteria include the radial forearm flap, rectus abdominis muscle flap, and latissimus dorsi muscle flap (Table 15.2). The choice of the flap may be altered by the contour of the recipient site; for wounds with irregular contours muscle flaps may be easier to inset and occlude any dead space. When placing a flap around the area of the foot in contact with footwear, fasciocutaneous flaps, and in particular the radial forearm, are good choices, because it has the tendency to be less bulky. The other fasciocutaneous flaps frequently are bulky and difficult to appropriately contour, especially in overweight patients. However, although muscle flaps are initially bulky, they atrophy with time; and debulking can be performed in the future if necessary.

Although microsurgeons are adept at working with vessels as small as 1 mm, microvascular surgery should be made as macrovascular as possible under the microscope. This means choosing flaps that have large-diameter vessels and a long pedicle. The longer the pedicle, the easier it will be to work out of the zone of inflammation at the recipient site, and the larger the diameter of the flap’s vessels, the easier it will be to work with the vessels.

| Table 15.2 The Pros and Cons of Commonly Used Flaps for Free Tissue Transfer |
|---------------------------------|-----------------|-----------------|
| Flap               | Pros                    | Cons                      |
| Latissimus dorsi     | Largest muscle           | Positioning may be issue    |
|                     | Long pedicle             | Seroma formation           |
|                     | Large pedicle            | Possible contour problem   |
|                     | Two-team approach        |                             |
| Serratus anterior    | Very long pedicle        | Positioning maybe issue    |
|                     | Large pedicle            |                             |
|                     | Two-team approach        |                             |
| Rectus abdominis     | Large muscle             | May cause respiratory splinting |
|                     | Two-team approach        |                             |
| Radial forearm       | Long pedicle             | Sacrifice major artery of hand |
|                     | Large pedicle            | Donor site cosmesis         |
|                     | Two-team approach        | Requires skin graft for donor site |

The artery of each of these flaps is typically free of atherosclerosis, the anatomy is reliable, and the flaps are relatively easy to harvest.
RADIAL FOREARM FLAP (SEE CASE 1 AND RESPECTIVE IMAGES)

The radial forearm flap is a fasciocutaneous flap based on the radial artery. In the distal forearm the radial artery lies in the subcutaneous tissue, whereas it can be found between the flexor carpi radialis and brachioradialis in the proximal forearm. The artery gives off branches to the overlying fascia and skin of the volar forearm from the area distal to the antecubital fossa to the wrist. Its use is ideally suited for lower extremity coverage requiring thin fasciocutaneous tissue, such as the dorsal surface of the foot.

The patient who will undergo free radial forearm flap ideally should have no vascular diseases of the upper extremity. At minimum an Allen test should be performed and documented, which can be done by using a hand-held Doppler in the palm or finger pulp while auscultating distal to the occluded radial artery. Signals heard distal to the occlusion suggest adequate circulation based on the ulnar artery.

Surgical Technique

The skin paddle of the radial forearm flap is usually designed on the distal volar forearm, with the proximal forearm used for the pedicle. Planning this way allows a larger flap with a longer and larger diameter pedicle. A template of the defect is made and placed distally along the distal volar forearm (Fig. 15.1A,B). A Doppler is used to mark out the course of the radial artery as it takes off from the brachial artery. A sterile tourniquet is placed over the proximal arm, the forearm is exsanguinated, and the tourniquet is inflated. The margins of the flap are incised down to the subcutaneous tissue and through the fascia. Flap elevation starts from the ulnar side of the flap where the fascia is thicker and easily defined. It is important to preserve the paratenon on the tendons. Dissection is in the subfascial plane, then proceeds radially, where the radial artery and its septum can be found between the tendons of the flexor carpi radialis and brachioradialis (Fig. 15.1C,D). At this point the dissection then proceeds from radial to ulnar toward the septum. The tourniquet is then deflated and the distal radial artery is occluded with a temporary atraumatic vascular clamp to ensure adequate perfusion of the hand based via the ulnar artery. A sterile hand-held Doppler is then used to confirm perfusion of the hand, and the hand is examined for clinical evidence of adequate circulation. The distal artery and venae comitantes are ligated distally, and proximal dissection takes place toward the brachial artery. Once the brachial artery is identified, the dissection is completed; ligation of the artery needs to be distal to the brachial artery. When the recipient site is ready for the flap, the radial artery is ligated distal to the brachial artery. The donor site is closed primarily or skin grafted as needed.

Figure 15.1 Case 1. A. A skin defect after débridement with exposure of bone. B. A template of defect transposed onto the forearm. The course of the radial artery was marked out with a Doppler and corresponds to the straight line. C. The local anatomic relationship of the radial forearm flap. Note the radial artery between the brachioradialis and flexor carpi radialis tendons. (Note that this is a different patient.) D. The flap after being elevated with brachioradialis, flexor carpi radialis tendons exposed, and pedicle surrounded with vessel loops. (Note that this is a different patient.) (continued)
has two sources of blood supply. For the microsurgeon, the thoracodorsal artery and vein are the vessels of interest. Because it is the largest muscle in the body, it is ideally suited for large wounds and those that require occlusion of dead space. It is also a flap that has a long and large diameter pedicle. Given that the pedicle of the flap or the flap itself may be compromised, caution is warranted in patients who have undergone axillary node dissection or patients who have had a thoracotomy, respectively.

This flap is elevated with the patient in the lateral decubitus position or a modification of this positioning (Fig. 15.2). When placing the patient in this position it is important to pad all pressure points. Use of a bean bag during flap elevation can facilitate the procedure (Fig. 15.2A,B).

In addition to the obvious vascular pitfalls during elevation of the flap, the surgeon should be careful with the superficial branch of the radial nerve, which runs with the artery, and removing the paratenon of the tendons. (If this is removed, skin grafting the donor site will be a problem.) Exposure of the tendons can be treated by local wound care using topical antibiotics until healing.

LATISSIMUS DORSI FLAP (SEE CASE 2 AND RESPECTIVE IMAGES)

The latissimus dorsi muscle can be raised as free muscle or musculocutaneous flap. The skin paddle is not frequently used for the lower extremity because it is bulky. This muscle has two sources of blood supply. For the microsurgeon, the thoracodorsal artery and vein are the vessels of interest. Because it is the largest muscle in the body, it is ideally suited for large wounds and those that require occlusion of dead space. It is also a flap that has a long and large diameter pedicle. Given that the pedicle of the flap or the flap itself may be compromised, caution is warranted in patients who have undergone axillary node dissection or patients who have had a thoracotomy, respectively.

This flap is elevated with the patient in the lateral decubitus position or a modification of this positioning (Fig. 15.2). When placing the patient in this position it is important to pad all pressure points. Use of a bean bag during flap elevation can facilitate the procedure (Fig. 15.2A,B).
Figure 15.2 Case 2. A. This patient underwent cancer excision with subsequent radiation therapy, hyperbaric treatment, local wound care, and recumbency for 1 year before referral to us. B. The patient is placed on a bean bag in the lateral decubitus position with padding, axillary roll, and use of a bean bag to hold the position. Note the marked out incision extending into the axilla. C. Note the longitudinal incision used for quick elevation of the flap. The superficial surface of the flap is demonstrated. The head is at the top, the sacrum is inferior, and the arm is to the right of the image. D. The latissimus muscle has been elevated and is only attached by its insertion into the humerus, and its pedicle. E. The latissimus flap is attached only by the pedicle. The head is cephalad, the spine is to the left of the image, and the arm is to the right of the image. When the recipient site was ready, the pedicle was ligated distal to the axillary artery. F. A free latissimus dorsi muscle flap with skin graft. Note that the fibula hardware is covered by the flap. G. The patient was ambulating 2 months after surgery with a healed wound.


**Detailed Surgical Technique**

Although this flap can be elevated with either a horizontal versus vertical incision, efficiency is important when raising this flap in a patient with multiple medical problems; thus, the longitudinal incision provides the quickest approach. This incision is placed parallel to the muscle edge, but 2 cm posterior to the axillary border of the muscle. As one approaches the axilla, the incision curves toward the location of the presumed pedicle without violation of the axilla (Fig. 15.2B).

After making the incision through the various layers of skin, the superficial layer of the muscle is identified (Fig. 15.2C), the surgeon must then make a decision about how large of a muscle flap to use. We try to limit the medial extent of the dissection to the lateral aspect of the paravertebral perforators; doing such preserves circulation to the overlying skin and prevents inadvertent intrathoracic retraction of a bleeding vessel. Once the muscle is exposed, the muscle is incised distally and is elevated from lateral to medial. This helps to minimize inadvertent elevation of the serratus anterior muscle (Fig. 15.2D). As one approaches the axilla, there is a fat pocket on the undersurface where the thoracodorsal vessels can be found; this should be dissected out toward the axilla where the branch to the serratus muscle is found. As one proceeds further proximally, one finds the circumflex scapular branch (Fig. 15.2E).

Both of these branches must be ligated. Dissection then proceeds to the axillary vessels. When the recipient site is ready for the flap, ligation of the thoracodorsal vessels is performed distal to the axillary vessels. Two large closed suction drains are placed in the donor site to help minimize seroma formation. The donor site is closed primarily and the muscle flap is typically covered with a skin graft.

Pitfalls during elevation of this flap include elevation of the serratus anterior muscle and seroma formation. The serratus can be reattached if it is elevated. Seroma formation can be treated by aspiration; occasionally serial aspiration is required. If this is unsuccessful, sclerosing agents can be injected into the seroma cavity; and if this is unsuccessful cavity seroma removal may be required.

**RECTUS ABDOMINIS FLAP (SEE CASE 3 AND RESPECTIVE IMAGES)**

The rectus abdominis flap can be raised as a free muscle or musculocutaneous flap; for the lower extremity the skin paddle is usually not incorporated for lower extremity reconstruction. It is supplied by the ascending branch of the deep inferior epigastric artery, which courses laterally to medial to lie between the peritoneum and the rectus muscle (Fig. 15.3C). The vascular pedicle is dissected to its origin from the external iliac artery. The extent of the required muscle flap is exposed and then the proximal belly of the muscle is transected and the muscle is elevated from proximal to distal, where it is taken off of the pubic tubercle (Fig. 15.3C). When the recipient site is ready for the microanastomosis, the deep inferior epigastric vessels are divided. One or two large closed suction drains are used to help minimize seroma formation at the donor site. The donor defect is closed primarily; the rectus sheath should be approximated and the skin closed in layers. If a myocutaneous flap is used, a portion of the rectus sheath has to go with the flap. Depending on the extent of fascial defect, a prosthetic mesh may be required to prevent hernia formation.

Pitfalls during elevation include inadvertent entry into the abdomen and injury to the vascular pedicle. Ventral hernia or abdominal wall bulging may be seen if the abdominal wall is not closed appropriately. Caution is advised in using this muscle for patients who have undergone appendectomy, cesarean section, or other lower abdominal operations because of the risk of inadvertent ligation of the vascular pedicle.

**GRACILIS MUSCLE FLAP (SEE CASE 4 AND RESPECTIVE IMAGES)**

The gracilis flap is good for small wounds that require muscle. It can be raised as a muscle or musculocutaneous flap. The skin paddle is usually not incorporated for lower extremity reconstruction. It is supplied by the ascending branch of the medial circumflex artery; it is a relatively small vessel when compared with the artery of the other flaps described. This flap can be raised with the patient in the supine position.

**Detailed Surgical Technique**

To identify the anatomic landmarks, the hip is externally rotated and flexed, and the knee is flexed. In this position the tendon of the adductor longus muscle can be palpated (Fig. 15.4). Two centimeters posterior to this the gracilis muscle can be found extending from the pubis toward the medial femoral condyle; a line should be drawn along this path.

An incision is made over this path and along the superior aspect of this incision, the saphenous vein and nerve can be found. These should be preserved. Dissection is taken down to the muscle; distally one can identify the tendon of the muscle, but to prevent confusion one should get around the muscle and apply traction to clearly identify the tendon. The tendon can then be detached distally from the femoral condyle. After this maneuver the flap can be elevated from distal to proximal. As one dissects toward to the pubis one encounters the pedicle, which can be found on the deep side of the proximal third
Figure 15.3  Case 3. A. This patient suffered a fractured fibula requiring ORIF. The wound broke down postoperatively and the plate became exposed. B. The rectus sheath is incised and mobilized bilaterally to expose the anterior surface of the rectus muscle. In this image the muscle is still attached to the costal margin. The head of the patient is cephalad, whereas the feet are inferior, and the flank is to the right of the image. C. The rectus free muscle flap being raised. The patient’s head is at the bottom of the image, whereas the feet are at the top, and the umbilicus at the right. The cephalad aspect of the muscle has been detached from the costal margin along with the superior epigastric artery. The vessel loop is around the deep inferior epigastric vessels, and the muscle is still attached to the pubic tubercle. The posterior rectus sheath and peritoneum are seen as the floor in the wound. When the recipient site is ready for the flap, the deep inferior epigastric artery is ligated distal to the iliac artery. D. End-to-end anastomosis with deep inferior epigastric artery and anterior tibial vessels. E. Hardware covered with free rectus muscle flap and skin graft. F. Note the bluish discoloration of the skin graft, but the adjacent beefy red flap. The bluish color is secondary to dependency.
Case 4. A soft tissue loss over the medial malleolus requiring coverage. B. The medial malleolus covered with reversal sural flap. C. The patient developed a wound infection over the lateral wound with exposure of the hardware. D. A defect over the distal medial leg and ankle, with exposure of the medial malleolus. E. To identify the gracilis muscle, the hip is externally rotated, abducted, and flexed while the knee is flexed. Palpate the adductor longus (ADL) tendon. The gracilis muscle which courses from the pelvis to the medial condyle of the knee, is 2 cm posterior. F. The patient’s knee is to the right of the image, and the pubis to the left. G. The flap has been detached from the pubis, which is to the left of the image, and the femoral condyle, which is to the right of the image. The pedicle can be identified on the deep surface of the proximal third of the muscle, deep to the ADL muscle. H. The flap has been detached from the pubis, which is to the left of the image, and the femoral condyle, which is to the right of the image. (continued)
of the muscle (Fig. 15.4G,H). The pedicle runs under the adductor longus muscle toward the circumflex femoral artery (Fig. 15.4H). There are muscular branches that can be ligated. Dissection of the pedicle can be facilitated by detaching the origin of the muscle off of the pubis. Once the recipient site is ready the pedicle is ligated and the donor site is closed over a drain and the skin is closed in layers.

Pitfalls with elevation of the flap include inadvertent elevation of other muscles instead of the gracilis; this can be avoided by identifying the adductor longus tendon. Caution is warranted when using this flap in patients with peripheral vascular disease because the main source, the profunda femoris, may be affected by atherosclerosis. When dissecting out the pedicle, motor branches to the adductor muscles should be preserved because they are adjacent to the pedicle.

POSTOPERATIVE MONITORING

Tobacco, caffeinated products, and pressors are avoided perioperatively. The patient is hydrated intravenously as indicated. The extremity is elevated for better venous drainage and edema control. The patient is placed in a warm room kept between 77°F and 82°F. Recently, we used the Bair-Hugger to keep the flap warm. Hypothermia predisposes the patient to vasoconstriction. In our institution, all of our free flap patients require intensive care unit (ICU) attention for stringent hourly monitoring protocol.

The monitoring of a free flap should be simple, inexpensive, reliable, and reproducible. Skin color, temperature, and capillary refill are easily monitored by the medical staff, but these are subjective. Objective monitoring such as Doppler ultrasound, pulse oximetry, and an implantable Doppler probe are commonly used. However, there is no consensus on which method is most effective for flap compromise. Most microsurgeons use a combination of clinical examination and any of the preceding monitoring devices.

Monitoring is performed every 30 minutes for the first 4 hours, then every hour for 4 to 5 days. The patient is then transferred to a regular ward for 4-hour checks until discharged from the hospital. The ICU care is not necessary as long as there is a ward that can provide the monitoring protocol and adequately trained personnel are available to recognize changes in the flap.

The flap is checked for color, presence of serous fluid, and Doppler signals (venous and arterial). Patients are not allowed to eat for 24 to 36 hours in the event that emergent return to the operating room is required. Any changes in the flap mandate immediate return to the operating room for exploration.

Patients are given prophylactic antibiotics as indicated. It is very important that the patient is provided adequate pain control because sympathetic overflow can cause vascular spasm. The use of anticoagulants and antiplatelets in microsurgery remain controversial. The use of anticoagulants has been asso-
associated with bleeding complications. However, postoperatively we use aspirin 325 mg once a day.

Incisions are kept clean. The flap is covered with none to very light dressing. Circumferential dressings around the flap are prohibited.

**REVIEW OF THE LITERATURE**

Musharrafieh et al. reviewed their experience using free tissue transfer in 10 diabetic patients with limb-threatening wounds of the lower extremity (11). Five patients required a procedure to improve arterial inflow into the leg, whereas the other five were felt to have nonreconstructible arterial system. Four patients in the latter group had a staged procedure with an arterial inflow procedure for the flap in which an arterial venous fistula was created; this was subsequently detached distally to serve as the arterial inflow for the flap. All 10 patients underwent successful free tissue transfer. During the postoperative period one patient died secondary to a myocardial infarct. Two patients required successful anastomosis revision. There was one flap loss requiring above the knee amputation, and one patient had a flap dehiscence that was treated with further surgery. In another patient, although the flap survived, the patient ultimately underwent a below-the-knee amputation secondary to persistent osteomyelitis. Overall, 2 years after free tissue transfer, seven of the surviving nine patients were able to ambulate full weight-bearing.

Colen reviewed his experience in seven diabetic patients undergoing 10 free tissue transfers for limb salvage (7). Patients who had ankle brachial indices <0.5 required revascularization procedures; seven of the 10 extremities required some type of such procedure before the free flap. Once all extremities had a biphasic waveform on Doppler exam and ankle brachial indices >0.7, free tissue transfers were completed, with all flaps successfully performed. However, one patient with cardiac disease eventually required a below-the-knee amputation for sepsis after the free tissue transfer. Unfortunately, there was no comment on whether these patients were able to ambulate on the reconstructed extremity.

Karp et al. examined 19 diabetic patients who had 21 free tissue transfers for foot wounds (13). Twenty of the flaps survived during follow-up. Seven of the patients suffered some type of flap complication. Four patients had wound problems that were treated with local care; two patients required repeat skin grafting; and one patient required exploration for a hematoma. Five patients eventually required amputation of the leg; however, this occurred 15.8 months after free flap surgery. Four of these amputations were secondary to peripheral vascular disease progression, problems unrelated to the free flap. The 20 patients who had a successful free tissue transfer were able to ambulate on their extremity.

Moran et al. reviewed their experience with 79 flaps in 75 patients with peripheral vascular disease, 76% of whom had diabetes (4). Five-year flap survival was 77%. The most frequent complication seen in this series was marginal flap necrosis, which was treated with flap advancement or healing by secondary intention. Six percent of the patients required an amputation and 8% lost their flap. Eight patients suffered a significant cardiac event during the initial 30 days of follow-up. Limb salvage was 63% at 5 years. The most frequent causes for subsequent amputation were recurrent infection and progression of ischemic disease. Sixty-nine percent (52/75) of the patients were ambulating at least 1 year after free tissue transfer.

Oishi et al. examined their series of 19 patients and found that 18 of the flaps were viable during follow-up; however, 24% of the patients went on to require an amputation of the limb that was flapped (14). Four of the patients suffered a severe systemic complication during the postoperative period, whereas 47% suffered a local complication at the recipient site. Six of the latter patients required a secondary procedure to achieve wound healing. Nonetheless, in patients who were followed-up for >6 months, 77% (10/13) were ambulatory.

Free tissue transfer has been performed in patients who had inadequate circulation into the foot or leg in the hope of revascularizing the surrounding wound via the free flap (10,15,16). Some have suggested that this occurs via neovascularization from the flap into the extremity (16), with some demonstrating this with angiography (15,16). Additionally, free flaps have survived after the arterial inflow into the flap was lost (4), suggesting that neovascularization took place between the underlying vascular wound bed and the flap. However, the use of free tissue transfer in this manner has not been widely reported.

**CONCLUSION**

Lower extremity wounds in the diabetic patient are often secondary to ischemia. Unfortunately, these wounds can become infected, requiring operative débridement with exposure of critical structures. These extremities may be at risk for amputation. Regrettably, these patients are at risk for amputation of the contralateral limb.

Even after arterial reconstruction, these wounds may be too large to heal without free tissue transfer. Free tissue transfer can lead to limb salvage in these patients and allow afflicted patients the opportunity to continue independent ambulation. However, diabetics have multiple comorbidities that may make free tissue fraught with significant morbidity and even mortality; thus, patient selection is crucial for good outcomes.

**REFERENCES**

INTRODUCTION
The Achilles tendon has been implicated as a major deforming force for foot pathology encountered in the diabetic patient. Specifically, a limitation of ankle joint dorsiflexion because of a contracture of the Achilles tendon is thought to be the cause. This limitation is termed equinus and has received much attention from clinicians treating diabetic foot issues, including chronic ulcerations and Charcot joint destruction. In this chapter, the relevant anatomy of the Achilles tendon, assessment of equinus, surgical techniques in the treatment for equinus, and final thoughts regarding equinus and the diabetic foot are discussed.

SURGICAL ANATOMY OF THE ACHILLES TENDON AND RELATED STRUCTURES
To better understand the influence of the Achilles tendon on the rest of the foot, its anatomic relationships and function must be examined. The soleus muscle originates on the posterior aspect of the tibia and fibula. The gastrocnemius muscle originates on the posterior aspect of the distal femoral condyles. The muscle bellies are supported by connective tissue called an aponeurosis, whose fibers continue distally and combine to form the Achilles tendon. The Achilles tendon inserts in unison on the posterior aspect of the calcaneus and functions to plantarflex at the ankle joint and also supinate at the subtalar joint during gait (Fig. 16.1). There is a visible rotation or torsion (from posterior to anterior) of the Achilles tendon as it progresses proximal to distal (1–4). An anatomical study conducted by Van Gils et al. demonstrated an average of 37 degrees of external rotation or lateral torsion starting about 12 cm proximal to the attachment over a tendon length of roughly 17 cm (3). This torsion should be considered when conducting an Achilles tendon lengthening. The tendinous portion of the Achilles tendon is enveloped by a tendon sheath, which allows for the tendon to slide within a closed envelope of tissue. The paratenon lies deep to the tendon sheath and is composed of fat and synovium. It functions to directly protect and nourish the tendon substance via small vessels that traverse through this layer.

The blood supply to tendons in the lower extremity is not as robust as compared with other soft tissue structures. Like all other tendons, the Achilles tendon receives its blood supply from three primary sources: the musculotendinous junction (namely, the posterior tibial artery), paratenon, and insertional location on the bone (via calcaneal periosteum and the calcaneus) (5). Studies have demonstrated that there is no completely avascular portion of the Achilles tendon. However, there is a diminished vascular segment 4 to 5 cm proximal to the insertion site on the calcaneus (6).

ASSESSMENT OF THE EQUINUS DEFORMITY
Equinus can be defined generally as a decrease in range of motion at the ankle joint due to a shortening or contracture of the posterior muscle group, including the gastrocnemius and/or soleus muscle complexes. Equinus can be determined by the inability of the foot to passively dorsiflex beyond ankle joint neutral position, although there is no clear consensus on the absolute definition of equinus. The assessment for equinus is conducted by passively dorsiflexing the foot at the ankle joint, while the subtalar joint is maintained in neutral position with the midtarsal joint maximally pronated. The traditional method for quantifying equinus is through the use of a goniometer or tracograph, with the lateral malleoli serving as the rotational axis point (7). The classic Root definition of equinus is based on the minimal range of ankle joint dorsiflexion that is necessary for normal locomotion, which Root states is 10 degrees (8). The exact amount of dorsiflexion required to be within “normal limits” is without consensus. A review of the literature of asymptomatic subjects evaluated for available ankle joint dorsiflexion reveals a range of normal numbers. This range is from 0 to 13.1 degrees in dorsiflexion with the knee extended, and 5 to 22.3 degrees with the knee flexed (9–12). Further, the weight-bearing measurement and the non-weight-bearing measurement for ankle joint dorsiflexion differ significantly. Baggett and Young reported that the non-weight-bearing measurement with
knee extended is 8.25 degrees, whereas the weight-bearing measurement is 20.90 degrees (9). However, others report a decrease in dorsiflexory range of motion at the ankle joint while weight-bearing versus non-weight-bearing (11). Clearly, standardization of normal values has been difficult to establish. Inconsistent technique in assessment may factor largely in misidentifying equinus. Researchers have attempted to standardize the measurement of equinus through the development of "equinometers" (13). These devices are purported to provide consistency of measurements and eliminate recorder error. DiGiovanni et al. in 2001 compared the agreement between the standard clinical assessment of equinus versus the equinometer (14). The authors argue that there is a difference in clinical measurement versus those taken from an equinometer which is more precise and reproducible. Although it would appear that the equinometer may be more precise, the use of an equinometer is impractical in a busy, nonacademic environment.

Equinus can be subdivided into gastrocnemius equinus or gastroc-soleal equinus. This subdivision can be clinically differentiated by conducting the Silfverskiöld exam (15). This exam is conducted with the knee fully extended and the knee flexed. If the foot is unable to be passively dorsiflexed beyond neutral with the knee fully extended and the knee flexed, the patient displays gastroc-soleal equinus. If the foot is unable to be passively dorsiflexed beyond neutral with knee fully extended, but is able to be dorsiflexed with the knee flexed, the patient is said to display gastrocnemius equinus (Fig. 16.2). The differentiation between gastroc-soleal equinus and gastrocnemius equinus can be explained anatomically by the fact that the gastrocnemius muscle bellies originate proximal to the knee joint. Hence, by flexing the knee the gastrocnemius is no longer under tension, which eliminates or reduces its influence. Delp et al. demonstrated this phenomenon in a computer simulation model (16). This study appears to indicate that the gastrocnemius and soleus can be individually isolated. However, others report that this delineation may not be as important to identify (17). The authors believe that this subdivision of equinus becomes important when considering various surgical lengthening procedures described in the following paragraphs.

**THE LINK BETWEEN EQUINUS AND THE DIABETIC FOOT**

Equinus has been cited as an important deforming force in the development and chronicity of pathologies encountered in the diabetic foot. The prevalence of equinus in the diabetic population has been reported to be 10.3% (18). Generalized limitation of joint mobility has been reported in the diabetic population (19). Specifically, the Achilles tendon undergoes structural changes such as overall thickening and increased packing density of collagen fibrils with general structural
Achilles contracture demonstrated by an increase in the talar deformities occurring at the Lisfranc’s joint from a chronic breakdown. There are several demonstrations of rotational stresses located in this area result in a fairly predictable along the medial column and midfoot. The result of the in-tent, the majority of increased areas of pressures appear to be tion of pressures around the ankle axis. In the neuropathic pa-equinus forces occurring at the ankle provide a significant rota-tions that occur to the soft tissue structures, including fi-brotic atrophy of the plantar fat pad with thickening of the plantar fascia and the Achilles tendon (35,36). Specifically, Robertson et al. suggest that an increase in peak plantar pressures play an important predictive role in the development of ulcerations (30). Others have also concluded that elevated peak plantar pressures place diabetic feet at risk for chronic ulcerations (31–33). However, the exact threshold that defines an “elevated peak plantar pressure” has not yet been clearly delineated (10,32,34).

Compounded with limited joint mobility are significant changes that occur to the soft tissue structures, including fi-brotic atrophy of the plantar fat pad with thickening of the plantar fascia and the Achilles tendon (35,36). Specifically, Robertson et al. suggest that an increase in peak plantar pressures is associated with a decrease in soft tissue density on the plantar aspect of the foot, which places the diabetic foot at risk for ulceration (37). It is generally agreed that it is the combina- tion of altered load distribution and a reduced tolerance to tis-sue stress that contribute to the formation and chronicity of ulcerations (38,39).

The equinus deformity appears to play a strong pathologic role in elevated peak plantar pressures, which results in a variety of diabetic foot problems. Lavery et al. directly related equi-nus with peak pressures by reporting that diabetic patients with equinus deformity have higher peak plantar pressures than diabetic patients that do not have equinus (18). The proposed pathologic mechanism is described by Armstrong et al. (40). This pathologic algorithm depicts an equinus deformity caus-ing increased forces experienced in the foot and midfoot, resulting in plantar ulcerations and midfoot breakdown.

The majority of the Charcot collapse occurs primarily at the midfoot/Lisfranc’s area. Anatomically, midfoot breakdown ac-counts for roughly 60% of Charcot patients, with the forefoot being 20% and hindfoot and ankle being another 20%. The equinus forces occurring at the ankle provide a significant ro-tation of pressures around the ankle axis. In the neuropathic pa-tient, the majority of increased areas of pressures appear to be along the medial column and midfoot. The result of the in-creased stresses located in this area result in a fairly predictable breakdown. There are several demonstrations of rotational deformities occurring at the Lisfranc’s joint from a chronic Achilles contracture demonstrated by an increase in the talar declination as well as decrease in the calcaneal inclination caus-ing these pressure areas to persist. The longstanding deformity presents as a rocker bottom foot. This is a precursor to pressure ulcerations and more subsequent problems.

An equinus deformity can cause or aggravate other diabetic foot conditions as well. Biomechanically, equinus causes compensatory changes within the subtalar and midtarsal joints. This compensation creates instability, which may result in de-formities such as pes planus, hallux abducto valgus, and hammer toes. These foot deformities are of significant consequence in the environment of neuropathy and ischemia, which may result in chronic ulcerations and joint breakdown. Furthermore, equinus must be addressed at the time of forefoot and midfoot amputations. The loss of the extensors creates a greater mechanical advantage by the flexors, thereby accentuating the equinus deformity. Thus, the distal stump sites are prone to breakdown and wound dehiscence because of the plantarf lexed attitude of the foot. Barry et al. report a 91% healing rate after a lengthening of the Achilles tendon in the treatment of recurrent ulcerations at prior transmetatarsal am-putation sites (41).

**SURGICAL TREATMENT OF THE EQUINUS DEFORMITY**

It is important to properly evaluate the type of equinus— gastrocnemius equinus or gastroc-soleal equinus—to ensure that the appropriate surgical lengthening is selected. In the au-thors’ experience, many of the patients who present for surgical reconstruction of non-Charcot and noninf ective situations have been shown to have a gastrocnemius equinus. On the contrary,
patients with significant Charcot deformities and chronic forefoot and midfoot ulcerations appear more often display gastroc-soleal equinus. Clearly, there are some exceptions to both of these categories, and this should be properly evaluated and discussed with each patient. Failure to address and recognize these deformities leads to chronic recurrence of medial and forefoot ulcerations and pressures and less than optimal outcomes in the correction of any deformity. Residual equinus left in the foot and ankle will continue to cause foot breakdown even after initial wound healing or joint stabilization.

There are two fundamental surgical approaches for the reduction of the equinus deformity. As described, the Silfverskiöld test allows us to delineate between a gastrocnemius equinus versus a gastrocnemius-soleal equinus. After this determination, a gastrocnemius recession or a tendo-Achilles lengthening (TAL) should be conducted.

The gastrocnemius recession is a technique whereby an isolated lengthening of the gastrocnemius is conducted. A variety of techniques have been used to lengthen the gastrocnemius (Fig. 16.4) (42–45). Generally, some variation of the gastrocnemius aponeurosis is transected. This technique can be conducted either through a small open incision or endoscopically. The endoscopic technique is not discussed in any further detail here. The open technique involves the following steps (Fig. 16.5). A thigh tourniquet is not necessary for hemostasis; however, we do recommend a local block using an anesthetic solution containing dilute epinephrine. This technique can be conducted prone or with the patient in a supine position with the knee bent and the hip externally rotated. The skin incision should be made just medial to midline two to three fingerbreadths distal to the gastrocnemius muscle belly. The fatty tissue overlying the sheath of the aponeurosis should be bluntly dissected. Care must be taken to retract and protect the sural nerve that traverses this area. The aponeurosis sheath is sharply incised and freed from the underlying aponeurosis. This can easily be conducted by sweeping an index finger between the aponeurosis and overlying sheath. Now the surgeon can select the type of gastrocnemius recession that is to be conducted. The authors prefer the Strayer procedure, which involves identifying the medial and lateral borders of the gastrocnemius aponeurosis and linearly transecting this structure from medial to lateral direction using a no. 15 blade. The foot is then maximally dorsiflexed and any remaining fibers are transected. A gap should appear in the aponeurosis, exposing the underlying soleus muscle belly. If the plantaris tendon is encountered, this should be transected as well. The authors do not recommend suturing of the lengthened aponeurosis to the underlying structures.

Alternatively, a tongue and groove lengthening can be conducted. While the foot is in a maximally plantarflexed position, the distal central one-third incision or distal medial and lateral one-third incisions should be made (dependent on whether the tongue is directed proximally or distally). The foot is then maximally dorsiflexed and the proximal central one-third incision or proximal medial and lateral one-third incision should be made (again, depending on whether the tongue is directed proximally or distally). The distance between the distal and proximal incisions should be anywhere from 3 to 6 cm, depending on the size of the aponeurosis and skin incision location. Any remaining fibers are transected and absorbable or nonabsorbable sutures can be used to adjoin the lengthened aponeurosis ends. Layered closure should be conducted beginning with closing the sheath using a small absorbable suture and the subcutaneous tissue and skin with a suture of the surgeon’s preference. Postoperatively, the authors recommend non–weight-bearing with the ankle in neutral position. Full weight-bearing can begin within 2 to 3 weeks in an immobilization device.

The gastrocnemius recession has been shown to increase ankle joint dorsiflexion up to 18 degrees (46). Sharrard et al. directly compared a TAL versus a gastrocnemius recession in cerebral palsy patients with gastrocnemius equinus and gastroc-soleal equinus. They reported a lower rate of recurrence of equinus in patients who received gastrocnemius recessions (47). Furthermore, the gastrocnemius recession has certain other advantages. This approach does not cause bulbous scarring, as seen with a TAL. In fact, there is commonly a palpable delve in the area in which the recession is performed. Furthermore, there is less likelihood of Achilles tendon ruptures because the Achilles tendon is not completely compromised and there is a good blood supply to this area, which expedites healing.

The TAL is a popular method for the reduction of an equinus deformity in the diabetic patient. The modern triple hemisectioning technique for lengthening the Achilles tendon was...
popularized by Dr. Michael Hoke in the 1920s. In 1943, White recommended hemisectioning the medial half proximally and anterior half distally (4). Cummins recommended hemisectioning the posterior two thirds of the tendon proximally and medial two thirds distally (1). White and Cummins based their respective techniques on the anatomic torsion of the Achilles tendon. Both techniques ensured hemisectioning of both the soleal and gastrocnemius portions of the Achilles tendon. The percutaneous incisional approach to the TAL was reported by Hodgen in 1938 (48). In 1947 Hatt revisited the Hoke technique by specifically outlining the triple hemisectioning procedure (49). He described a frontal plane approach using a tenotome, in which three, one-third segments of the Achilles tendon were transected. The most proximal and distal transections were released anteriorly, whereas the middle hemisection was conducted in a posterior direction. In 1969 Conrad used a specialized instrument called a luck fasciotome to transect the medial three fourths of the Achilles tendon distally and the lateral three fourths of the tendon proximally (50). Others have reported variations in the hemisectioning of the Achilles tendon (51).

The most commonly performed TAL technique conducted today is through three percutaneous hemisections (Fig. 16.6).

However, others advocate a complete transection of the Achilles tendon proximal to the distal attachment of the Achilles tendon on the calcaneus. Others advocate an open approach with a midline incision made over the Achilles tendon with hemisectioning or Z-plasty lengthening in the sagittal or frontal plane. The most popular TAL technique can be conducted in a prone or supine position with the leg elevated and the knee fully extended, which allows for visualization (Fig. 16.7). Prior to incision, the medial and lateral aspects of the Achilles tendon should be palpated and the skin marker should be used to make more precise cuts. The percutaneous approach involves piercing the skin, subcutaneous tissue, and Achilles tendon with a no. 11 blade in succession approximately 3 cm apart. The blade should be oriented perpendicular to the skin surface and after puncturing the tendon, the cutting edge of the blade should be rotated away from the midline. The blade should then be advanced toward the skin surface with the blade edge facing out. The proximal and distal hemisections should be made in a medial direction, whereas the central hemisection should be conducted in a lateral direction. After these incisions have been made, the foot is maximally dorsiflexed and a gap is evident where the hemisections were made. If the lengthening of the Achilles tendon does not take place, the surgical blade is reintroduced into the incision.
sites to attempt to release uncut fibers. The skin can be closed with a couple of sutures or can even be left to heal on its own. The sequence of hemisectioning does not appear to matter, whether it is medial-lateral-medial or lateral-medial-lateral. The degree of lengthening does not appear to be affected, and hence is a matter of surgeon preference (52). The argument for the lateral-medial-lateral approach is based on the fact that the sural nerve and small saphenous vein are located laterally. The degree of increased dorsiflexion varies from 3 to 12 degrees for every centimeter of lengthening of the Achilles tendon (52,53). Non–weight-bearing status is highly individualized. Conservative management with non–weight-bearing for 3 to 4 weeks with progression to full weight-bearing may be needed. However, some surgeons allow for immediate full weight-bearing in an immobilization boot or other immobilization device. The ankle should be maintained in a neutral position. It is most likely that adjunctive procedures were conducted at the time of the TAL or gastrocnemius recession. These adjunctive procedures are the limiting factors in the patient’s return to full weight-bearing and not the TAL or gastrocnemius recession.

**CLINICAL OUTCOMES OF EQUINUS REDUCTION**

The overall purpose for lengthening the gastrocnemius or the gastrosoleal complex is to decrease the plantarflexory deforming force on the foot. There is good clinical evidence for wound healing after conducting a TAL with a healing rate for chronic diabetic ulcerations after a TAL being reported to be greater than 90% with a low reported risk of recurrence (24,25,40,54,55). Lin et al. examined diabetics with neuropathic ulcerations located on the plantar aspect of the foot (25). They compared a group who received a TAL and total contact casting (TCC) with patients who received TCC alone. They report no recurrence of the plantar forefoot ulcerations for the TAL group at an average of 17.3 months. The most robust study examining the efficacy of a TAL for the healing of chronic diabetic ulcerations was conducted by Mueller et al. (55). This is a prospective, randomized trial that compared a TAL plus TCC with TCC alone. They reported no difference in the number of healed ulcerations or time to healing between the two groups. However, they do report a lower recurrence rate with the TAL plus TCC group at 7 months (15%) and 2.1 years (38%) versus the TCC alone group at 7 months (59%) and 2.1 years (81%). Additionally, the recurrence of an ulcer happened sooner in the TCC alone group. Interestingly, the authors report that the peak plantar pressures and peak torque returned to baseline levels at 7 months in the TAL group despite the fact that the increase in ankle joint dorsiflexion remained at the immediate postoperative levels.

As discussed, the purpose of the TAL is to increase the range of motion at the ankle joint by lengthening the Achilles tendon, thereby reducing a deforming force in the diabetic foot. However, there are potential consequences as well. One of the more devastating complications is overlengthening the Achilles tendon. Heel ulcerations can be a result of this overlengthening with reported rates of 13% to 14% (54,55). Hence, the patient runs the risk of potentially replacing one chronic ulceration with a potentially more devastating problem. An important addendum to this issue is raised by a study published by Shaw et al. (33). They prospectively evaluated the peak forces experienced in the foot during gait. They report that all diabetic groups displayed increased peak vertical forces as compared with healthy controls. However, these peak vertical forces occurred during heel strike, not at push off in the neuropathic diabetic group. This challenges the notion that neuropathic diabetics are at high risk of ulceration because of higher forces experienced in the plantar forefoot during gait. Furthermore, by performing a TAL these patients may be at an even higher risk of plantar heel ulcerations. Other biomechanical abnormalities may also result from overlengthening. The loss of Achilles tone may cause in compensatory flexor substitution. This can lead to a hammertoe deformity and an increase in metatarsal pressures. This in turn may lead to ulcerations located at the digits and/or submetatarsal heads.

Another potential complication of a TAL is Achilles tendon ruptures. Achilles tendon ruptures have been reported to occur 10% of the time (54). The percutaneous approach to a TAL is a blind procedure. Hence, regardless of the deliberation by the surgeon, it is possible to completely compromise the Achilles tendon. Furthermore, because of poor patient education or patient noncompliance, the surgically incised Achilles tendon is at risk for a complete rupture. This will significantly alter gait patterns and potentially cause new ulceration production in the area of the heel or contralateral limb. It is important to recall our discussion about the soft tissue changes that occur in the diabetic Achilles tendon. The Achilles tendon of a patient with diabetes already has an impaired healing response;
hence, surgery may further compromise the structural integrity of the tendon (56).

CONCLUSION

An equinus deformity certainly plays a role in the development of pathologies encountered in the diabetic foot. However, the exact mechanism of how this occurs and the accurate assessment for equinus remains to be elucidated. The performance of a gastrocnemius recession or a TAL is not a one-time definitive surgery. The TAL does not address the inherent structural changes within the tendon caused by the diabetic disease process. Redevlopment of equinus should be expected, and repeated lengthening may be necessary. These repeated surgeries may have additive deleterious effects on an already-damaged Achilles tendon, further compromising this area. This may eventually lead to complete Achilles tendon rupture, causing other gait abnormalities and leading to other harmful consequences. The gastrocnemius recession and TAL continue to be a popular adjunctive procedure in the treatment of diabetic foot pathologies. There is ample evidence to support their use in the treatment of diabetic foot ulcers. However, the clinical and surgical significance of a gastrocnemius recession or a TAL is not a one-time definitive surgery. The TAL does not address the inherent structural and surgical significance of the Achilles tendon in diabetic patients who are at high risk for ulceration of the foot. J Bone Joint Surg Am 1999;81A(4):535–538.

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INTRODUCTION

Equinus is known to produce devastating effects on the diabetic foot (1–6). These include forefoot ulcerations, midfoot collapse, and Charcot fractures/dislocations (7,8). Subsequent amputation is common. The impact on patient quality of life as well as the medical system is tremendous and costly (9,10). For these reasons, many foot and ankle surgeons actively perform Achilles lengthening procedures to reduce equinus-related problems in the patient with diabetes (3,8). Most commonly, variations of the percutaneous tendo-achilles lengthening (TAL) are performed (8,11). However, failure of the TAL in this patient population may result in more deleterious consequences than the patient’s initial presenting problem. These complications may include: over-lengthening, complete Achilles tendon rupture, calcaneal gait leading to heel ulceration, osteomyelitis leading to partial or total calcaneectomy, and below-knee amputation. In particular, heel ulcerations are a consequence of this over-lengthening, with reported rates of 2% to 14% (8,12,13).

Calcaneal gait identified by gait analysis after Achilles lengthening has been reported to be as high as 30% when performed for spastic paraplegia (14). Achilles tendon rupture may occur in up to 10% of cases (12). Worse yet, a resultant segmental Achilles defect may be irreparable in the diabetic patient with a poor skin envelope, existing tissue glycosylation, lower extremity vascular disease, immunopathy, and poor healing potential.

This chapter focuses on strategies to reconstruct the failed TAL and prevent TAL complications in the first place. Admittedly, failure is uncommon but its presence provides an opportunity to re-examine the purpose for performing these procedures. Perhaps, a less invasive approach in which the vulnerable Achilles tendon is spared and the equinus is treated via selective aponeurotic lengthenings (i.e., gastrocnemius intramuscular aponeurotic recession) in the calf may be an area that needs particular attention. The technique of aponeurotic lengthening is also highlighted.

ANATOMIC CONSIDERATIONS

It is paramount to have a thorough understanding of the anatomy that results in equinus. The Achilles tendon is the conjoined tendon of the gastrocnemius and soleus muscle (Fig. 17.1). The gastrocnemius muscle originates above the knee on the posterior femoral condyles, whereas the soleus muscle originates below the knee, on the tibia and fibula. Gastrocnemius has two muscle origins (sometimes referred to as heads), the medial head and the lateral head. Both the gastrocnemius and soleus form aponeuroses that ultimately fuse to form the Achilles tendon. An important distinction regarding the aponeurosis of these muscles is that the gastrocnemius muscle fibers are posterior to its aponeurosis, whereas the soleus muscle fibers are anterior to its aponeurosis. This arrangement leaves both gastrocnemius and soleus aponeuroses adjacent to each other. The Achilles tendon inserts onto the posterior aspect of the calcaneus.

THE PERCUTANEOUS TENDO-ACHILLES LENGTHENING

The percutaneous TAL is often performed as an adjunctive or ancillary procedure when diabetic patients undergo surgical management of equinus related deformities—most notably forefoot ulcerations and their complications (12). Some surgeons perform the TAL as a hospital-based procedure, whereas others perform them as an outpatient type of procedure. The percutaneous TAL is often favored over an open TAL because the former is quick and easy, and may be performed supine with local anesthesia alone. Potential problems with the percutaneous technique include iatrogenic intraoperative over-lengthening, patient-induced over-lengthening, or complete rupture of the Achilles complex if the surgical site is not protected until healed. In contrast, with an open TAL, the desired amount of lengthening may be secured with suture on the operating table (Fig. 17.2), although one must consider that many diabetic patients are poor surgical candidates for an open TAL, and postoperative wound dehiscence over the heel cord can be disastrous.

Several techniques for percutaneous lengthening have been described. The most popular techniques involve two or three stab incisions along the Achilles tendon (8,11,15,16). The two-incision technique requires that half of the Achilles tendon is transected proximally and the other half of the tendon is...
transected distally. With controlled dorsiflexion of the foot, this is typically performed with a no. 11 or 15 blade through small stab incisions (8,11). Obviously, this technique results in a partial side-by-side controlled iatrogenic rupture of the Achilles tendon. The three-incision technique takes advantage of the anatomic internal twisting of the Achilles tendon fibers by selectively targeting the medial fibers from the lateral fibers as they course distally (17). Typically this technique is performed with a medial stab incision about 1 to 4 cm proximal to the Achilles insertion at the calcaneus, a lateral stab incision over the Achilles about 3 cm proximal to the most distal medial incision, followed by another medial incision 3 cm proximal to the middle stab incision (8,11). Again, a partially controlled side-by-side iatrogenic rupture of the Achilles tendon is performed.

The postoperative course for percutaneous and open TAL varies. The most sensible option is to keep these patients non-weight-bearing in a cast until the surgical lengthening heals—approximately 6 weeks, although this may not be feasible in the diabetic population because of the following possible comorbidities or challenges: overt noncompliance, obesity, contralateral ulceration, contralateral amputation (foot or leg), and/or contralateral Charcot deformity. As such, the postoperative protocols may involve total contact casts, partial weight-bearing casts, or removable controlled ankle motion walkers (18).

Figure 17.1 Medial view of cadaveric specimen illustrating the pertinent anatomy of the triceps surae and Achilles tendon. The gastrocnemius and soleus muscles fuse to form the Achilles tendon. The gastrocnemius run-out is the muscular free portion of the gastrocnemius aponeurosis. It is important to note that the aponeuroses of the gastrocnemius and soleus aponeurosis are adjacent to each other. The gastrocnemius aponeurosis is anterior to its muscle belly, whereas the soleus aponeurosis is posterior to its muscle. (Modified with permission from Blitz NM, Rush SM. The gastrocnemius intramuscular aponeurotic recession: a simplified method of gastrocnemius recession. J Foot Ankle Surg 2007;46(2):133–138.)

Figure 17.2 Intraoperative photograph of open tendo-achilles lengthening in a diabetic patient with equinus. A Z-lengthening is performed. Here the tendon ends are secured with suture to prevent migration of the lengthening to avoid overcorrection.

Figure 17.3 Intraoperative photograph of open tendo-achilles lengthening in a diabetic patient with equinus. A Z-lengthening is performed. Here the tendon ends are secured with suture to prevent migration of the lengthening to avoid overcorrection.

Failed Percutaneous Tendo-Achilles Lengthening

Loss of gastrosoleal function on the foot may result in a calcaneal gait as load is transferred from the forefoot to the rearfoot (8,14,19). In the sensate patient this may be tolerated without major side effects. However, in the patient with diabetes and neuropathy, this increased load on the heel may result in calcaneal ulceration(s), leading to osteomyelitis and/or contralateral Charcot deformity. As such, the postoperative protocols may involve total contact casts, partial weight-bearing casts, or removable controlled ankle motion walkers (18).
Calcaneal gait is a well-known occurrence of the over-lengthened or neglected rupture of the Achilles tendon (8,14,19). This is probably the first clinical manifestation. Neuropathic patients are at higher risk to develop heel ulcerations, and these are more likely to manifest in obese patients with increased calcaneal plantar pressures (Figs. 17.3 and 17.4). If heel ulcers do not occur, then over time a next possible clinical manifestation is the development of hammertoes or claw toes from flexor substitution in the setting of a weakened triceps surae. Digital deformities in insensate patients may progress onto digital and/or forefoot ulcerations requiring treatment and possible amputation(s).

Calcaneal ulcerations are very serious problems in the patient with diabetes (20). Ulceration leading to osteomyelitis of the heel is difficult to manage and has limited reconstructive options. In some cases a calcanectomy (complete or partial) is necessary (Fig. 17.5) (8,21,22). Functionally, patients status post-calcanectomy are somewhat disabled and often require custom-made bracing (20). The risk of reulceration is high as well (20). Sural neurocutaneous island flaps, flexor digitorum brevis muscle flaps, or the like have allowed for some patients with soft tissue loss about the heel to be managed without amputation (8,23). Of course, there are limitations with flap use such as patient candidacy, the extent of soft tissue coverage required, and the possibility that prior surgery precludes the use of some local flaps. Nonetheless, over-lengthening of the Achilles tendon should be avoided.

**Figure 17.3** Diabetic patient with plantar heel ulceration secondary to over-lengthened Achilles tendon and resultant calcaneal gait. (Image courtesy of Thomas Roukis.)

**Figure 17.4** Diabetic patient with plantar heel ulceration secondary to over-lengthened Achilles tendon and resultant calcaneal gait. (Image courtesy of Thomas Roukis.)

**SURGICAL RECONSTRUCTION OF THE FAILED PERCUTANEOUS TENDO-ACHILLES LENGTHENING**

The failed percutaneous TAL often results in a segmental tendon defect, which is especially challenging to surgically correct in patients with diabetes and its comorbidities. Not only does the Achilles tendon unit need to be restored, but so does plantarflexion strength to maintain musculotendinous balance across the ankle and subtalar joints. Depending on the duration of time from the index operation to the reconstruction, it may be impossible to simply reattach the Achilles tendon ends, as the...
gastrosoleal complex may be degenerated and/or irreversibly weakened. More often than not, the remnant tendon ends require some débridement and a resultant tendon defect exists. In many situations, both a viable tendon and its associated muscle unit are needed to restore both function and tendon structure. This can only be accomplished with a local tendon transfer.

The options available for Achilles augmentation and reconstructive procedures have included tendon transfers, flaps, or advancements such as the flexor hallucis longus, gracilis, peroneus brevis, fasciocutaneous free flaps from more remote areas, harvested fascia lata, Achilles tendon allograft, or acellular tissue graft (11,24–31).

The most commonly used local options are the peroneal tendons or flexor hallucis longus (FHL) (11,32,33). The choice of tendon transfer is based on location, ease of transfer, phase, and surgeon experience. The main advantages of the FHL are as follows: (a) it is a same-phase tendon transfer; (b) its muscle is located in the deep posterior compartment of the leg and therefore a relatively easy harvest; and (c) a variable tendon length may be obtained. The FHL tendon may be harvested behind the ankle within the tarsal tunnel, in the midfoot at the master knot of Henry, or distally at its insertion on the great toe. In contrast, the peroneals are lateral compartment muscles that function as partial antagonists to the powerful anterior tibialis. The main advantage of using the peroneals is that it is less challenging to harvest similar length tendons, when compared with the FHL. The author of this chapter prefers the FHL transfers from a pure anatomic and functional standpoint (Fig. 17.6). As one considers a reconstruction of the Achilles, a thorough preoperative evaluation is absolutely necessary because this population has many risk factors for failure. Vascular status and skin quality must be intact; otherwise, the surgeon could be left with a large nonhealing wound in a difficult area.

**TECHNIQUE FOR FLEXOR HALLUCIS LONGUS TRANSFER**

The procedure is performed in a prone position (Fig. 17.7). The foot should hang off the bed enough to allow for intraoperative evaluation of ankle joint dorsiflexion; this also facilitates a tendon harvest in the midfoot or great toe. One to three incisions are needed, depending on the tendon harvest length required. First, a posteromedial incision is made along the Achilles tendon centered at the defect site, so that the Achilles defect can be assessed (Fig. 17.8). It is preferred to keep the incision more medially based off the midline of the Achilles tendon. Also, the sural nerve and its vascular network should be protected because use of a sural neurocutaneous island flap may be needed in case of soft tissue failure over the Achilles.

**Figure 17.6** A 69-year-old patient with diabetes and neuropathy status post percutaneous TAL that went onto complete Achilles rupture secondary to noncompliance with postoperative weight-bearing protocols (top). A flexor hallucis longus tendon transfer (harvest at hallux) was performed to recreate the Achilles tendon (bottom). Arrows demonstrate that the segmental Achilles defect was corrected with the tendon transfer.

**Figure 17.7** A 77-year-old patient with diabetes and neuropathy with over-lengthened Achilles on the right. With the patient prone and the knees bent, an over-lengthened Achilles complex may result in hyperdorsiflexion of the affected side. Also, one may physically see the prominence of the posterior calcaneal tuber and absence of the Achilles tendon. The Achilles area may also be firm or tendinosed when palpated.
After the tendon ends are débrided, the length of the defect is measured and the quality of the insertion is also inspected. When the Achilles tendon ends are in good approximation with an intact insertion, then the FHL may be harvested behind the ankle through the same posteromedial incision. The Achilles tendon ends are retracted and the deep fascia is longitudinally incised anteriorly, exposing the FHL muscle belly. The neurovascular bundle is also exposed, and care must be taken to retract it medially. The FHL muscle belly is followed distally until it becomes tendinous. The FHL tendon is transected as far distally into the tarsal tunnel as possible without injuring the neurovascular bundle. More tendon length may be gained with plantarflexion and inversion of the foot while plantarflexing the hallux. The FHL tendon is then anastomosed to the Achilles with appropriate strength suture.

When the Achilles tendon defect is significant and its insertion into the calcaneus is poor, then both the Achilles tendon needs to be recreated as well as its insertion, requiring a lengthy tendon (midfoot or hallux harvest) and rerouting through the calcaneus and back onto itself to form a sturdy “new” Achilles tendon.

Several approaches may be used for the midfoot dissection, namely, a direct plantar or medial approach. Obviously, the main advantage of a medial approach is avoidance of an incision on the bottom of the foot. The master knot of Henry is the anatomic location in which a tendinous communication between FHL and flexor digitorum longus (FDL) exists (Fig. 17.9). However, one should be careful during the midfoot dissection as a recent cadaver study simulating FHL harvesting distal to the master knot Henry identified iatrogenic nerve injury in 33% of the 24 foot specimens (34). Additionally, anatomic variation exists in the midfoot, as the long flexors to the second or third toes may originate from the FHL rather than the FDL (Fig. 17.10). Once the midfoot interconnection between FHL and FDL are released,
Chapter 17  Surgical Reconstruction of the Failed Percutaneous Tendo-Achilles Lengthening

the FHL may be transected at the midfoot or additional length may be obtained with harvest from the great toe (Fig. 17.11).

The FHL is then pulled through proximally at the ankle, tagged with suture, and ready for transfer through the calcaneus (Fig. 17.12). An appropriate-size hole is created from medial to lateral through the heel near the anatomic insertion of the Achilles (central one third of the heel). A percutaneous incision is created at the exit point of the drill. A subcutaneous tunnel is developed from this percutaneous incision extending to the Achilles defect. The FHL tendon is passed through the heel, then through the subcutaneous tunnel into the Achilles incision (Fig. 17.13).

Reconstruction of the Achilles is performed with the ankle at neutral, favoring a slight equinus. One should consider that it is impossible to postoperatively correct for an over-lengthened Achilles; however, a reconstructed Achilles iatrogenically placed in some equinus could be stretched out. Moreover, it may be difficult to adequately assess the physiologic position of the FHL at the time of surgery and, this author believes that the surgeon should err on the side of slight equinus. It is very important that the final position of the Achilles ends and FHL be considered simultaneously prior to suturing the construct to avoid a slack in either suture if they were repaired independent of each other (Fig. 17.14).

The postoperative course involves non–weight-bearing for about 6 weeks. In most situations, the patient is kept in a cast rather than a boot to avoid rerupture from noncompliance or overaggressive physical therapy. Additionally, any postoperative equinus may be gradually corrected with the cast during this period.

APONEUROTIC LENGTHENING OF THE CALF

Aponeurotic lengthenings of the calf are not an entirely new concept. In patients with spastic equinus, multiple aponeurotic lengthenings of the gastrocnemius and soleus were initially described in 1986 (35). More recently, the technique has been modified for nonspastic equinus by performing a single transection of the gastrocnemius aponeurosis through a small medial incision—better termed the gastrocnemius intramuscular aponeurotic lengthening (GIAR) (36) (Fig. 17.15). The procedure allows for the surgical treatment of equinus by attacking the problem proximally at the muscle and aponeurosis, rather than distally at the tendon.
Figure 17.13  These three images (from left to right) demonstrate passage of the FHL through the subcutaneous tunnel. A tendon passer is useful in facilitating this procedure.

Figure 17.14  Final intraoperative picture demonstrating the reconstructed Achilles tendon using the FHL tendon.

Figure 17.15  Drawings demonstrating the GIAR procedure, before (A) and after (B). It is important to make the linear transection of aponeurosis within the muscular bound portion of the gastrocnemius aponeurosis. (Reproduced with permission from Blitz NM, Rush SM. The gastrocnemius intramuscular aponeurotic recession: a simplified method of gastrocnemius recession. J Foot Ankle Surg 2007;46(2):133–138.)
In patients with diabetes, aponeurotic lengthenings such as the GIAR have several theoretical advantages. The surgery is performed at the level of the mid-calf, which may have better healing potential in certain patients with peripheral vascular disease. This procedure also avoids the sural nerve, lesser saphenous, and Achilles tendon, which may avoid many of the complications discussed earlier while preserving the anatomy for a sural pedicle flap if needed at a later time. With regard to the lengthening, it is possible to better control the amount of lengthening and titrate the final position appropriately. The major advantage of the gastrocnemius aponeurotic recession over the percutaneous or open TAL is that the soleus muscle and tendon are left intact, preventing overcorrection and allowing patients to regain quicker rehabilitation (8,36). The postoperative course after a GIAR allows for immediate protected weight-bearing in a removable walking boot, and this may obviate the potential overload of the contralateral diabetic limb that may be susceptible to ulceration and/or Charcot destruction.

The surgeon should perform the Silfverskiöld test preoperatively, understanding that the GIAR will only affect the gastrocnemius equinus, although it is possible to also perform concomitant aponeurotic lengthenings allowing some correction of soleal equinus to be managed as well.

The GIAR is performed with the patient supine. A medial approach is used to access the calf (Fig. 17.16). The incision should be placed proximal to nonmuscular bound portion of the gastrocnemius aponeurosis, better termed the gastrocnemius run-out. If properly placed, the incision need not be >5 cm. Once the deep fascia is incised, the surgeon identifies the interval between the gastrocnemius and soleus with the surgeon’s index finger or a Cobb elevator (Fig. 17.17). The skin incision may need to be extended either proximal or distal to allow for the gastrocnemius aponeurotic transection to be performed at a location in which there is adequate underlying muscle to support the lengthening.

Adequate visualization of the surgical field is achieved by placing a deep retractor to lift the soleus anteriorly (Fig. 17.18). The aponeurosis is transected with a scalpel from lateral to medial within the transection zone (Figs. 17.19 and 17.20). Only the aponeurosis is transected, not its underlying associated muscle. Cutting the muscle may result in a deep bleeder that may be difficult to coagulate. The surgeon should remember that the calf musculature has an abundance of venous channels. Any remaining lateral aponeurosis may be transected with a Mayo scissors, still protecting the underlying gastrocnemius muscle. If the plantaris tendon is encountered, it should be severed.
After the GIAR has been performed, the transected aponeurosis lie proximally and distally to the separated gastrocnemius muscle. It is extremely important to transect only the gastrocnemius aponeurosis and not its underlying muscle. Also, the transection should only be performed where there is enough underlying muscle to support the lengthening, otherwise a full-thickness muscle rupture may occur. Also, it may be beneficial to use a long handled no. 15 blade for the most lateral portion of the transection. (Modified with permission from Blitz NM, Rush SM. The gastrocnemius intramuscular aponeurotic recession: a simplified method of gastrocnemius recession. J Foot Ankle Surg 2007;46(2):133–138.)

With complete release of the gastrocnemius aponeurosis, a controlled dorsiflexion of the foot with the knee extended allows for an intramuscular lengthening of approximately 1 to 3 cm. If the aponeurotic transection is made too far distally and/or there is not enough supporting muscle (thin muscle) a full-thickness muscle tear may occur. If more dorsiflexion is needed to achieve the clinical result, parallel transections of the gastrocnemius aponeurosis may be performed to achieve more dorsiflexion. Additionally, an aponeurotic transection of the soleus could also be performed. Adequate closure of the deep fascia is performed to prevent herniation of the underlying musculature or adhesions to the skin (Figs. 17.21–17.23).

Postoperative care of isolated cases of GIAR typically involves full weight-bearing in a removable walking boot, which is worn full-time for 4 weeks. Early in the postoperative period, patients are encouraged to do range of motion exercises. In the diabetic neuropathic patient, the postoperative course may be adjusted for a period of non–weight-bearing, but this would depend on the clinical situation.

The deep fascia is closed with 3-0 absorbable suture.
Perform the procedure through an incision as small as 3 cm.

REFERENCES

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REFERENCES


Surgical Reconstruction and Stepwise Approach to Acute Charcot Neuroarthropathy

INTRODUCTION
Charcot neuroarthropathy causes bone loss and joint subluxation/dislocation, which produces abnormal osseous prominences that are areas for potential ulceration. The resultant deformed pedal position alters the muscle-tendon balance and weight-bearing forces, which increases the risk for ulceration. When ulcers are present, osteomyelitis can develop; thus the best treatment results are achieved when treatment is initiated early (1,2). Treatment of Charcot neuroarthropathy often is based on the stage at which the deformity presents. The Eichenholz system is the most commonly used classification system that divides Charcot neuroarthropathy into three stages (developmental, coalescent, and reconstructive) (3).

In Charcot deformity the ulcer location is a significant indicator of the overall prognosis of the foot. Plantar ulcers correlate to the anatomic location of the Charcot neuroarthropathy and are associated with the degree of stability of the foot. Ulcers along the medial column are generally associated with Lisfranc and Charcot medial column collapse. Lisfranc and Charcot deformities are typically stable because of the interlocking anatomy and are successfully treated conservatively or with a limited surgical approach (4,5). However, ulcers that are located plantar central or plantar lateral are associated with midfoot Charcot and are typically unstable. Instability of the lateral column leads to recurrent ulcers, whereby complex surgical reconstruction often becomes necessary (6,7).

The goal of treatment for acute Charcot neuroarthropathy (i.e., Eichenholz stage 1) is to stabilize the osseous anatomy to avoid bone loss and joint subluxation/dislocation (8,9). Total contact casting for immobilization is the traditional treatment. Total contact casting or cast immobilization has been the treatment of choice to allow the acute Charcot to stabilize and convert to stage 2. However, total contact casting has disadvantages because of the patient’s inability to bear weight while in the cast, which produces osteopenia of the ipsilateral foot and an increase in the weight-bearing forces on the contralateral foot. Osteopenia makes it difficult for sequent surgical reconstruction. Also, overloading of the contralateral foot can result in ulceration. Maintaining non-weight-bearing status is not easy for the neuropathic patient for multiple reasons (e.g., muscle atrophy, diminished proprioception, and obesity).

Recently, a method was described for treating acute Charcot neuroarthropathy by applying a static external fixator, which acts like a cast by stabilizing the affected joints and bones (10). The advantage of the static external fixation is that it allows partial weight-bearing, limiting osteopenia, and it maintains the existing foot position. I have taken this approach a step further, in that I apply an adjustable external fixation device that allows stabilization with subsequent adjustability. Applying a static ring fixator on the acute Charcot foot is performed by avoiding the affected Charcot region. Thus, external fixation pins are placed adjacent but not into the Charcot joint and region. Additionally, olive wires and threaded rods or struts are strategically placed to afford dynamic gradual correction once the acute Charcot has pasted (typically 3–6 weeks). After gradual realignment of the osseous segments a second-stage surgery is performed to maintain the foot position (formal fusion of the Charcot joint). The fixator is maintained for at least 3 months thereafter. A third surgery is required for removal of the fixator. The ability to evaluate a patient in the acute stage of Charcot is not common, as most Charcot patients typically present with an ulcer and foot collapse (Fig. 18.1A–N).

The chronic Charcot foot (i.e., Eichenholz stage 2 or 3) can be stable or unstable. The unstable Charcot foot is difficult to shoe or brace and typically results in ulceration. The stable Charcot foot is easier to shoe or brace but is still prone to ulceration. The stable Charcot foot can be treated without surgery. The goal of surgical treatment in cases of chronic Charcot neuroarthropathy (i.e., Eichenholz stage 2 or 3) is to establish a stable plantigrade foot. Achilles tendon lengthening, osteotomy, débridement, osteotomy, arthrodesis, and open reduction with internal fixation are well-known surgical reconstructive procedures aimed at re-establishing normal foot position. Acute correction via open reduction with rigid internal fixation or plantar plating is frequently used for reconstruction (11).
Figure 18.1  A. Midfoot Charcot neuroarthropathy deformity (Eichenholz stage 1, unstable, with superficial medial ulceration). This 60-year-old man was first seen in the office with a red, hot, swollen foot without an ulcer and placed in a non-weight-bearing cast for 2 weeks. A clinical photograph of the foot after 2 weeks of casting shows a superficial medial ulcer just prior to surgery. B. An anteroposterior view radiograph shows a shortened first ray. A collapsed navicular is noted medially. C. A lateral view radiograph shows elevated and shorted first ray. Note the break in Meary’s angle. D. The maximum dorsiflexion lateral view still image, obtained by using video fluoroscopy, confirms the equinus. E. The maximum dorsiflexion lateral view still image, obtained by using video fluoroscopy after tendon Achilles lengthening, confirms the dorsiflexion of the ankle above neutral with the knee extended. F. The anteroposterior view still image, obtained by using video fluoroscopy, shows insertion of the olive wires from proximal to distal, capturing the medial cuneiform. (continued)
Figure 18.1 (Continued) G. The lateral view still image, obtained by using video fluoroscopy, shows insertion of the olive wires from proximal to distal, capturing the medial cuneiform in two different directions. This allows for the olive wires to have separate vectors of pull, thus increasing the strength and decreasing the risk of pull out. H. The anteroposterior view still image, obtained by using video fluoroscopy shows a trailing distraction of the medial cuneiform; note the 5-mm gap. The transverse metatarsal wire captures only the lesser metatarsals. I. A clinical photograph of the stable external fixator is shown. Note the two slotted threaded rods that hold the two olive wires at the tip of the great toe, which are set up for distraction. J. The anteroposterior view still image, obtained by using video fluoroscopy, shows a distraction of the medial cuneiform adjacent to the intermediate cuneiform, note the 1.5-cm distraction gap. Distraction was performed at a rate of 1-mm/day only after the acute Charcot event. (continued)
Also, acute correction via open reduction with application of static external fixation has been reported (10,12). Recently, we presented a new, minimally invasive method of gradual distraction with external fixation that provides both realignment and stabilization (13).

MINIMALLY INVASIVE GRADUAL CHARCOT FOOT RECONSTRUCTION

The goals of surgical intervention for the Charcot foot are to restore alignment and stability, prevent amputation, prepare for a shoe or brace, and allow the patient to be ambulatory. Historically, open reduction with internal fixation was the mainstay for treatment of Charcot foot deformities. Large open incisions were made to remove the excess bone, reduce the fragmented or dislocated bone, and fix the bones with screw or plantar plating in an attempt to stabilize the Charcot joint. These invasive surgical procedures generally resulted in a nonanatomic correction (e.g., shortening of the foot or incomplete deformity correction) and occasionally resulted in neurovascular compromise, incision healing problems, infection, and the use of non-weight-bearing casts or boots.

Gradual deformity correction with external fixation is preferred for large Charcot foot deformity reductions. Correction with external fixation is minimally invasive, allows for gradual, accurate anatomic realignment of the dislocated/subluxated Charcot joints without loss of foot length or bone mass, provides

Figure 18.1 (Continued) K. The anteroposterior view still image, obtained by using video fluoroscopy shows a Hitterman distractor maintaining the distraction gap for placement of the bone graft. Note the guidewire placed in the medullary canal of the first metatarsal. L. The anteroposterior view still image, obtained by using video fluoroscopy, shows a fresh frozen fibula allograft with fixation in position. M. Weight-bearing anteroposterior view radiograph postdistraction and fusion of the Charcot medial column shows a stable lengthened medial column. Note the medial foot ulcer has healed and the intact intramedullary metatarsal screws were inserted to stabilize the midfoot. N. Weight-bearing lateral view radiograph postdistraction and fusion of the medial column Charcot shows a normal or zero Meary’s angle.
for partial weight-bearing, and limits neurovascular compromise as the correction occurs slowly during a period of time.

A stable or coalesced foot with Charcot deformity requires an osteotomy for correction of the deformity. For an unstable or an incompletely coalesced Charcot foot, correction can be obtained through gradual distraction. Despite the radiographic appearance of coalescence, the majority of Charcot deformities can be distracted through the joints to realign the pedal anatomy without osteotomy. The first stage, osseous realignment, is achieved with a Taylor spatial frame (TSF) (Smith & Nephew, Memphis, TN) using the principle of ligamentotaxis. After realignment, the correction is maintained by arthrodesis (the second stage) using percutaneously inserted intramedullary metatarsal screws. This minimally invasive, two-stage correction is a new technique that has been shown to have excellent short-term follow-up results (13).

SURGICAL TECHNIQUE

The first stage consists of osseous realignment achieved by performing ligamentotaxis. The TSF forearm 6 × 6 butt frame construct is applied and provides gradual relocation of the forefoot on the hindfoot. The distal tibia, talus, and calcaneus are fixed with two U-plates joined and first mounted orthogonal to the tibia in both the anteroposterior and lateral planes. The U-plate is affixed to the tibia with one lateromedial 1.8-mm wire and two to three other points of fixation (combination of smooth wires or half-pins). For additional stability, a second distal tibial ring can be added to create a distal tibial fixation block. It is essential to fix the hindfoot in a neutral position; an Achilles tendon lengthening typically is required to achieve a neutral hindfoot position. With the hindfoot manually held in a neutral position, the U-plate is fixed to the calcaneus with two crossing 1.8-mm wires. A 1.8-mm medial-lateral talar neck wire also is inserted and fixed to the U-plate. Next, two 1.8-mm stirrup wires are inserted through the osseous segment just proximal and distal to the Charcot joint(s). Stirrup wires are bent 90 degrees just outside the skin to extend and attach but are not tensioned to their respective external fixation rings distant from the point of fixation. These stirrup wires capture osseous segments that are far from an external fixation ring, thereby providing accurate and precise Charcot joint distraction. A full external fixation ring is then mounted to the forefoot with two 1.8-mm crossing proximal metatarsal wires and the aforementioned distal stirrup wire. Digital pinning often is required whereby the digital wires (1.5 or 1.8 mm) are attached to the forefoot ring. Smooth wires in the foot are preferred in the neuropathic population. Finally, the six TSF struts are placed and final radiographs obtained (anteroposterior and lateral views of the foot to include the tibia). Orthogonal anteroposterior and lateral view fluoroscopic images are obtained of the reference ring; the images provide the mounting parameters that are needed for the computer planning. The choice of which ring (distal or proximal) to use as the reference ring is the surgeon’s preference (typically, a distal reference is chosen for foot deformity correction). Superimposition of the reference ring on the final films is critical for accurate postoperative computer deformity planning. It is important to fully understand the TSF planning before attempting this procedure. In synopsis, the surgeon enters the deformity and mounting parameters into an Internet-based software program that produces a daily schedule for the patient to perform adjustments on each of the six struts. The rate and duration of the patient’s schedule is controlled by the surgeon’s data entry. The patient is clinically and radiographically followed in the office weekly or biweekly.

Fixation construction is creative because of the small pedal anatomy, which renders it difficult to apply external fixation. When applying the forefoot 6 × 6 butt frame, it is important to mount the U-plate on the hindfoot and the full ring on the forefoot as posterior and anterior as possible, respectively. The greatest distance between the forefoot and hindfoot ring is critical to accommodate the TSF struts. Bone segment fixation is important; otherwise, failure of osteotomy separation or incomplete anatomic reduction occurs. Small wire fixation is preferred in the foot because of the size and consistency of the bones. When treating a patient with neuropathy, building extremely stable constructs is extremely important. Charcot deformity correction with external fixation should include a distal tibial ring with a closed foot ring.

After gradual distraction with the TSF has realigned the anatomy of the foot, the second stage of correction is performed. In the second stage, the external fixator is removed while simultaneously performing minimally invasive arthrodesis of the affected joints with percutaneous insertion of internal fixation. Gradual distraction for realignment of the displaced Charcot joint(s) is obtained in approximately 1 to 2 months. Before frame removal, small transverse incisions (2 to 3 cm in length) overlying the appropriate joint(s) are made to perform cartilage removal and joint preparation for arthrodesis. Minimally invasive arthrodesis is easily performed because the Charcot joint(s) are already distracted. Under fluoroscopic guidance, the guidewires for the large-diameter cannulated screws are inserted percutaneously through the plantar skin incision into the metatarsal head by dorsiflexing the hallux. After the lateral and medial column guidewires are inserted to maintain the corrected foot position, the frame is removed and the foot is re-prepped. Typically, three large-diameter cannulated intramedullary metatarsal screws are inserted: medial and lateral column partial threaded screws for compression of the arthrodesis site and one central fully threaded screw for additional stabilization. These screws span the entire length of the metatarsals to the calcaneus and talus, provide compression across the minimally invasive arthrodesis site, and stabilize adjacent joints. The intramedullary metatarsal screws cross an unaffected joint, the Lisfranc joint, thereby protecting the Lisfranc joint from experiencing a future Charcot event. The minimally invasive incisions are then closed, and a well-padded U and L splint is applied. Before hospital discharge (length of hospital stay ranges from 1 to 4 days), the patient’s operative splint and dressing are removed and a short leg cast is applied. A non-weight-bearing short leg cast is maintained for 2 to 3 months, and then gradual progression to weight-bearing is achieved. Therefore, the entire treatment is completed in 4 to 5 months. We have used this gradual distraction technique during the past 5 years and have achieved good to excellent success (13). Our short-term results are promising considering that neither recurrent ulceration nor deep infections have occurred. The advantages of our method are preservation of foot length and restoration of the soft tissue and osseous anatomy. In addition, our method is minimally invasive (Fig. 18.2A–F).
Figure 18.2  A. Illustration of a midfoot Charcot neuroarthropathy with equinus deformity (Eichenholz stage 2 or 3, with ulceration). Lateral view shows equinus (calcaneal pitch, 0 degrees) and rocker bottom (talar-first metatarsal angle, 25 degrees). B. Percutaneous Achilles tendon Z-lengthening is performed to acutely correct the equinus deformity. (Inset modified with permission from Springer-Verlag; 12). C. The hindfoot and ankle are then fixed in the corrected position with the Taylor spatial frame (forefoot 6 × 6 butt). Note the initial forefoot position. D. Gradual distraction (5–15 mm) and realignment of the forefoot to the hindfoot are performed with the fixator. Just before fixator removal, a minimally invasive fusion of the midtarsal joint is performed. E. After inserting the percutaneous guidewires for the large-diameter cannulated screws, the fixator is removed. Partially threaded intramedullary metatarsal cannulated screws are inserted beneath the metatarsal head percutaneously to compress both the medial and lateral columns of the foot. (Panels A, C, D, E, and F are used with permission from Sinai Hospital of Baltimore [Rubin Institute for Advanced Orthopedics].) (continued)
CONCLUSION

Although I present new, different, and complex treatment protocols for correction of the Charcot foot deformity, the basic surgical principles are maintained (obtain correction, then maintain correction). Identifying the stage and location of the Charcot foot allows the surgeon to choose the appropriate treatment plan. Many surgical and non-surgical options exist with the aim of improving the patient’s quality of life and preventing amputation. It is critical for the surgeon to choose the best option for the patient from the aforementioned list of treatments.

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INTRODUCTION

The surgical approach to Charcot diabetic foot reconstruction has slowly evolved over time and remains a subject of some controversy. First, earlier authors warned of catastrophic outcomes following Charcot repair, particularly during the initial or inflammatory phase of the disorder. Reports of loss of correction, hardware failure, and infection with resultant amputation likely had a chilling effect on pursuing surgical treatment for this malady (1,2).

The result has been the development of an extremely conservative attitude about treatment of this pathology. This is based largely on protection during the initial inflammatory and coalescence stages with total contact casting (TCC), off-loading boots, and non-weight-bearing status until quiescence of the involved process has occurred. Subsequent treatment then revolves around the wearing of special molded shoes, braces, and splints to accommodate a chronically fractured and dislocated limb, which is advised to be used only as needed. Literature continues to recommend basic surgical bone exostectomies for ulceration produced by the resultant fracture dislocations in lieu of anatomic repair (3). In spite of literature replete with gratifying outcomes when principles of surgical stabilization are employed to salvage these feet and their attendant limb, no comprehensive approach to this surgical undertaking has been described in the literature (4–8). This chapter seeks to readdress this omission and is directed toward the surgeon who is committed to proceeding with the repair.

HISTORICAL PERSPECTIVE

Jean Martin Charcot (1825–1893) is thought by many to be the father of the neurologic sciences. In his long and illustrious career at the Salpêtrière Hospital in Paris, he revolutionized the study of neurology. He was the first to describe such neurogenic ailments as amyotrophic lateral sclerosis, Charcot-Marie-Tooth, and his other namesake, Charcot neuro-osteoarthropathy. He was able to match many specific neurologic lesions to the resultant disease, including stroke, epilepsy, and multiple sclerosis. His famous teaching style is depicted in the oil on canvas by French artist Andre Brouillet in 1887 (Fig. 19.1). In this painting, Brouillet depicts the typical "theatrical style" of Charcot. In the painting, Charcot is showing his students a woman (“Blanche” [Marie] Wittman) in a "hysterical fit."

Wittman is supported by Charcot’s student, Joseph Babinski. Along with Babinski, Charcot trained or otherwise influenced many well-known neurologists; in fact, it was Padgett in 1881 who first attached the name of Charcot to the condition of neuro-osteoarthropathy. However, his most famous student was undoubtedly Sigmund Freud. Charcot taught Freud the art of hypnosis, thus paving the way for Freud to develop the modern methods of psychoanalysis. Freud thought so highly of his mentor Charcot that he named his first son after him.

In 1703, Musgrave was the first to report the condition of neuropathic osteoarthropathy (9). He thought this was an arthralgia secondary to venereal disease. In 1831, J.K. Mitchell was the first to suggest a relationship between a spinal cord lesion and subsequent “rheumatism of the lower extremities” (10). In 1868, Charcot provided a concise description of the neuroarthropathic component of the disease (11). Charcot believed that the disease process was the result of a spinal lesion related to tabes dorsalis, or syphilis. Syphilis was in fact the most common form of the disease up to 1936 when Jordan linked neuro-osteoarthropathy to diabetes mellitus (12). Today, despite over 300 years of investigation, the Charcot process continues to stimulate debate regarding its etiology, diagnosis, and treatment. Charcot joint affects up to 0.16% of all patients with diabetes and may occur in up to 29% of diabetics with end-stage sensory neuropathy (13). It is a progressive condition that results in joint dislocations, pathologic fractures, and severe deformity. Resultant deformity and instability often herald the onset of plantar soft tissue breakdown and ulceration. Because we know that 84% of all lower extremity amputations are preceded by ulceration, it is imperative that all lower extremity physicians and surgeons become proficient in the prevention, diagnosis, and treatment of this devastating phenomenon (14).
AN ALGORITHMIC APPROACH TO CHRONIC CHARCOT FOOT RECONSTRUCTION

The goal of any surgery on the chronic or postacute Charcot foot is to create a stable, plantigrade foot that can be accommodated in appropriate shoe gear. Exostectomies are reserved for those feet in which there exists a bony prominence that represents an ulcer/skin breakdown risk, but whose bony architecture remains stable and positioned to fit well into shoe gear. Surgical reconstruction is reserved for those feet whose posture prevents the wearing of shoe gear and whose architecture is grossly unstable.

In the case of the unstable, non-shoeable Charcot foot, it is the authors’ opinion that the most definitive and long-term stability may be obtained by aggressive fusion techniques. Although there is literature to support deformity correction via application of external fixation followed by either acute or gradual correction without major fusion, the authors do not currently subscribe to this form of intervention. When addressing the apex of the primary deformities, it is often a good idea to incorporate the joints distal and proximal to this area to obtain the most stable postsurgical construct. When performing bone and cartilage resection, the surgeon must remove all nonviable segments to obtain adequate fusion. With this concept in mind, the authors always attempt to remove just that amount of cartilage and subchondral bone needed to obtain osteosynthesis. However, on occasion, especially with advanced deformity, large segments of nonviable fibrotic bone need to be resected to obtain the ultimate goal of a stable foot.

PREOPERATIVE CONSIDERATIONS FOR CHRONIC CHARCOT FOOT SURGERY

The surgical patient for Charcot salvage must undergo a rigorous preoperative evaluation prior to surgery. This should include a comprehensive arterial examination, including toe pressures and repair of any deficits preoperatively. Marginal vascular status does not necessarily preclude surgery in severe or at-risk Charcot limbs; a percutaneous approach may usefully be considered, as will be discussed in the following. A thorough medical examination preoperatively, including cardiac clearance when indicated, is mandatory. Preoperative laboratory studies should include screening for bone metabolism aberrations, including serum calcium, 25-hydroxyvitamin D, serum osteocalcin, and 24-hour urine calcium. Abnormalities must be treated before elective surgery can proceed. If there are open ulcers associated with the Charcot fracture dislocations, then combination technetium/indium bone scanning should be considered to rule out attendant osteomyelitis. Osteomyelitis of the Charcot foot does not of itself preclude reconstruction, but its treatment should precede it; this is also discussed in the text.

SURGICAL GOALS FOR SUCCESSFUL CHRONIC CHARCOT RECONSTRUCTION

The repair of the Charcot fracture dislocated foot ideally should produce a foot without any open ulcerations as a final result, a foot that fits satisfactorily into standard diabetic or athletic shoe footwear. It should not be grossly foreshortened because of an aggressive resection of the avascular and/or dislocated bones. The Achilles tendon should not be overlengthened, resulting in apropulsion, calcaneal gait, and heel ulceration. The insertion of peroneus brevis and its function should be protected to avoid iatrogenic cavovarus deformity.

Radiographically, the calcaneal positive inclination angle should be restored, as well as the Meary’s angle. On lateral radiographic examination, the calcaneal inclination in Charcot is often reversed to a negative angle and this is mainly because of the contracture of the Achilles tendon. This contracture is contributed to either the fact that the midtarsal fracture instability is no longer resisting the tonic pull of the tendon at rest or due to glycosylation of the diabetic Achilles tendon with shortening and loss of elasticity or possibly because of both factors. This must be surgically corrected to permit the ensuing redress of the bony Charcot deformities.

Meary’s angle, briefly defined as lines bisecting the first metatarsal and talus on lateral radiographic view, should be restored to as close to parallel as possible compared with the acute negative angle often created by Charcot collapse (Fig. 19.2A–C). On anteroposterior (AP) projection, the Charcot diabetic foot often presents with fracture dislocation at either the Lisfranc or midtarsal joint, with resultant severe abduction of the midtarsus or Lisfranc joints or conversely adduction. A more careful inspection of the radiographs sometimes reveals superimposition of the metatarsal bases on the cuneiforms. In other cases, AP radiographs reveal superimposition of the metatarsals or cuneiforms on the navicular and/or cuboid. When this is appreciated on AP projections, a review of lateral radiographs typically reveals plantar dislocation of the navicular, cuboid, or both, usually with the medial cuneiform, or fourth and fifth metatarsal bases resting above them. The plantar dislocation of the navicular and especially the cuboid is a key and an ominous radiographic finding with Charcot, typically correlating with either bony prominences or frank ulcerations plantarly on the Charcot foot (Fig. 19.3A,B).
PRINCIPLES OF CHRONIC CHARCOT FOOT RECONSTRUCTION

It is the authors’ contention that Charcot foot repair can be approached in a consistent manner with gratifying results for both the surgeon and most especially the patient. Four surgical techniques may be employed in virtually all Charcot foot reconstructions, including:

1. Tendo-Achilles lengthening (TAL)
2. Anatomic restoration of subtalar and midtarsal fracture dislocations; resectional arthrodesis of Lisfranc joint
3. Alignment of the midtarsal and Lisfranc joints with large diameter intermedullary stainless steel screws that act as “beams” of support. Alternatively, recently locking plates have been advocated by one of the authors as a substitute for the screws. Therefore, both of these internal fixation methods are presented in this chapter.
4. Application of an Ilizarov-type external fixator to aid in compression arthrodesis of the realigned fracture fragments

This systematic approach can be used as a basic framework to equip the tentative reconstruction surgeon with tools that can be relied on in the midst of a repair procedure, which can unfold with unforeseen difficulties not entirely anticipated at the onset of the surgery. By returning to the stepwise method described, the difficulties encountered intraoperatively can be addressed and the procedure successfully completed.

STEPWISE APPROACH TO CHRONIC CHARCOT RECONSTRUCTION

THE ROLE OF ACHILLES TENDON LENGTHENING

Lengthening the Achilles tendon is the first step in Charcot reconstruction. There is basic science supporting the notion that contracture of the Achilles tendon may have some etiologic causality for the development of Charcot neuroarthropathy in diabetic patients. In 1997, it was reported that the morphologic structure of the Achilles tendon was altered in a series of diabetic patients undergoing Charcot re-
pair compared with nondiabetic patients undergoing reconstructive surgery. Specifically, the bundles of type A collagen that could be visualized as being in parallel bundles under the electron microscope were found to have lost their parallel bundle arrangement. (Fig. 19.4A,B). This was further described as an increased packing density of collagen fibrils and subsequent decrease in their diameter with overlapping and in Charcot diabetic tendons. This morphologic aberration suggested a potential alteration in function of the Charcot diabetic Achilles tendon (15).

Subsequently, a second paper addressed this question of altered Achilles function in the diabetic Charcot foot. Twenty diabetic Charcot Achilles tendons were compared with nine nondiabetic control tendons for ultimate tensile strength and Young’s modulus of elasticity. Results showed significantly less tensile strength and elasticity in Achilles tendons from the Charcot feet. Again, the mechanism for this is believed to be nonenzymatic glycosylation of the collagen (16).

The decreased elasticity may translate clinically as a short tight tendon unable to stretch to permit normal dorsiflexion as the body crosses over the foot during gait. The decreased tensile strength of the Achilles in Charcot may be generalized to include other collagen structures of the foot, including the ligaments, which principally stabilize the midfoot joints; these are potentially prone to failure, and especially so when equinus of the Achilles tendon forces the midfoot joints; they stabilize to dorsiflex as compensation during midstance and toe-off (Fig. 19.5). In fact, some early Charcot midfoot dislocations can be readily surgically managed with lengthening of the Achilles tendon and percutaneous screw stabilization of the subluxing Lisfranc’s joints.

Virtually every Charcot foot reconstruction should begin with an open Z-plasty of the Achilles tendon to an extent that a 90-degree relationship is established between the plantar heel and an imaginary line bisecting the fibula (Fig. 19.6A–C). This re-establishes a positive calcaneal inclination angle as well as decompressing the severely fractured midfoot joints, thus permitting the reconstructive surgeon easier access to these structures for repair (Fig. 19.7A,B).
Chapter 19 Surgical Reconstruction and Stepwise Approach to Chronic Charcot Neuroarthropathy

The Lisfranc joint is the easier of the two to repair in Charcot deformity. Depending on whether the forefoot is ab ducted and dorsiflexed or adducted and inverted, a medially or laterally based osteotomy is cut through the articular surfaces of the Lisfranc joint. After a dorsal envelope, including the neurovascular structures, is created, it is helpful to place two Kirschner wires (K-wires) under fluoroscopic guidance to act as guides for the correctional osteotomy, thereby minimizing excessive bone resection. Once the wedge of bone is resected, the forefoot can be readily manipulated into a correct position against the hindfoot and temporarily held with K-wires until permanent internal fixation is placed (Fig. 19.8A–D).

The repair of the midtarsal joint is considerably more challenging to perform and is at times associated with the need to arthrodese the Lisfranc joint. Often the navicular is resting below the displaced medial cuneiform medially; in these instances, the talus usually accompanies the navicular, producing a near vertical talus on lateral radiographic examination. On AP radiograph, the navicular may appear missing, as the talus appears to articulate with the medial cuneiform, which is blocking the view of the navicular. Similarly, the cuboid is often plantar dislocated beneath the bases of the fourth and fifth metatarsals, such that it appears foreshortened on AP radiographic viewing. On the lateral view, it is often possible to detect that the cuboid is plantar dislocated beneath the metatarsal bases. It is here, laterally at the site of the plantar dislocated cuboid, that an intractable ulceration often forms at the site of most plantar pressure. This ulceration is unlikely to resolve with bracing or special shoe gear.

It is the authors’ preferred method to incise both the medial and lateral midtarsal joints with linear incisions beginning...
Stepwise Approach to Chronic Charcot Reconstruction

Figure 19.8  A. Lisfranc’s Charcot repair osteotomy with K-wire fluoroscopic guidance. B. Manual manipulation of the bony wedge osteotomy. C. Another example of using the K-wires as an axis osteotomy guide. D. Bony wedge resection at Lisfranc’s joint with K-wire guidance.
approximately 1 cm inferior to and distal to the malleoli, extending distally medially to the base of the first metatarsal and laterally to the base of the fourth metatarsal. Both incisions are deepened to gain direct visualization of the plantar dislocated navicular and/or cuboid. Using a combination of curved osteotomes, lamina spreader and sharp dissection with Sistrunk scissors or scalpel, the dislocated tarsal bones are either relocated into anatomic position, or more often removed from the wound and passed off to the back table for removal of all articular cartilage.

Once the dislocated tarsal bones are removed, it is relatively facile to manipulate the foot into a rectus alignment on all three body planes and temporarily hold it in place with K-wires. At this time, fluoroscopy imaging is used to determine areas of bony deficit, which can be repaired with grafting of the surgeon’s choice. If either or both tarsal bones have been rendered unsuitable for grafting because of the Charcot process or infection, alternatives include freeze-dried iliac crest, fresh-frozen femoral head, or even shortening of the midfoot with arthrodesis of remaining viable bone. This last method, resection of the entire Charcot midfoot, which produces a grossly shortened foot, was the initial technique used for salvage and remains a viable alternative to amputation in cases of osteomyelitis of the midfoot, often complicated by ischemic necrosis and cellulitis of the dorsum of the foot.

**INTERNAL FIXATION OF CHARCOT DEFORMITIES USING THE BEAMING TECHNIQUE**

One of the authors developed a beaming technique to internally fixate Charcot midfoot and hindfoot deformities, and has used this method with gratifying results since 1994. The technique was then reported at the American College of Foot and Ankle Surgeons (ACFAS) Meeting in Palm Springs in February of 1997.
Initially, the technique of internal beaming was developed because of breakage of small screws used for fusion whenever pseudarthrosis occurred in these salvage surgeries. Often the broken screws resulted in loss of correction and redeformity. A second reason for development of this technique was as an alternative to large plates, which require removal in instances of dehiscence, again with possible loss of correction.

The use of large-diameter stainless steel screws has many advantages, including:

1. The screw placed within the medullary canal of the first metatarsal accepts the loads of the medial longitudinal arch, namely, tension plantarly and tension dorsally. Thus, its placement is physiologic, acting as a beam to accept both types of loads through the arch (Fig. 19.10A,B).

2. Placement of the medial column screw entering within the head of the first metatarsal and ending in the talus allows an anatomic recreation of Meary’s angle laterally; in fact, an arch can be produced with this technique from a collapsed foot. On AP viewing, the screw aligns the forefoot with the hindfoot directly, correcting varus or valgus angulation.

3. Because a large diameter cannulated screw is used, its guide pin can be used first under fluoroscopy to readily line up all bone segments on both AP and lateral views. This ability to align the forefoot to the midfoot and hindfoot with a single guide pin on all body planes, followed by rigid internal fixation with a large-diameter intermedullary screw, is an enabling factor of value to the surgeon attempting complex realignment (Fig. 19.11A,B).

4. Bending moment calculations at the Lisfranc’s joint indicate that a cannulated stainless steel screw of at least 7.2 mm diameter provides a 2× safety factor against failure in a 300-lb patient.

5. The lateral column also may require beaming; this is particularly true when the cuboid has dislocated or subluxed, and is now relocated. In this case an arthrodesis needs to be effective between the fourth and fifth metatarsal bases to cuboid, and cuboid to calcaneus. In this case a second large-diameter screw is placed laterally, entering the adjacent bases of the lateral metatarsals. This screw should lock its head into at least one metatarsal base to ensure locking of the Lisfranc’s joint to the cuboid; otherwise, if fusion at the Lisfranc’s does not occur, the reactive forces of walking can cause recollapse, or at least loss of some correction (Fig. 19.12A,B).

The beaming technique has proved consistently successful over time in cases in which a true arthrodesis of Charcot joints was obtained, and likewise in cases in which pseudoarthrosis is
the final outcome. If the screw diameters are large enough, and the beam is placed across the defective Charcot bone such that both head and tip of the screw are in (relatively) satisfactory bone, then the correction should not fail in spite of pseudoarthrosis.

One issue that has not been fully resolved in these cases has been the question as to whether or not to fuse the subtalar joint in cases of severe Charcot hindfoot and midtarsal collapse. The subtalar joint when fused connects the independent medial and lateral columns into a unified (regarding weight-bearing) entity. If the columns are locked together, then load sharing between the columns can occur. If pseudoarthrosis is the final outcome in such a case, then by locking up the subtalar joint through arthrodesis, the medial and lateral column beams can load share, thus protecting the correction from recollapse.

**THE USE OF EXTERNAL FIXATION IN CHRONIC CHARCOT RECONSTRUCTION**

The Ilizarov technique has proved especially useful in cases of Charcot arthropathy. The external fixator frame is extremely useful to compress segments of bone to achieve arthrodesis, offload and protect plantar wounds, bridge across sites of defective or infected bone, and allow access to postoperative diabetic wounds during the healing process (17–19). Some surgeons initiate weight-bearing with their patients after Charcot reconstruction in an Ilizarov frame with the belief that this load-sharing between the plantar foot on the floor and the external fixation protects the correction and actually speeds bone healing. Recent research proposes a different possible mechanism for this type of healing with Ilizarov bent wire compression frames. Bent wire compression frames showed more compression across an experimental midfoot osteotomy site than a noncompression frame, parallel K-wires, or parallel screws. Additionally, the best compression was shown to occur with a combination of internal screws and an external fixator bent wire frame (20).

External fixators do carry with them an elevated complication rate with pin or wire tract infections, broken wires and/or half pins requiring reapplication, and need for frame adjustment. These complications do not appear to reasonably detract from enhanced outcomes in these difficult cases. The Ilizarov frame presently represents a cornerstone for Charcot limb salvage technique.

**THE USE OF LOCKING PLATES IN CHARCOT RECONSTRUCTION**

Thus far we have discussed the concepts of beams and external fixation. The common theme is that successful Charcot reconstruction is dependent on intersegmental stability during the biologic fusion process. Another method of obtaining significant stability into the surgical construct is via the use of locking plate technology (Fig. 19.13A–E). The primary advantage to the use of a locking plate along the medial and/or lateral column resides in the plate’s ability to resist strain across the fusion site (4). Perren’s theory of strain states that there is a relationship between decreasing strain and increasing the potential for osteogenesis across a fracture or fusion site. The strain theory states that for two given fracture segments, the healing interface will have a force-generated motion potential that is contingent on the stability of the original fixation construct. Mathematically, strain is equal to the change in the interface length divided by the original interface length for any given disruptive force. Therefore, with an unstable construct, the healing gap may undergo excessive motion that is described...
as excessive strain. Strain $<2\%$ is considered to be equal to absolute stability, and therefore results in primary bone healing. Strain $>10\%$ is described as an unstable construct, and therefore is at great risk of nonunion or delayed union. If strain resides between $2\%$ and $10\%$, there is micromotion at the bone healing interface, which results in predictable secondary bone healing. In a locking plate construct, in which the plate and the locked screws function as one unit, there is significant resistance to any change in the interfragmentary gap length for any given force. Thus, failure of the locking plate construct only occurs in the face of catastrophic forces at all of the locked screw–bone interfaces.

Figure 19.13 This 64-year-old man presented with a grossly unstable midfoot. A. The apex of the deformity was at the tarsometatarsal and naviculocuneiform joints. A,B. The dominant plane of the deformity was sagittal. C,D. The patient underwent reconstruction via TAL, medial column stabilization via an anterior cervical locking plate, limited internal screw fixation, and static external fixation. E. Note the re-establishment of structural alignment. The time to union and external fixation removal was 10 weeks.
Application of locking plates to the medial and/or lateral column is technically simple and follows the same concepts as any other standard plate fixation. However, care should be taken so that the plate is well-contoured to the bone prior to locked screw insertion. This is because, unlike non-locking plates, the screw does not compress the plate to the bone since the threaded head obviates a lag effect. Also, a small locking plate may be used when the primary fixation is that of a large fragment lag screw placed in a beam technique. This is because the beam provides excellent stability to sagittal and transverse forces, but does little to resist rotational or coronal forces. Therefore, in this construct, the small locking plate acts in a similar way as the static locking screw of an intramedullary rod.

CONCLUSION

Neuro-osteoarthropathy with resultant instability and deformity continues to be a vexing problem today, just as it was in the time of Jean Martin Charcot. However, unlike Charcot, the foot and ankle surgeon of the twenty-first century has many advantages, including advanced diagnostic and imaging techniques, a better understanding of the biomechanics and biology of the disease process, and a multitude of fixation materials.

REFERENCES

INRODUCTION

Charcot neuroarthropathy (CNA) involving the foot and ankle is a rather challenging clinical entity for the foot and ankle surgeon. Although nonoperative therapy is most often effective in maintaining a stable and ulcer-free limb, there are times when surgical management is often necessary for limb salvage. This chapter deals with surgical management of CNA involving the hindfoot and ankle. The use of intramedullary nail fixation is presented in detail. A review of indications, contraindications, technical execution, postoperative management, and complications is presented.

PREOPERATIVE CONSIDERATIONS

Those diabetic patients undergoing CNA reconstruction require an extensive preoperative evaluation. This should include cardiac assessment given that these patients often have silent cardiac disease. Cardiology consultation or thorough cardiac evaluation by the primary treating physician, including an echocardiogram or stress thallium scan, is often necessary to ensure that these patients are safe candidates to undergo a complex reconstructive procedure.

The soft tissue envelope should be thoroughly evaluated for wounds or poor-quality tissue. It is prudent to operate with a closed soft tissue envelope. There is clear evidence that elective surgery in the presence of an open wound increases the incidence of postoperative infection (1). However, there are times when surgery may be necessary in the presence of an open wound. It is important to ensure that there is no evidence of clinical infection within the wound site in these situations. Serial débridements, local wound care, offloading, and antibiotic therapy may be necessary before proceeding to any type of advanced surgical reconstruction.

Some patients may require a social services consultation prior to undergoing surgery. There is a relatively long period of convalescence following surgical intervention that includes non-weight-bearing and limited mobility. Therefore, patients are nonambulatory for an extended period of time. They may require postoperative deep vein thrombosis prophylaxis or have other special needs that are difficult to meet in a home environment. Unfortunately, these patients may have very little family support or are unable to manage themselves. It is often beneficial to have these patients placed in a subacute or rehabilitation facility to assist them during the initial period following surgery.

Advanced imaging may provide some benefit prior to surgical management. CNA often results in avascular bone, which is difficult to ascertain on standard radiographs. Avascular bone requires extensive débridement to obtain a healthy cancellous substrate that will proceed to primary union. Advanced imaging, such as magnetic resonance imaging (MRI), may provide insight as to whether or not avascular necrosis is present and will help with surgical planning. Bone scintography also may be of benefit in situations in which osteomyelitis is a possibility. This is especially beneficial in patients with longstanding open wounds that have failed to heal. It is important to ensure that osteomyelitis is not present prior to surgical reconstruction.

One of the most important preoperative considerations is to thoroughly evaluate the patient’s existing deformity. These patients need to be evaluated both clinically and radiographically. The majority of patients with CNA involving the hindfoot and ankle that have failed nonoperative care usually have frontal plane deformity. Unfortunately, frontal plane deformity, whether grossly unstable or fixed and nonreducible, is often difficult to manage with bracing or shoe therapy. Additionally, a frontal plane deformity is difficult to manage with percutaneous techniques in the presence of a nonreducible deformity. These patients usually require open surgical management. The authors often employ long-leg axial radiographs to evaluate the deformity (2,3). These radiographic views demonstrate the relationship of the tibia, talus, calcaneus, ankle joint, and subtalar joint relative to one another. These views specifically show which anatomical sites are involved and whether one is dealing with a translational versus an angulational deformity (Fig. 20.1).
CONTRAINDICATIONS

There are some specific contraindications to CNA reconstruction of the hindfoot and ankle. Uncontrolled diabetes mellitus or malnutrition is an obvious contraindication. Those patients demonstrating elevated hemoglobin A1C levels or longstanding hyperglycemia are precluded from undergoing surgical management. Patients who are medically unfit for any reason, including poor cardiac and renal status and severe peripheral vascular disease, should not undergo any extensive surgical reconstruction. Active infection of either soft tissue or bone is an absolute contraindication to surgical reconstruction. Any soft tissue or osseous infection should undergo thorough débridement, antibiotic therapy, and complete resolution before proceeding to any complex reconstruction. Patients and their families must thoroughly understand what is required during the postoperative period. A patient’s inability to comply or comprehend is an obvious contraindication to surgery. Complications, extended convalescence, and return visits to the hospital and operating room are not uncommon following surgery. These patients must be thoroughly evaluated to ascertain whether they understand what is required following surgery.

Traditional literature has described the acute inflammatory phase of CNA as a contraindication to surgical reconstruction. Sydney Eichenholz has stated that “an arthrodesing procedure to stabilize a Charcot joint during the stage of
development is doom to failure.” Furthermore, he states that “the optimal time for surgery is at the completion of the reconstruction stage” (4). More recent literature, however, has shown that operative intervention during the early stages of CNA produces good outcomes. Shibata presented his results of ankle arthrodesis in Leprotic neuroarthropathy. Twenty-six ankles were reviewed in an average of 9.5 months following ankle arthrodesis. Four of the patients who underwent surgery were early-stage CNA that went on to primary union. However, seven of the 22 patients who were late-stage CNA developed a nonunion. He concluded that arthrodesis was more successful in earlier stages of CNA (5). Simon et al. presented 14 patients undergoing midfoot arthrodesis for CNA. All patients had stage I midfoot involvement. All procedures were successful with no report of ulcerations or complications. They concluded that early operative intervention may expedite the reversal of the destructive CNA process (6). Although the timing of surgical intervention is traditionally recommended in the quiescent stages of CNA, it remains somewhat controversial and should be based on the patient’s unique set of circumstances.

INDICATIONS

Indications for surgical reconstruction of CNA involving the hindfoot and ankle include a nonreducible deformity with increased plantar pressure, resulting in a nonhealing wound (Fig. 20.2). This includes patients with wounds that proceed to heal when offloaded, but recur when weight-bearing resumes. Surgical intervention to offload an at-risk foot is warranted when bracing and shoe therapy have not been effective or have failed to maintain these patients ulcer free.

The other primary indication for operative intervention is significant deformity with gross instability that is not amenable to brace treatment. Some patients may have significant difficulty tolerating brace therapy. Surgical management should be considered to impart stability to the limb such that brace therapy can be tolerated when gross instability is present.

The primary goals of surgical management are to maintain the patient’s ability to transfer or remain a short distance ambulator. Surgery should restore stability and alignment such that footwear and bracing can be effective.

ANCILLARY PROCEDURES

It is important that a completely plantigrade foot be obtained at the time of the surgery. Therefore, bony resection or realignment must be sufficient to completely reduce any existing deformity. Structural bone graft is rarely necessary in the majority of patients. The authors have found that patients tolerate limb shortening quite well, so long as the foot is plantigrade. Bone graft or bone graft substitutes are often used to enhance arthrodesis. The authors typically use regional bone graft such as the fibula. A bone mill or reamer can be used to morselize the fibula. Morselized autogenous bone can be combined with an orthobiologic substance such as demineralized bone matrix to provide an excellent enhancer to arthrodesis. Additionally, the fibula can serve as a source of structural bone graft should the need arise.

Posterior muscle group lengthening in the form of gastrocnemius recession or Achilles tendon lengthening is required in virtually all patients undergoing CNA reconstruction. This is especially important where there is complete loss of calcaneal inclination. Restoration of calcaneal inclination is difficult without some type of posterior muscle group lengthening.

INTRAMEDULLARY NAIL FIXATION

Intramedullary (IM) nail fixation is preferred when possible. An IM nail with interlocking screws will maintain alignment, length, and stability when bone loss or osteopenia is present. This is often the case in CNA involving the hindfoot and ankle.

Figure 20.2  A–C. Fixed Charcot hindfoot/ankle varus with secondary neurotrophic ulcer along the fifth metatarsal base area.
Additionally, delivery of an IM nail results in minimal disruption of soft tissue relative to fixation devices such as large plates. The proximal and distal interlocking screws impart excellent stability. Additionally, an IM nail serves as a rigid, load-sharing device. This is especially advantageous in CNA patients with poor-quality bone. There are some contraindications to using an IM nail in CNA patients. An insufficient heel pad or a heel with previous ulceration is often a contraindication. These nails are delivered through the plantar aspect of the heel and soft tissue problems may result if the fat pad is insufficient or of poor quality. Any proximal deformity in the tibia is also a contraindication. Proximal deformity often results in delivery of an IM nail that is too short. Short nails are to be avoided because there is an increased incidence of tibial stress fractures. Lastly, the inability to obtain collinear reduction between the tibia, talus, and calcaneus is an obvious contraindication. A straight IM nail cannot be delivered without collinear reduction of all osseous components.

The IM nails used in hindfoot and ankle reconstruction have evolved to provide greater compression and rotational stability. The first IM nails used in foot and ankle surgery were distal femoral nails designed for supracondylar femur fracture fixation (7,8). The interlocking screws were directed from lateral to medial. Second generation nails added calcaneal locking in the posterior-to-anterior direction to provide rotational stability. In addition, these IM nails allowed compression across the arthrodesis site. Second-generation nails have been shown to provide excellent biomechanical stability. The biomechanical strength can be attributed to the dense bone purchased near the sustentaculum tali and by neutralizing sagittal plane forces at the ankle joint (7–10). Humeral nails have also been evaluated in foot and ankle surgery. The curve in the distal portion of the humeral nail allows for insertion of the nail without medialization of the foot (11). This eliminates the necessity of an additional medial incision and partial resection of medial malleolus or extensive medial malleolar dissection to achieve medial translation of the osseous segments (8,11,12).

In original biomechanical studies, the IM nail has been shown to provide stability similar to other forms of fixation. Investigations of primary stability following tibiotalocalcaneal (TTC) arthrodesis with various implants have not proved one implant more superior to another (13,14). Comparative studies between IM nail fixation and blade plate have shown varied results (15,16). In view of the fact that all implants are similar, factors such as osteopenia, quality of soft tissue envelope, and surgeon preference should determine the choice of implant.

IM nails have become a useful device to obtain stability in the foot and ankle. Pinzur et al. reported on 21 CNA ankle fusions with retrograde locked IM nails. They showed 20 cases achieved fusion at 12 to 31 months when takedown was not required. Overall, they describe their results to be satisfactory (17). The authors prefer to use an IM nail supplemented by a static external fixator whenever possible.

TECHNICAL EXECUTION

Surgery is performed under general inhalation or spinal anesthesia. The authors typically employ a pneumatic thigh tourniquet until osteosynthesis has been achieved. Thereafter, the pneumatic tourniquet is released and hemostasis is achieved prior to a closure. There should be a sandbag or blankets placed under the ipsilateral hip such that the foot can be easily accessed and manipulated from medial to lateral. The foot is usually suspended over a large sponge block or a set of blankets to enhance intraoperative imaging.

The procedures are performed through a combination of medial and lateral incisions. The lateral incision extends from the distal one third of the fibula to the sinus tarsi. Full-thickness dissection is typically employed. All soft tissues are completely elevated and the fibula is resected and saved for possible use as a bone graft. All soft tissues are dissected from the anterior and posterior aspect of the ankle and subtalar joint. Depending on the nature of the deformity, the subtalar joint is thoroughly demuded of all cartilaginous tissues. Small osteotomies can be used to methodically break the subchondral plate. This can also be performed with a side-cutting burr. Attention is then directed to the medial aspect of the ankle, where an incision is made along the anterior aspect of the medial gutter. Care must be taken to tie off vessels that are part of the anterior ankle capsule. The incision is then carried down through the ankle joint capsule and all soft tissues are elevated from the ankle. This gives complete visualization of the ankle joint. The joint is then resected with the use of a sagittal saw. Joint and bony resection depends on the nature and extent of the deformity. One must thoroughly evaluate this area for avascular bone or fibrocartilaginous tissue. Avascular bone and diseased soft tissue must be thoroughly evacuated. It is important to carry out débridement down to a level of healthy cancellous bone to enhance primary union between bony segments.

Following bony resection and joint preparation, the osseous segments are aligned in a collinear fashion. The talus and calcaneus must be translated medial for proper positioning because the position of the calcaneus is about 1 cm lateral to the distal tibia. Failure to medially translate the foot may result in fracture of the medial cortex of the calcaneus or damage to vital neurovascular structures. Positioning of the foot under the leg to achieve optimal alignment is the most critical aspect of the procedure. Failure to medially translate the foot may result in placement of the IM nail in a valgus angle which can lead to a stress riser along the cortex of the tibia. At times, it may be necessary to resect a portion of the medial malleolus to allow for adequate translation; however, this is uncommon. After translation has been achieved, evaluation of rotational (transverse plane) deformity should be performed to ensure the ankle is not in excessive internal or external position. Alignment should be confirmed with image intensification, including anteroposterior (AP) and lateral view of the ankle and a calcaneal axial view. These three views are usually adequate to ascertain reduction of the osseous segments. Provisional fixation can be obtained with Steinmann pins. An IM nail is then delivered in standard fashion. The exact steps for nail delivery depend on the type of the nail that is being used. Placement of the IM nail should be anterior to the weight-bearing aspect of the calcaneus and slightly lateral to avoid neurovascular structures. Sequential reaming is required for preparation of the intramedullary canal. Most IM nail manufacturers recommend reaming 0.5 mm larger than the nail diameter being inserted. The nail is then delivered with the amount of countersink into the plantar calcaneus, depending
on placement of lateral-to-medial screws. Orientation of the screws will be lateral-to-medial at the level of the calcaneus and talus. A posterior-to-anterior screw is also available in some nails, which has been shown to offer better rotational stability. The tibial screws are inserted and can be placed in a medially-to-lateral or lateral-to-medial direction. The nail is inserted in an internally rotated position to bring the interlocking screw holes to a position anterior to the fibula. Every attempt should be made to obtain complete bone-nail interface. This can be difficult because of the small calcaneal bone at the site of insertion and the medially placed nail. A medially placed IM nail may not leave adequate bone for purchase with the lateral-to-medial screws. Compression can be achieved after the proximal screws have been inserted through a mount-ing device. The distal screws are then inserted in either a lateral-to-medial (LM) or posterior-to-anterior (PA) direction. Although the PA screw may provide additional torsional stability to the construct, the surgeon should consider complications of the screw as well. Soft tissue breakdown at the screw head in this area of poor soft tissue coverage can occur. This entire process is performed under image intensification to ensure appropriate alignment, cortical screw purchase, and appropriate screw length. The authors sometimes supplement this construct with large-diameter screws to increase stiffness. The pneumatic ankle tourniquet is then released and hemostasis achieved. Bone graft is then placed to augment arthrodesis sites and/or provide structural support. A close suction drain is beneficial. A static external fixator, which serves as a neutralization device, is often applied.

The nail length should extend beyond the distal isthmus of the tibia. The surgeon should consider using a nail that is as long as possible in the majority of these cases. Longer nails provide for additional stability, particularly in neuropathic patients. Additionally, the use of a longer nail often reduces the incidence of stress risers. Noonan et al. performed a biomechanical analysis of nail length on cadavers that included a strain gauge analysis of cadaver tibiae. They performed an analysis of standard-length IM nails versus longer nails. The standard-length nails increased strain of the posterior tibial cortex at the level of the proximal interlocking screw 5.3 times than that of the longer nail. They concluded that the longer retrograde nails may be more appropriate in patients with neuropathy or osteopenia (18).

The primary goal is complete reduction of frontal plane deformity. Ultimately, a plantigrade foot should be obtained at the time of surgery. Often this requires extensive bone resection and secondary shortening of the extremity. Shortening is usually acceptable and well tolerated in the majority of the patients. However, there are unique situations in which shortening may be rather extensive and a structural bone graft may be necessary. The fibula provides an excellent source of structural autograft if it is viable. The authors also use frozen femoral head allograft, which is osteoconductive and provides volume (Fig. 20.3). This provides an adequate source of structural bone graft. Otherwise, the authors morselize the fibula and combine it with an orthobiologic substance such as demineralized bone matrix. The IM nail is delivered following resection and realignment. The foot segment is then distracted distally over the nail until adequate length is obtained. Interlocking screws are then delivered and the structural bone graft is placed into the deficit (Fig. 20.4).

However, this is rarely necessary. More often than not, shortening is well tolerated and easily accommodated with postoperative bracing and shoe therapy (Fig. 20.3).

**POSTOPERATIVE MANAGEMENT**

These patients require an extended period of non-weight-bearing during the postoperative course. Patients are maintained in a static external fixator or a modified total contact cast following surgery. They must be completely offloaded until the hindfoot and ankle undergo complete consolidation. Patients are evaluated with serial radiographs and clinical assessment. Patients are permitted partial weight-bearing in a pneumatic fracture brace or Charcot Restraint Orthotic Walker (CROW) if the extremity demonstrates limited edema and minimal warmth (19). Edema and temperature should be compared with the contralateral extremity. Some patients may require placement in a subacute or extended care facility depending on their social situation. An implantable bone growth stimulator can be inserted at the time of surgery or an external bone growth stimulator can be used over the cast. However, if the surgeon is considering a static external fixator to supplement the IM nail, an implantable bone growth stimulator is preferred. All patients are ultimately placed into some type of permanent bracing. The combination of casting, external fixator, and weight-bearing transition device usually extends up to 8 months.

**COMPLICATIONS**

Complications are not uncommon following CNA reconstruction of the hindfoot and ankle. Infection is always a concern. These patients should be given prophylactic antibiotics, and the authors consider an extended course of antibiotics if a wound is present at the time of surgery. Patients should be seen at frequent intervals following surgery so that early signs of infection can be identified and addressed. Alternatively, home nursing can provide evaluation and treatment of surgical wounds, pin sites, and ulcers. Additionally, if patients are placed into a cast, the cast should be changed frequently so that the postoperative wounds can be frequently inspected and to ensure that the cast has not caused iatrogenic wounds.

Tibial stress fractures can develop with the use of an inadequate length IM nail (Fig. 20.6). Short IM nails are often delivered when there has been inadequate frontal plane reduction of the osseous segments, the foot is not adequately translated in a medial direction, or the nail is delivered at an angle to the long axis of the tibia. The most common site of stress fracture is at the proximal interlocking screw (Fig. 20.7). Therefore, the use of long IM nails is recommended in these diabetic neuropathic patients.

Malunion and nonunion are also possible complications. Malunion is especially difficult to address. Malunion or residual deformity results in a fixed non-plantigrade foot with the potential for wounds to develop at some point in the future. It is imperative to obtain a plantigrade foot at the time of surgery. Nonunion is typically addressed in standard fashion with bone growth stimulators, extended non-weight-bearing immobilization, and sometimes surgical management. Nonunion can also result in broken hardware that can be difficult to retrieve.

*(text continues on page 253)*
Figure 20.3  A,B. Preoperative radiographs showing Charcot deformity. C,D. Immediate postoperative radiographs demonstrating intramedullary nail with frozen femoral head as structural graft following complete evacuation of talar body. E,F. Lateral and AP radiographs at 7 months status post demonstrating consolidation of bone graft.
Figure 20.4  A–C. Preoperative clinical radiograph and demonstration of Charcot deformity with absence of the talar body. D,E. Intraoperative AP image demonstrating guide pin placement and delivery of the intramedullary nail while maintaining length. A structural bone graft will be placed into the deficit. (continued)
Figure 20.4  (Continued) F–H. Intraoperative view of the structural allograft followed by a lateral and AP image demonstrating the tibiotalocalcaneal (TTC) fusion and implantable bone stimulator. (I) Application of a static external fixator as a supplement to provide neutralization.
Figure 20.5  A–C. Clinical picture and radiographs demonstrating severe Charcot deformity with gross instability. D. Intraoperative view of the ankle and subtalar joint demonstrating severe degeneration. E. Note generous resection of distal portion of tibia. F. Lateral intraoperative imaging demonstrating delivery of IM nail. (continued)
Figure 20.5  (Continued) G-H. Eight months anterior and posterior postoperative clinical pictures. I-M. Significant shortening of the reconstructed right limb that is accommodated with appropriate bracing and foot gear.
Figure 20.6  A–C. Three months status post radiographs demonstrating consolidation at the arthrodesis sites following the use of an intramedullary nail and external fixator.  

D–F. Five months status post radiographs demonstrating stress fracture within the midshaft of the tibia. Note the short length and angulation of the intramedullary nail.  

G,H. Fracture healing complete after an extended course of immobilization and nonweight-bearing.
Figure 20.7  A,B. Intraoperative images demonstrating AP image of the ankle and a calcaneal axial view. Note the failure to translate the calcaneus and the medial placement of the intramedullary nail within the calcaneus. C,D. Stress fracture noted at the most proximal interlocking screw.
Wound problems can develop with overzealous retraction or when excess tension results following realignment. This can lead to wound necrosis that requires serial débridements, wound care, and antibiotic therapy. These problems can be addressed with negative pressure wound therapy (NPWT), delayed primary closure, secondary intention healing, and plastic surgical intervention (Fig. 20.8).

Hardware problems may occur. Interlocking screws can loosen, back out, and may require removal. Additionally, IM nails that are not completely flush with the plantar calcaneus can sometimes become a problem when patients begin weight-bearing. This is especially an issue if the foot is not completely plantigrade.

The authors have also presented their results of tibiotalocalcaneal arthrodesis with retrograde IM nailing in 2004. Interestingly, all major complications occurred in their diabetic patient population (20).

**CONCLUSION**

Ultimately, the surgeon and patient must decide if surgery is the best option to address CNA of the hindfoot and ankle. Waters et al. have shown decreased energy expenditure with patients maintaining bipedal gait relative to those patients undergoing below-knee amputation (21). This is especially beneficial in a patient population who already has limited cardiac reserves.

Limb loss can often result in a social situation in which patients may be required to alter their lifestyle and work.
status. Limb salvage certainly maintains independence and quality of life for some patients.

The financial costs of CNA reconstruction of the hindfoot and ankle are high. These patients require multiple visits to the hospital, return visits to the operating room, long-term bracing and casting, etc. The financial costs of these therapeutic interventions can be quite high and more than likely approximate the costs of a below-knee amputation.

Reconstruction of CNA involving the hindfoot and ankle is a reasonable alternative to below-knee amputation in a certain group of patients. These patients require multiple procedures and hospitalizations. The patient and their family should clearly understand the intensity and burden of postoperative care prior to surgery. Timing of surgical intervention in CNA probably should be reconsidered. The patient’s unique needs and circumstances should be taken into account when timing of surgery is being considered. Goals must be realistic for both the patient and surgeon when undergoing a limb-sparing procedure.

REFERENCES

INTRODUCTION

As the global incidence of diabetes increases, the associated complications are on the rise. For the lower extremity in years past, complication in the diabetic patient meant amputation. Our increasing knowledge of the long-term sequelae after major lower extremity amputations, including mortality and energy requirements, has placed emphasis on limb salvage. Today, a shift has been made toward minimizing deformity in the initial stages, and deformity correction of the chronic stages.

The natural history of diabetes and the devastating neuroarthropathy that can result has been described and staged. In previous years, surgery in patients with diabetes, especially those in the early stages of Charcot, was discouraged. As we look to limit deformities from this neuropathic process, earlier intervention during stage 1 is being revisited. During this stage, the deformity is “plastic” and many times reducible. Maintaining this correction for months until coalescence is not as straightforward. Long-term results of current trends, whether these deformities remain stable, and whether we have truly salvaged not only a limb but a better quality of life have yet to be proved.

The intent of this chapter is to familiarize the reader with current limb salvage techniques in the difficult malunions and nonunions encountered in the diabetic patient. It covers deformity planning and common fixation and surgical techniques for these complex deformities.

INDICATIONS/CONTRAINDICATIONS

The natural history of the at-risk diabetic limb is well known. Deformities and abnormal pressure distribution lead to ulceration and possible loss of limb. With this knowledge, indications for repair of nonunions or revision of malunions in diabetic patients are those resultant deformities that are unstable and unbraceable or rigid and unable to be accommodated (Fig. 21.1). Long-term sequelae of these deformities are well known. The goal is to produce a stable, braceable, plantigrade foot.

Contraindications include severe peripheral vascular disease and certain infections. Undertaking major limb salvage in a severely insufficient limb or in a nonambulatory patient may not give the preferred results. Infections are not an absolute contraindication, but should be considered. Placing an intramedullary rod through known osteomyelitis is not indicated, but external fixation in this situation may be useful, giving stability and allowing for a staged salvage. Infectious disease and vascular consults are required for a comprehensive approach.

Many of these patients have poor health and comorbidities. Aggressive medical management and glucose control can help decrease complications. Other considerations should be given to the patient’s daily life. A patient without family or friends to aid in daily activities and doctor appointments is more likely to have complications. The long recovery period for these patients requires a good support system.

DEFORMITY PLANNING

Malunion and nonunion of the rearfoot and ankle are complicated deformities that require planning and forethought. Many of these deformities are further complicated by concurrent medical problems and difficulty with compliance during the long recovery period. Proper planning minimizes complications and reduces the number of surgeries on a single patient.

The concept of deformity planning is to restore function by returning the limb to “anatomic.” In this sense, anatomic is a stable limb that approximates normal angles and relationships. This allows for improved gait and reduction of abnormal pressures. Knowledge of biomechanics and radiographic angles is essential, and is the cornerstone of deformity planning and guide correction.

The concept of the center of rotation and angulation (CORA) has provided guidelines and made deformity planning reproducible. Proper radiographs are obtained. Angles representing specific axis and joint positions are compared with normal values. This information is then used to correct deformity.
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The abnormal angles and measures are corrected through osteotomies and fusions to return the limb to more normal values (Fig. 21.2).

Deformity in the distal tibia can occur in any plane. Single plane deformities are conceptually easier. Although one should keep in mind the osteotomies rules and their sequelae, angles are drawn and intraoperatively osteotomies are performed for correction. When multiple planes or involved, including length abnormalities, it becomes more complicated.

Deformity of the ankle is many times treated like a long bone deformity. It acts similar with weight-bearing forces primarily running in an axial direction. Because of this, external fixation and intramedullary rods are excellent forms of fixation. The ankle should be in two to four degrees of valgus and neutral in the sagittal plane with the talus and foot displaced posterior to align the lateral talar process with the tibia medullary canal. Recurvatum and procurvatum should be recognized and corrected as well.

Figure 21.1  Radiographic example of a rigid deformity (A). An unstable deformity (B). Both of these deformities failed conservative treatments.

Figure 21.2  Example of a severe valgus ankle malunion (A). Principles of deformity correction reveal a significant decrease in the lateral distal tibial angle (LDTA), which can be compared with the normal values (B) to determine the wedge needed for correction.
Rearfoot deformities many times have multiple CORA. As the connection between the ankle and midfoot, both sets of relationships should be addressed. This also makes them much more unstable and unpredictable. During correction, the rearfoot should be brought back into its relation with the ankle and lower leg, and then the midfoot can be reduced on to the stabilized rearfoot. Preoperative deformity planning is more involved and complicated in these patients. Midfoot osteotomies can be difficult to accurately plan when the rearfoot is not anatomic to the leg. Proper angles and relationships of the midfoot require that the rearfoot be anatomic first. Equinus should be addressed and then attention should be directed to the medial column. Much correction is based radiographically on the talar-first metatarsal angles, both laterally and from an anteroposterior (AP) view. Osteotomies and fusions are designed to correct these angles.

Conservative treatment of isolated midfoot deformities is well documented with moderate results. However, midfoot deformities are often not solitary. In the event of instability, deformity, or chronic limb threatening ulceration, reconstruction is an option. One of the issues in the past has been adequate fixation for midfoot reconstruction, fusions, and osteotomies. Forces in this area tend to be sheer and angular, leading to hardware failure with traditional techniques (Fig. 21.3). The trend recently has been toward plates, locking constructs, and external fixation. Correction again attempts to recreate normal talar-first metatarsal relationships.

**Basic Surgical Principles**

Achieving stable, reproducible outcomes requires adherence to basic principles. When performing fusions, debridement to healthy bleeding subchondral bone is critical. Corrective osteotomies and resectional wedges should remove adequate bone for the best chance at union. This frequently means loss of length or height and should be considered, but is a secondary concern. Large varus or valgus deformities are some of the most common in the lower extremity. During corrective osteotomies, a decision should be made on acute versus chronic correction. Acute correction may place neurovascular structures at risk, but chronic correction requires external fixation or multiple surgeries.

If acute varus correction is performed on a rigid or long-standing deformity, a prophylactic tarsal tunnel release may be indicated. During acute valgus correction or acute correction causing shortening >2 cm, one should be careful of vascular insult in the form of vessel kinking, and appropriate steps need to be considered. At times, staged or gradual correction is the better option. Intraoperative and postoperative Doppler examinations can be used to monitor for vascular insult.

Other considerations include the skin incisions used to perform the surgery. Long standing deformities that are corrected acutely may make closing skin difficult and under extreme tension. One example is the use of a medial incision for long-standing valgus deformities undergoing rearfoot arthrodesis. This for the needed exposure, but it also keeps the incision away from the often difficult to close lateral side.

Fluoroscopy is a necessity in revisional surgeries. It aids in incision placement, hardware retrieval, and osteotomy planning. With the surgical areas exposed, Kirschner wires (K-wires) can be placed under fluoroscopy to act as a guide for the planned osteotomy. Proper technique will allow for better imaging intraoperatively with decreased exposure.

Osteotomies are often performed with a microsagittal saw. A long tapered blade works well in most applications. Pulsing the saw blade and irrigation helps minimize heat necrosis. Using K-wires as a guide keeps the saw time to a minimum and maintains the correct position of the osteotomy (Fig. 21.4).
Osteotomes may be used and do not produce the heat, but thin flexible osteotomes are preferred to limit prying and leverage.

Achieving stability is another basic principle, and knowledge of proper techniques and current technology is required. Stability can be achieved with larger screws, locking plates, blade plates, and a combination of internal and external fixation.

During recovery, weight-bearing should be considered. In the leg and ankle, ground forces are mainly axial through the surgical area. In the foot, forces are now 90 degrees to much of the fixation, increasing shear and torque on the implants. These two basic models require different fixation types and applications. What works in the ankle for stability may not be the case in the midfoot. With this in mind, weight-bearing status is adjusted accordingly.

In the presence of neuropathy, additional fixation has been gaining popularity in patients with diabetic ankle fractures. Stage 0 Charcot is a concept that injury automatically makes progression through traditional Charcot stages more likely. Because of this, diabetic ankle fractures should be treated accordingly. These fractures require additional stability and longer periods of protection and follow-up. If these fractures are not dealt appropriately on the initial visit, complications can be catastrophic and limb threatening (Fig. 21.5). There are

Figure 21.5  Example of a diabetic ankle fracture (A,B) treated with traditional methods. Without additional stability, this went on to failure (C), and subsequent revisional fusion of the ankle and subtalar joints (D).
many techniques to gain increased stability. These should be considered on a case-by-case basis.

The easiest addition is a transfixation Steinman pin from inferior through the calcaneus and talus into the anterior tibial cortex (Fig. 21.6). This was initially used in severe comminuted ankle fractures, but has gained popularity for a simple way to increase fixation stability. The change to locking plates also aids in stability with minimal change in technique or added skill. These plates have characteristics that are useful in osteoporotic or comminuted bone, acting as a unit in a fixed angle design. Additional syndesmotic screws and larger screws are recommended as well. Finally, external fixation can be applied as an adjunct and in this application are simple and quick to apply (Fig. 21.7).

Large incisions are required for many revision surgeries. In some cases, staging with external fixation initially or smaller stab incisions for passage of a Gigli saw may be adequate. However, for a majority of these complex deformities visualization is a necessity to allow complete access, proper cultures, biopsies, bone grafting, deformity correction, and fixation.

For deformities of the ankle, the main utilitarian incision is an extensile lateral. This incision begins along the fibula, approximately 6 cm proximal to the lateral malleolus, and extends over the sinus tarsi. This allows access to the ankle and subtalar joints as well as the lateral calcaneus for possible corrective osteotomies. The distal fibula is available and may be harvested to be used as graft.

Many times a second incision is needed medially. This incision begins proximal to the medial malleolus, curving distally between the tibialis posterior and tibialis anterior tendons. The incision gains access to the medial ankle and medial column.

These incisions are carried out without undermining. Communication between the two incisions is accomplished by lifting a full-thickness layer from the anterior tibia and ankle using a key elevator. With a malleable retractor placed from medial to lateral to protect the anterior structures, the ankle can be débrided or corrective osteotomies performed (Fig. 21.8). Care is taken posterior to avoid neurovascular complications.

For midfoot correction, a similar technique is available, comprised of two utility incisions. The first is along the medial

**Figure 21.6** Increased stability in a diabetic ankle fracture with the addition of a transfixation pin from the plantar calcaneus into the anterior tibial cortex.

**Figure 21.7** Examples of increased stability in diabetic ankle fractures with multiple syndesmotic screws and a pin and bar configuration (A), and a multiplanar ring configuration with transfixation pin (B,C).
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Figure 21.8 Standard utility incision, lateral (A) and medial (B), used for reconstruction of the ankle and rearfoot (C). This incision allows safe access to the entire medial column.

Laterally, a similar incision is created, protecting the peroneal tendons. Full-thickness layers can then be connected medial to lateral both dorsally and plantarly. This is accomplished with elevators lifting full-thickness soft tissue attachments from the bone. Malleable retractors are placed to protect the soft tissues during the deformity correction (Fig. 21.9).

Although these are common incisions for larger revisional cases, there are exceptions. As salvage, many of these surgeries have retained hardware, and previous incisions are common. Preoperative planning should take this into account to minimize possible complications. Smaller accessory incisions may be required to aid in reduction or for removal of bone and hardware.

Once incisions have been made and the surgical sites are visualized, retained hardware can then be removed. Cultures and biopsies are sent for examination regarding possible infection or osteomyelitis. The pathology department should be notified, and be aware of any concerns. Samples are sent for immediate gram stain as well as white blood cells per high-powered field. For any revisional or complex case, a comprehensive preoperative plan may include different options if these intraoperative tests are positive.

For rearfoot and midfoot applications, the first task encountered is realignment of the calcaneal inclination angle. Equinus is often one aspect of the multiple CORA present. To reduce this deformity, a tendo-Achilles lengthening or tenotomy may be performed. A half pin is placed in the calcaneus from the posterior inferior aspect following the calcaneal body. This half pin is then used as a “joystick” to reduce the calcaneus out of equinus (Fig. 21.10). Holding reduction, a Steinman pin is
placed under fluoroscopy from plantar through the calcaneus, into the talus if present, and ending in the anterior tibial cortex to maintain the rearfoot. This gives a stable construct on which to later reduce the midfoot. The half pin and even the Steinman pin can later be secured to an external fixator for added fixation and stability (Fig. 21.11).

If the final fixation is external rings, temporary fixation is applied and the wounds are closed. Large Steinman pins are common and are later removed either in the clinical setting or during external fixation removal. If internal fixation is appropriate, it is placed using fluoroscopy and should be doubled or maximized. Trends are toward larger screws and locking plates. Locking plates act more as a load-sharing device, and are much less likely to fail acting as an “internal external fixator.”

In the midfoot, screws frequently cross nonessential joints. These include the navicular-cuneiform, intercuneiform, and to some extent the tarsometatarsal joints. To gain increased purchase and stability, screws can cross these joints without much sequela.

**EXTERNAL FIXATION**

External fixation has become common in revisional foot and ankle surgery. It affords fixation around infection in patients with inadequate bone stock or can augment internal fixation. External fixation has also aided in the midfoot, where adequate fixation can be difficult. However, one should not confuse external ring fixation with the Ilizarov technique. Many applications in the foot and ankle use ring fixators, but the constructs and anatomic areas do not allow for true Ilizarov principles.

There are two basic workhorse external fixation constructs, one for ankle and rearfoot, and the other for midfoot.
or combined deformities. In reality, there are many constructs to choose from and there is no absolute correct configuration (Fig. 21.12). Certainly, no one frame can achieve results for all needs, so appropriate principles should be followed and adjustments made.

The external fixation construct for distal tibia, ankle, or tibial-calcaneal deformities consists of two “segments.” These segments consist of two rings for the leg and the rings and/or foot plate distally. These deformities can be thought of as a long bone, which makes them somewhat easier conceptually.

For each segment, a “block” is needed to ensure stability. Ideally, both segments are fixated to at least two rings each for adequate stability. With this construct, the two “blocks” can then be manipulated in relation to each other for deformity correction. For example, for ankle fusion, a talar ring and a foot plate constitute a distal block with a proximal block of two full rings in the tibia. During the postoperative period, compression is adjusted using the connecting threaded rods. The distal block is brought closer to the proximal block adding compression across the operative site (Fig. 21.13).

For this type of construct and anatomic location, weight-bearing is not as much of an issue or as controversial as in the midfoot. There has been much debate over weight-bearing in external fixation for these deformities, but in this type of application, rotation and angulation are minimized and the minimal axial motion that is permitted acts in a trampoline effect. This controlled micromotion in the axial plane may stimulate bone healing, much like dynamization of an intramedullary rod, and is one of the principles of the Ilizarov technique.

In midfoot correction, foot plates are common. They do have limitations in pin placement and postoperative adjustability, so one should be familiar with other constructs. One alternative, consists of the typical tibial block, but a 5/8 ring or short foot plate is used as a “heel ring” in place of the typical foot plate. The shorter ring is placed in the normal fashion around the heel. The foot is then fixed to a ring that is circumferential about the midfoot or forefoot. This ring is then attached to the heel ring and allows more adjustment postoperatively. When a standard foot plate is used, the correction and compression achieved postoperatively is more difficult to adjust and connections become crowded (Fig. 21.14).

Weight-bearing is an issue when working in the midfoot. Although often debated, anecdotally more complications occur, including skinny wire failure. External fixation can be used in the rearfoot and midfoot, but the true Ilizarov principles do not apply. Some constructs based on design cannot bear weight. Forces from weight-bearing in the midfoot are not axial in nature. They are more angular and shear 90 degrees from the classic examples in the long bones of the leg. This significantly limits postoperative weight-bearing and should be considered.

Depending on the deformity and during planning, the external fixator’s design is decided. If needed, extra rings or levels can be added to aid in stability or gain length with callous distraction simultaneously. Alternatives include unilateral or even pin-and-bar type fixators. These are best used only for temporary stability and not for long-term deformity correction.
Advances continue, and now deformity correction can be aided with computer programs and newer external fixator designs. The Taylor spatial frame (TSF) (Smith & Nephew, Memphis, TN) frame combines computer-aided correction with an adjustable fixator. It has some advantages and is an option, but is not necessary for every patient. There is a steep learning curve, and the computer software can be difficult, especially in foot applications. Constructs are more expensive, but can gradually correct difficult deformities in multiple planes, slowly limiting stress on neurovascular structures. For the foot and ankle, butt and miter frames are available. These constructs allow midfoot deformities (Fig. 21.15), and those with multiple CORA to be addressed simultaneously. However, the easiest place to begin with this system is the ankle or a long bone application. The software, frame constructs, and three-dimensional understanding are simpler than the foot models.

**Application of External Fixation**

Application of an external fixator takes experience and knowledge of basic technique, systems, and principles for good outcomes. The first principles are in the external fixator’s (frame) design. The number of rings and connecting rods, size of rings, overall configuration, and other factors are considered during the process and overall effect on frame stability (Fig. 21.16). Once the frame is applied, the number of skinny wires and half pins as well as their placement and orientation also determine overall frame stability.

For many applications, a partially prebuilt frame minimizes operating time and is part of the planning process. Once the deformity is corrected, temporary fixation is applied. The percutaneous K-wires and/or Steinman pins that were used for temporary fixation are then cut appropriately and before the frame can be placed over the foot and leg. Final adjustments to connecting rod lengths are made and fluoroscopy is used to ensure that the rings correspond to their anatomic position.

With the frame over the leg and foot, folded towels are used posteriorly to keep the leg away from the frame during application to allow for postoperative swelling. Once the position is appropriate and confirmed using fluoroscopy, a skinny wire is placed from medial to lateral through the calcaneus as the start point. With this wire first, the relation of the plantar foot to the frame is set.

After the initial axial calcaneal wire, a second is placed in the proximal ring through the tibia. This is also an axial wire and is parallel to the initial in the calcaneus. With these two wires, the frame is connected to the leg and is made stable but still adjustable. The frame can then be tapped medial or lateral as a unit until the leg and foot sit in the proper anatomic position. The frame can then be tapped medial or lateral as a unit until the leg and foot sit in the middle of the construct (Fig. 21.17). With this accomplished, a third wire is then placed in a different plane, thereby “locking” the frame.

The remaining tibial rings are stabilized using axial, medial face, or fibular skinny wires, depending on the location and surrounding anatomy. Half pins are frequently placed as well to augment stability and fixation. Throughout the application, olive wires can be used for added stability. A common technique is to oppose two or more in the heel and foot to ensure they are locked in the construct (Fig. 21.18).

In the foot, wire placement depends on the deformity. The heel finishes with two skinny wires and possibly a half pin that was used as a “joystick” during the deformity correction, as discussed. All are attached either to a full foot plate or heel ring depending on requirements.

The midfoot and forefoot fixation depends on the situation and anatomy. If correction was performed in the rearfoot...
Figure 21.15  An acute midfoot Charcot (A) with a Taylor spatial butt frame (B) for management. After 2 weeks, the deformity is distracted and corrected (C), allowing medial and lateral column beaming (D).

Figure 21.16  Example of an unstable construct (A) with minimal wires and incomplete hybrid ring configuration. A more stable construct (B) with increased number of rings and wires.
or ankle, then wires in the midfoot and forefoot are for stability and maintenance of neutrality. In these instances, a standard foot plate is sufficient, and three to four wires through the midfoot and forefoot are used to maintain the ankle and foot in neutral position.

If the deformity and correction are performed through the midfoot, increased stability is required on both sides of the surgical site. This is difficult at times with such little bone remaining in the forefoot to apply fixation. Using a standard foot plate, you can apply two metatarsal wires and at least two in the midfoot. It is generally difficult to catch all five metatarsals with one wire. For increased fixation and better stability, the wires are instead passed following the normal transverse arch. In most cases, a wire passes through metatarsals one and two, and a second wire is passed through the remaining lesser metatarsals. Wires in this configuration are at such an angle that posts are required for attachment.

An alternative technique in midfoot reconstruction is to connect the rearfoot and calcaneus in the usual fashion, but use a shorter heel ring. In this case, the forefoot wires are then attached to a ring that surrounds the forefoot. This permits room for extra wires with increased flexibility of their placement. Once the wires are attached to the heel ring, it is then connected to the heel ring with threaded rods. Further attachment of the forefoot ring to the distal tibial ring affords triangular stability. In many cases, this construct affords more adequate fixation and permits adjustment post-operatively.

**INTRAMEDULLARY NAIL PLACEMENT**

Intramedullary (IM) nail fixation has seen growth in the recent years as an option in limb salvage technique. Although not a new concept, IM nails are commonly used in many long bone trauma applications. In the foot and ankle, the need for this technique in trauma is limited, and initially IM nails were reserved for revisional ankle fusions. In recent years, they have seen increasing indications in the limb salvage arena for rigid rearfoot and ankle fixation.

The IM nails themselves also have evolved. Many nails now offer posterior-anterior and angled calcaneal screws in combination with the traditional medial-lateral tibial screws. These constructs offer better rotational stability and increased fixation for complex reconstruction. Compression during initial placement has advanced, along with increasing number of lengths and diameters to accommodate needs. This permits the surgeon greater flexibility, and increases the deformity correction options.

Dynamization is a concept one should be familiar with while using IM nails. The nails themselves are initially placed in a static configuration. This means the deformity is corrected and the nail holds the segments rigid. In this respect, it is considered a load-bearing device. However, if the static screws are removed from the proximal rod, the construct then becomes a load-sharing device. The distal segment is permitting controlled micromotion at the fusion site. This occurs in the axial plane, whereas rotation and angulation are maintained by the remaining screws and the nail inside the canal. In cases with incomplete fusion, this action may help stimulate union, and is a common practice with this type of fixation (Fig. 21.19).

The exact technique for insertion of an IM nail depends somewhat on the particular device used, but there are general concepts common to all. After deformity correction, temporary fixation is applied. One should remember not to place temporary fixation across the intramedullary space where it
will interfere with nail placement. A large Steinman pin or an extra guide pin from the IM nail set can be placed using fluoroscopy from the plantar heel into the anterior tibial crest. This should be kept anterior to keep the canal open. An alternative is crossed K-wires anterior, run from proximal to distal. Temporary fixation should be applied with the foot and ankle in proper position.

The guide pin from the set is then inserted. Fluoroscopy is used to ensure proper alignment of the guide pin. It should pass centrally through the talus into the tibial canal on the anterior-posterior view and through the lateral talar process into the tibial canal on lateral view. An incision is then made plantar, approximately 5 cm in length. The initial drill is passed just into the tibial medullary canal. A ball tip guide wire is exchanged for the original guide pin, and reaming is performed (Fig. 21.20). The longer guide pin is required, if the short initial guide is used, it may be pushed proximal into the tibia or come out with the reamer. Reaming of the canal ends about 1 mm larger than the planned nail size. Remember, as a general rule, reamers are never run on reverse. Once reaming is completed, the ball tip guide wire/pin is exchanged for a smooth guide and the IM nail is inserted. Using a ball tip guide wire for reaming is not necessary, but does protect against losing a reamer tip. It should be replaced before nail placement, however, or the ball tip will not allow for wire removal after nail placement (Fig. 21.21).

The IM nail is placed under fluoroscopy until it is in its desired position. The end position is dictated many times by the calcaneal screw holes. Revisional fusions and calcaneal deformities do not always allow for the nail to be level with the plantar calcaneus. In some cases the nail is proud plantarly, but the screws should be within the calcaneus and this takes priority. Care is taken to maintain desired position until the screws are in place. Even with temporary fixation, the foot can plantarflex or rotate until locked in position (Fig. 21.22). The ankle should be in neutral and the second toe in line with the tibial crest.

After nail placement, screw fixation is accomplished using the outrigger jig (Fig. 21.23). The guide pin is removed and the distal screws are placed. Placing screws posterior to anterior distally in the calcaneus increases overall stability. This requires access to the posterior heel by positioning or supporting the limb during the process. Screws may pass into the midfoot for added strength in cases of bone loss or osteopenia.
Figure 21.20 Intraoperative fluoroscopy of the initial guide pin (A) in the correct position. This is exchanged for a ball tip guide pin (B) for reaming.

Figure 21.21 Intraoperative reaming for the IM nail insertion.

Figure 21.22 Intraoperative photo of an IM nail insertion. Note the foot and ankle continue to be held in the correct position with the ankle in neutral and the second toe in line with the tibial crest during insertion.

Figure 21.23 Outrigger jig for intramedullary rod placement for medial-lateral screw placement (A) and posterior-anterior placement (B). This decision is based on deformity and physician preference.
The jig is now adjusted and the proximal tibial screws are inserted. Most configurations contain a slot for a dynamic screw and a static screw. If available and desired, compression can be achieved before proximal screw placement. Care is taken during the proximal screw placement not to torque the jig arm. The jig aligns the drill bit with the screw hole of the nail inside the tibia. If too much manipulation of the jig occurs, the drill bit and screw may not engage the nail.

Once the final screw is placed, fluoroscopy should be used to run a live picture, starting proximally, down the entire nail to ensure screw placement. This should be done in both the anterior-posterior and lateral views. Screws in the proximal nail on anterior-posterior views may appear in proper placement, but on lateral view they have passed anterior to the nail, and should be exchanged. This can lead to tibia stress risers and should be avoided (Fig. 21.24).

**POSTOPERATIVE CARE**

Postoperative management depends on the surgery and fixation. However, family and friend support is crucial. Lengthy recovery with long periods of limited mobility is common after salvage. Patients need support with daily activities and frequent doctor appointments. Patients should be seen often, even weekly, to limit complications.

Weight-bearing is a decision based on surgeon experience and the surgery and fixation used. An overwhelming majority of these surgeries need non–weight-bearing for extending periods. Although some external fixation constructs may limit and transmit forces appropriately, it is best to remain non–weight bearing. Neuropathy significantly limits the patient’s ability to monitor himself or herself, and this added stress on the surgery and fixation leads to complications (Fig. 21.25). With internal

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**Figure 21.24** Radiograph of a complication during an IM nail placement. The initial nail was much shorter, and the tibial screws missed anterior. During attempted replacement, the tibia fractured. The IM nail was then exchanged to a much longer for adequate stability and proper screws were placed.

**Figure 21.25** Breakage of midfoot (A) and forefoot (B) skinny wires. The wires should be properly tensioned and the external fixator should have adequate strength to minimize these problems. Shear forces in the foot may predispose these wires to fail during weight-bearing.
fixation, non-weight-bearing is 3 months with slow progression from that point using walking casts, boots, or Charcot Restraint Orthotic Walkers (CROW) walkers. External fixators are kept in place as long as tolerated, typically 10 to 12 weeks. After removal, the patient is kept non-weight-bearing for an additional month and progresses slowly. These patients require long periods of offloading and typically custom made shoes and bracing for an extended period of time.

For pin and/or wire care, keep it simple. Soap and water daily or every other day is sufficient, and then cover with dry gauze. Minimizing the amount of motion and irritation to the pin- and/or wire-skin interface will limit drainage and complications (Fig. 21.26). Pieces of foam can be wrapped around the external fixator and held in place with a large compressing wrap or Velcro to protect the contralateral limb and keep dirt and debris away from the surgery site.

Antibiotics are not required and may not be used during the entire recovery process. They are used immediately after the surgical procedure and if necessary, oral antibiotics can be given for a week at a time during follow-up visits and depending

Figure 21.26 Examples of the well maintained wire-pin interface (A,B), and wires and pins becoming infected and in need of attention (C–E).
on local signs of infection. The external fixator should be examined at every visit, and all bolts need to be re-tightened if necessary. Increased local irritation from loss of tension or loosening will cause local signs of infection and/or cellulitis and immediate treatment is initiated. If drainage and erythema continue to increase with signs of purulence, or if erythema extends beyond 2 cm, the external fixator will need to be revised. This is common and should be discussed with the patient and family preoperatively. The revision of the external fixator is usually performed as outpatient surgery with wires and half pins replaced as necessary.

CASE STUDIES

CASE 1

A patient was referred to our center with a history of an ankle fracture 6 weeks prior to her initial visit (Fig. 21.27). She was treated conservatively by another physician because of her history of diabetes, peripheral neuropathy, and obesity. On initial exam, vasculature was intact, but obvious neuropathy was present. She had no open lesions, but clear deformity and instability of the ankle. Radiographs revealed a neglected bimalleolar ankle fracture.

Figure 21.27  Radiographs of Case 1 with a neglected diabetic ankle fracture (A,B) and the clinical appearance and instability (C,D). (continued)
fracture with subluxation and callous formation. The ankle was unstable, and moved into significant valgus. Skin compromise was a concern and conservative treatment was not an option. Salvage with an ankle fusion was planned for long-term stability. Because of the patient’s multiple comorbidities, an external fixator was used to allow heel touch for transfers.

A two-incision approach was used to clear the medial gutter and aid in reduction after many weeks of subluxation. The medial malleolus was impeding reduction and was sacrificed. Three rings and a foot plate were used to increase stability. It also permitted adjustment of compression across the ankle joint postoperatively.

CASE 2
A patient was referred to our center with a chief complaint of severe edema to the left foot and a history of diabetes and neuropathy but no known injury (Fig. 21.28). Swelling continued over a 3-week period until she notified her primary care physician and radiographs were ordered. She was referred for fracture
Figure 21.28  Initial radiographs and clinical photos (A–C) of Case 2 with a comminuted navicular fracture. Initial management with external fixation (D–H) to help manage the subsequent dead space and continue compression with the medial threaded rod. (continued)
care. Clinically she had edema, erythema, and some increased temperature to the dorsal midfoot. There was no obvious deformity, but clinically there was significant instability about the midfoot. Radiographs revealed a clear navicular fracture with significant comminution and displacement.

Because of the fracture and possible neuropathic changes of the talonavicular joint and gross instability, surgery was planned. Long-term fusion would provide stability and limit recurrent posttraumatic neuropathic failure. Initially, however, surgical débridement and stability were required until her acute event began to coalesce. This was performed with a small dorsal incision and external fixator. The navicular fragments were removed except the tuberosity and the talus and cuneiforms were prepared for fusion.

The external fixator was applied and because of the loss of length, somewhat modified. A full ring around the foot could not be used because it would impinge on the ankle. The tibial ring was placed slightly higher on the leg to allow for clearance as well. This configuration allowed continued compression and adjustment over the next several weeks to decrease the dead space and aid later fusion. It also permitted stability until the acute neuropathic process began to consolidate.

Once the skin temperature and overall appearance of the foot had progressed through acute stages of the fracture and/or neuropathic changes, a definitive surgery was planned. This was later performed with a bone graft and rigid internal fixation with a modified plate for a medial column fusion.

**CASE 3**

A patient with diabetes mellitus and neuropathy was evaluated in our center for a long history of foot and ankle ulceration and deformity (Fig. 21.29). She previously had undergone surgical débridements and ostectomies by other physicians for lateral

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*Figure 21.28* (Continued) Final radiographs of the medial column fusion with a plantar-medial plate modified with a 90-degree bend for increased fixation in the talus (I, J).
Figure 21.29  Initial clinical photos and radiographs (A–D) of Case 3 showing the significant varus deformity and chronic lateral ulceration. Intraoperative application of Taylor spatial frame (E), and subsequent correction to rectus over a 3-week period from plantar view (F,G), anterior view (H,I), and radiographic anterior-posterior (J,K).  (continued)
The frame was later removed and an IM nail placed (L), with radiographic and clinical follow-up (M–O). (continued)
performed through the ankle joint level from lateral to medial, with fluoroscopy used to ensure that the osteotomy was complete. The external fixator was applied with standard technique and online computer-aided correction was performed. Adjustments to the external fixator were made by the patient and home nursing daily over a 3-week course. Once the ankle was in a rectus alignment, straight compression was applied and plans were made for permanent fixation. The external fixator was later removed, and an IM nail was placed. Following the postoperative course, custom made high-top shoes were fabricated with a lift and mild rocker to accommodate for the talectomy and tibiocalcaneal fusion (PQ).

CASE 4

A patient with diabetes mellitus and neuropathy was referred to our center for another opinion after a failed midfoot fusion (Fig. 21.30). She had previous Charcot changes to the midfoot requiring fusion. After several months, the deformity continued...
Figure 21.30  Clinical photos and radiographs of Case 4, revealing nonunion and the forefoot abduction and medial column failure (A–D). Intraoperative photos of external fixation with a forefoot and heel ring (E,F). (continued)
and there was concern about possible ulceration along the medial column where a bone callous formation was noted. There was no history of wound complications.

Clinically, she had failure of the medial column and forefoot abduction with callous under the first metatarsal cuneiform joint. Previous incisions medial and dorsal midfoot were well healed. Radiographs revealed an attempted Lisfranc fusion with internal fixation. The talo-first metatarsal angle on anterior-posterior radiographs measured 42 degrees of forefoot abduction, and a fault was noted on the lateral radiographs at the first metatarsal cuneiform joint. Revision was planned with removal of the hardware, cultures, reduction of the sagittal and transverse plane deformities, and application of external fixation.

The original incisions were used and the hardware removed. Cultures and biopsies were taken. A bicorrectional osteotomy was then performed with axis guides and fluoroscopy. Temporary fixation was achieved with Steinman pins and the wounds closed. The external fixator was applied using standard technique. The final configuration consisted of a tibial segment, and a foot segment with a separate heel and forefoot ring. This configuration would allow for continued compression during the postoperative course. Intraoperative cultures were positive, and she was treated with the appropriate antibiotics and further consultation with the infectious disease team. The external fixator was removed at 3 months and she progressed with our standard postoperative protocol without any complications.

**CASE 5**

An elderly woman from a nursing home was referred to our center with a history of an ankle fracture that occurred 2 weeks prior to her visit and during transfer to her bed (Fig. 21.31). It was treated conservatively in a posterior splint; on follow-up, the deformity had progressed, along with onset of pressure sores on her heel, ankle, and plantar aspect of the foot from the posterior splint. She had a history of diabetes mellitus and neuropathy but was ambulatory.
Figure 21.31  Initial clinical photos of Case 5, showing the unstable deformity and decubitus ulcerations (A,B). The initial radiographs (C,D) and repeat films at 2 weeks (E,F). (continued)
Figure 21.31 (Continued) Note the significant progression of the trimalleolar fracture and posterior ankle dislocation. Intraoperative fixation showing initial alignment with towels posterior (G), and axial tibial wire placement (H). The posterior malleolus was reduced with an olive wire placed posterior to anterior (I) and then attached to the foot plate (J,K). (continued)
On physical examination she had gross instability of her ankle and three preulcerative areas with eschar on the posterior heel, anterior ankle, and plantar fourth metatarsal head. There were no drainage or signs of infection. The most recent radiographs revealed a posterior dislocated trimalleolar ankle fracture. This was a limb-threatening unstable fracture in a diabetic patient, with wounds that would not heal with this deformity.

A closed reduction with external fixation was performed. The ankle was grossly reduced and a transfixation pin placed. This was done initially to hold reduction and later for added stability. A standard external fixator was applied to the leg and foot. It consisted of two tibial rings and a foot plate. Once applied, the ankle was distracted with the connecting rods to aid fracture reduction. Next, the posterior malleolus was reduced with the aid of an olive wire placed posterior to anterior. It was pulled anterior until reduction noted and attached to the foot plate. The external fixator allowed stability for the fractures and wounds. It also allowed access for a negative pressure wound therapy (NPWT) that was used on the heel and ankle postoperatively.

**TIPS/PEARLS**

Be efficient with intraoperative fluoroscopy to achieve the images you need, but limit exposure.

Plan osteotomies and fixation methods preoperatively.

Make sure osteotomies are complete for later gradual correction.

Take intraoperative cultures and send biopsies and frozen sections.

Increase fixation stability in diabetic ankle fractures.

Increase non-weight-bearing period and clinic visits in diabetic ankle fractures.

Be prepared for change in fixation plans, and have equipment available.

Check that skinny wires bend at the correct cortical margin to ensure placement.

Use olive wires to increase stability and aid in reduction.

Add more connecting rods, wires, and half pins at the end of each case.

Check all connection parts and fixation at the end of the case.

Use a half pin as a “joystick” to aid in calcaneal reduction.

Do not torque the intramedullary nail jig while placing screws.

Check in 2 views to ensure intramedullary screw placement.

Use long guide wires for reaming the tibial canal.

**CONCLUSION**

The surgical management of malunions and nonunions of the diabetic neuropathic lower extremity poses a great challenge to the reconstructive surgeon. These complex cases require a team of medical and surgical specialties with interest in diabetic limb salvage. Patient and family education, prevention combined with a vast knowledge, and surgical experience with external fixation and preoperative planning will provide successful long-term outcomes.

**REFERENCES**

INTRODUCTION

Bone grafting as a concept started out as simple experiments in an attempt to save lives. It has progressed over the last 400 years as an essential tool for the reconstructive surgeon. To fully benefit your patients and achieve optimal results with profoundly complex surgeries, each surgeon must keep up to date on current grafting concepts and also have a full and working knowledge of the varieties, availability, and applications of orthobiologics.

This chapter comprises both clinical and surgical applications of bone grafting concepts and orthobiologics. The emphasis is on useful surgical applications.

TERMS AND VOCABULARY

- **Autograft**: Cortical or cancellous bone graft harvest from the same patient. Examples: iliac crest, proximal tibia, distal tibia, calcaneus
- **Allograft**: Bone harvested from another human. It is processed and supplied in various forms. Examples: Cancellous bone chips, demineralized bone matrix, freeze dried bone grafts, fresh frozen graft
- **Bone morphogenic protein (BMP)**: Protein substances found within bone matrix that stimulate bone production through chemical signals and enzymes to affect chondrocytes, mesenchymal stem cells, endothelial cells, and osteoblasts. Various orthobiologic products containing BMPs would be osteoinductive. Examples: DBM (variable in amounts of BMP), BMP-2 (Infuse, Medtronic Sofamor Danek, Memphis, TN), BMP-7 osteogenic protein 1 (OP-1, Stryker Biotech, Hopkinton, MA)
- **Calcium ceramics**: Purely osteoconductive component of hydroxyapatite and mineral crystals that can be manufactured and processed to mimic the lattice of human bone.
- **Calcium phosphate**: A group of graft substitutes that are purely osteoconductive. They are mixtures of different calcium phosphates which can also be combined with other components of hydroxyapatite. The biological and mechanical differences are based on the differing chemical structures.

Examples: Alpha-BSM (DePuy, Warsaw, IN), Norian SRS (Norian Corp., Cupertino, CA), Vitoss (Orthovita, Malvern, PA), Conduit (DePuy, Warsaw, IN)
- **Calcium sulfate**: Calcium-based group of materials that degrade fairly rapidly. They provide minimal osteoconductive scaffold because of their rapid dissolution. They are good transporters of heat-stable antibiotics. Examples: Osteoset (Wright Medical Products, Nashville, TN), BonePlast (Interpore Cross, Irvine, CA), and JAX (Smith & Nephew, Memphis, TN)
- **Collagen materials**: Combining collagen with calcium phosphates and HA. Examples: Healos (DePuy, Warsaw, IN) and Collagraft (Zimmer, Warsaw, IN)
- **Demineralized bone matrix (DBM)**: The composite material processes from cortical and cancellous allograft bone. Different DBM products vary in the carrier of the product and especially in the amount and type of BMPs. They are freeze-dried and are osteoinductive based on their BMP levels. Examples: Accell DBM100 and Accell Connexus (IsoTis, Irvine, CA), AlloGraftTM (Stryker Howmedica Osteonics, Allendale, NJ), AlloMatrix (Wright Medical, Arlington, TN), DBX (Synthes, Paoli, PA), Grafton (Osteotech, Eatontown, NJ), InterGro TM (Interpore Cross, Irvine, CA), DynaGraft & Osteofill (GenSci Regeneration Sciences and Innova Technologies Corp., Toronto, Ontario, Canada).
- **Hydroxyapatite (HA)**: Grafts and materials that are processed from the exoskeletons of Gonioptera species of coral. These products come in various pore sizes to mimic cortical and cancellous bone structure. HA is purely osteoconductive and has excellent biocompatibility. HA is considered a xenograft. Examples: ProOsteon 200R and 500R (Interpore Cross, Irvine, CA). HA coating has been used in external fixation pins to help provide stability at the pin to bone interface.
- **Mesenchymal stem cells (MSCs)**: These are processed stem cells that have the ability to stimulate all aspects of bone healing on a cellular level. They are osteoprogenitor or precursor parent cells to osteoblasts, osteocytes, hematopoietic stem cells, and osteoclasts. MSCs can be delivered by attaching them to cancellous allograft. MSCs have properties of osteogenesis and osteoinduction. Example: OsteoCel (Osiris Therapeutics, Baltimore, MD)
• Orthobiologically/osteobiologically: The group of synthetic materials that mimic bone autograft and its desirable characteristics. They may also be combination of allograft and synthetic materials. Examples: Calcium ceramics, calcium phosphate; Vitoss (Orthovita, Malvern, PA), Conduit (DePuy, Warsaw, IN), calcium sulfate: OsteoSet (Wright Medical, Arlington, TN), BonePlast (Interpore Cross, Warsaw, IN), and JAX (Smith & Nephew, Memphis, TN), Calcium cements: Norian SRS (Norian Corp., Cupertino, CA) and alpha-BSM (DePuy, Warsaw, IN), HA: ProOsteon 200R and 500R (Interpore Cross, Irvine, CA). DBM and BMPs may be included as a broad definition.

• Osteoinductive: Ability of a material or substance to signal and stimulate host cells to produce bone. Examples: Cancellous allograft chips, HA, and tricalcium phosphates.

• Osteoconductive: Ability of a material or substance to signal and stimulate host cells to produce bone. Examples: MSCs and autograft bone marrow aspirate.

• Platelet gel concentrate: Concentrated growth factors derived from autograft platelets. This concentrate of spun down platelet granules assist in new tissue formation by mediating chemotaxis, cell adhesion, and new formation or osteogenic cells. Examples: Symphony Platelet Concentrate System (DePuy, Warsaw, IN), Interpore Cross AGF system (Interpore Cross, Warsaw, IN).

• Xenograft: Different species graft such as coral or HA (1–24).

AUTOGRRAFTS

Autografts, or a same-person donor, have been considered the gold standard for bone grafting and have stood this test over time. Their lack of immunologic reactions, availability, and ideal molecular characteristics has been unmatched. This has only been rivalled by the morbidity of graft site harvest, the limited amounts available for procurement and the ease of obtaining both bone bank allograft and orthobiologic materials. Advancement in stem cell research and other orthobiologics will continue to challenge the standards in surgical grafting (1,3,5,12,25–29).

Orthobiologically enhanced allograft materials have allowed many of the same benefits as that of autografts. Many surgeons also combine autografts with orthobiologic/allograft materials to extend the autograft. This combination has some of the ideal characteristics of the autografts and allows the smallest amounts of autograft to go further.

ILIAC CREST BONE HARVEST

The iliac crest has been an excellent site for larger autograft bone grafting. This is an excellent site for 10 to even well over 50 cc of bone grafting material. The bone graft obtained from this site may also be incorporated with a tricortical wedge and is excellent for application in foot, ankle, and lower leg reconstructive surgery. These grafts are well incorporated as are all autografts and can be adjusted some based on the site of application need (26,28–30).

PROXIMAL TIBIA BONE GRAFT HARVEST

The proximal tibia at the anterior medial face of the tibia is an excellent site for bone graft harvest (12,30,35,37,38). There are minimal neurovascular structures in this region and the site could be easily and readily accessed in limited surgical time. Consistently 5 to 25 cm² of excellent cancellous bone can be procured. This bone is of adequate quality in most patients, and particular incisional care must be taken to avoid continued neuritic symptoms. Intraoperative prevention of fracture at the harvest site, infection, continued neuritic symptoms, and invasion into surrounding structures, such as the abdomen and hip joint itself. However, it is still an excellent site with a small lateral incision directly over the anterior superior iliac spine (ASIS). Care should be taken to avoid the lateral femoral cutaneous nerve (25,31–33). Most patients have minimal donor site tenderness past the usual postoperative course (Fig. 22.1). This concurs with multiple studies, although out of all sites in the lower extremity from which the author harvests bone, this site stays particularly painful for a longer duration (25,30–36).

If a larger amount of bone is needed, harvest it from the posterior superior iliac spine (PSIS). The approach for this type of graft is more difficult and repositioning is usually needed to allow exposure and access to the reconstruction site once harvested. This harvest can be difficult in obese patients, and particular incisional care must be taken to avoid lateral femoral cutaneous nerve damage takes specific attention to dissection technique (25,31,32). In general, the author avoids this site, as positioning and harvesting at this site has almost always doubled the anesthesia time for patients.

In the author’s experience, unless a larger amount of quality bone needs to be taken, the proximal tibia and distal tibia are far more optimal for most foot, ankle, and lower leg needs. In most practices, a separate surgeon is used for the iliac gift harvest, which may or may not be beneficial.
vested and present varies depending on the age and bone stock of the patient. In older patients, or with marginal bone stock, the quantity of bone in this region can be somewhat limited to 10 to 15 cc in many cases.

The main limitation is creating a separate harvest site. The proximal tibia harvest is almost never residually painful. Other reported complications are fracture into the knee joint, infection, and harvest site pain (14,30,38,39). More common complications are a hematoma (when the cortical cap is not replaced), and also a dehiscence and hematoma when bone void filler such as calcium sulfate or calcium phosphate are introduced into the harvest site and have leaked out into the soft tissue. The other deficit of this type of harvest is a lack of true tricortical graft strut and its availability in this region. This site may be used with placement of tibia half pins and circular frames, which in theory may create a stress riser in the tibia with a potential for fracture (Fig. 22.2A), caution should be taken not to create such a riser. Bone void filler is used when taking grafts >5 cm² (Fig. 22.2B,C).

Proximal tibia graft is most useful in applications such as pilon and/or ankle fractures, ankle fusion, excision of a more distal malunion, or specifically in the midfoot, hindfoot, or ankle reconstruction in patients with diabetes mellitus and neuropathy. It is also useful in complex nonunions. In theory, harvesting a proximal tibia graft, given its proximity to the knee, has less associated morbidity than a more distal harvest site simply because most diabetics have better blood flow at this level. This may be thought of as one less incision and wound to heal in a diabetic with already impaired distal healing potential.

**Technique**

Attention is directed 2 to 3 cm below the tibial tubercle on the anterior medial face of the tibia (Fig. 22.3A–F). A 5-cm incision is then carried parallel to the centerline of the tibial shaft. A hemostat is used to spread bluntly to periosteum. Sharp periosteal dissection is made. There are minimal neurovascular structures; however, care is taken to avoid any anomalous genicular structures and the infrapatellar branch of the sphenoid nerve (which is rarely seen by the author). A small drill is used to provide uncritical stress relief to the four corners of the entrance site. Next, a small saw is used to connect the drill holes. Care is taken not to burn the bone with the saw. An astrodome may be used to finish the cuts once started. The cortical cap is lifted, which is saved for replacement latter or use distally. Rounded burn curettes are used to scoop upward toward the knee. The desired amount of graft is harvested. The wound is irrigated and the
Figure 22.3  Proximal tibia bone graft harvest. A. Incisional site below the tibia tubercle. B. Medial tibia face exposure. C. Cortical cap and tibia predrilled corners. D. Cortical cap bone graft. E. Cancellous graft from proximal tibia. F. Postoperative radiograph showing the proximal tibia bone harvesting site.
void may be filled with allograft bone chips, calcium phosphate, or a mixture of bone-void filler. The cortical cap is replaced. Care is taken to avoid bone-void filler or allograft from leaking into soft tissue. Meticulous periosteal closure is made, followed by irrigation and layered closure.

**DISTAL TIBIA BONE GRAFT**

The distal tibia is an excellent source of cancellous bone (37,40–43). Many times, the cortical face or cap may be applied to the donor site in applications in midfoot fusion. This may be used in overlying Lisfranc and Lapidus fusions to provide some structural strength and integrity (Fig. 22.4). Its size also lends to metatarsal nonunions in which the nonunited portion can be excised and the cortical cap along with cancellous underlying bone can be laid directly in the nonunited void and overlaid with fixation.

The main limitation in this region is its proximity to the ankle joint if an ankle fusion or other distal tibia or fibula type of surgery is to be performed. Other limitations are availability of bone, which is typically limited between 10 to 20 cc of cancellous bone grafting. The author has not found the cancellous quality of bone in the distal tibia medullary canal as variable in older patients with poor bone stock and osteopenia as with a proximal tibia bone graft. The other benefits of this harvest site are its proximity to the operative site, ease of the procedure, and minimal operative time.

Complications have been reported, such as fracture, entrance into the ankle joint, and entrapment of the saphenous nerve and graft site host pain, which could also include neuritis and donor site tenderness. This is an excellent site with minimal associated morbidity. It is very rare to have any significant graft harvest site tenderness from this region (30,41–43).

To help facilitate bony ingrowth similar to any significant harvest site, replace the cap over the harvest site, unless using it distally. Taking special attention and care to oversee the periosteal tissues and will almost always fill this with either calcium phosphate or a mixed calcium ceramic and bone allograft void filler to provide an osteoconductive bridge to regrow

and fill in the medullary canal either proximal or distally in the tibia.

**Technique**

Attention is directed on the anterior medial face of the tibia (Fig. 22.5A–K). The medial malleolus is felt. Four to six centimeters (cm) above this is the incision starting point. A 3- to 5-cm incision is then carried proximally parallel to the centerline of the tibial shaft. A hemostat is used to spread bluntly to the periosteum. A sharp periosteal dissection is made. There are only two neurovascular structures, the saphenous nerve and vein; they may be visualized and avoided. If the saphenous vein or branches are cut, they may be ligated. Conformation of proximity to the joint may be confirmed via fluoroscopy, but is not necessary. A small drill is used to provide unicortical stress relief to the four corners of the entrance site. Next, a small saw is used to connect the drill holes. Care is taken not to burn the bone with the saw. An osteotome may be used to finish the cuts once started. The cortical cap is lifted, which is saved for replacement later or use distally. Round burn curettes are used to scoop downward toward the ankle. Care is taken in soft or osteoporotic bone not to enter into the joint. The desired amount of graft is harvested. The wound is irrigated and the void may be filled with allograft bone chips, calcium phosphate, or a mixture of bone-void filler. The cortical cap is replaced or used distally. Care is taken to avoid bone-void filler or allograft from leaking into soft tissue. Meticulous periosteal closure is made, followed by irrigation and layered closure. Saphenous nerve entrapment is avoided; however, most often this nerve is not seen.

**FIBULA**

The fibula can be a fair source of bone when a cortical strut is needed. It has a limited length and amount of bone to be harvested and in many studies there is a significant graft site morbidity associated with harvesting the central third of the fibula (14,30,44,45). It is generally accepted that the distal third should be allowed to remain for adequate stability to the ankle joint. This is the area most commonly harvested for a vascularized graft. The exception would be when performing an ankle fusion or a pantalar fusion. The distal fibula is an excellent source to be used either as a ground corticocancellous graft or a partial fibula onlay strut graft. The amount of bone that can be harvested usually depends on the quality of the central medullary canal of the fibula and whether the fibula has been operated on previously (as is the case in many ankle fractures). The author typically uses the fibula as an onlay strut graft, transecting it in half and shortening it, in ankle and pantalar fusions (Fig. 22.6A,B). In ankle fusions—fixating either the proximal or distal portion, but not both—it has been the author’s experience that the remaining portions of the fibula graft are ground up within the prepared joints to help compensate for the shortening that occurs with multiple joint fusions.

Fibula grafts are limited because the quality of the graft is often poor. There is very little central cancellous bone, and these central grafts are almost all cortical material. Often when resecting the fibula as either a vascularized strut graft or onlay strut graft, the central medullary canal is very poor in cancellous stock, and the major portion of the bone itself is

![Figure 22.4 Application of an autologous tibial cortical-cancellous cap at first met-cuneiform fusion.](image)
Chapter 22  Bone Grafting and Orthobiologics for Reconstruction of the Diabetic Lower Extremity

Figure 22.5  Distal tibia bone graft harvest. A. Clinical picture showing the distal tibia harvest site at the medial ankle. B. Preoperative radiograph for the tibia bone graft harvest site. C. Medial distal tibia exposure with saphenous nerve avoidance. D. Unicortical drill holes. E. Saw cut connecting drill holes. F. Utilization of a sharp osteotome to complete the saw cuts. G. Removal of the cortical cap. H. Round curette for cancellous bone graft harvest. (continued)
cortical. High donor site morbidity in this region has been reported and care must be taken to avoid injury to the peroneal tendons, sural nerve, and/or fracture at the harvest site. The author saves this particular graft harvest for only when all other choices have been exhausted or cannot be applied. The exception is fibula strut grafts for ankle and pantalar fusions and fusions of the distal tibia-fibula syndesmosis for nonunions or malunions and painfully unstable syndesmotic injuries that fail other care.

**Technique**

Attention is directed to the lateral 5 to 10 cm of the fibula (Fig. 22.7A). Dissection is then carried to bone. The posterior
Figure 22.7  Fibula strut graft harvest. A. Preoperative radiograph of an ankle fracture with retained hardware and post-traumatic changes and arthritis at the ankle joint. B. Fibula exposure with peroneal tendons spared. C. Saw resection of the distal fibula. D. Removal of the distal fibula. E. Transection of the fibula. F. Fibula is divided into two halves. G. Fibula onlay strut graft at the lateral aspect of the ankle fusion site. H. Proximal fixation of the fibula onlay strut graft. (continued)
pouch of the peroneal tendons is preserved. Care is taken to avoid the sural nerve posterior and the more medial branches of the peroneal nerve above the ankle. The fibula is resected via power saw. It is then removed distally. The fibrotic tissue and distal ligament attachments are cleaned off the bone. It is then held firmly with a bone forceps and split down the midline. The remaining portions are shaped to fit the application. Use as onlay or viable graft portions may be ground.

CALCANEUS

The calcaneus is an excellent source of cancellous bone. It is an excellent source when needing 5 cc or less of bone and has at times taken up to 25 cc. The bone in this region is cancellous and vascular-rich and almost always seems to be of fair quality, even in the poorest bone stock. The harvest sites in this region have minimal morbidity, and the incisional tenderness tends to be no more than the surrounding surgical sites (5,12,25,30,37,38).

The main harvest sites have been described as the medial instep of the calcaneus and more often the lateral wall of the calcaneus. Incisional entrapment above the sural nerve and medial calcaneal nerve regions has been described with the above harvest sites (5,12,25,38). However, the author has found that this is usually short-lived. The other main limitation in the distal amount of blood flow in the diabetic patient leaves them another wound to heal unless incorporated into one of the other surgical incisions. Other times harvesting graft through the calcaneus can impair surgical correction, such as in rearfoot fusions, unless used in the midfoot or forefoot application sites.

**Technique**

Attention is directed to the lateral wall of the calcaneus (Fig. 22.8A–G). The tip of the fibula is marked. The base of the fifth metatarsal is marked and the peroneal course is visualized. The course of the sural nerve is visualized (the lateral dorsal cutaneous nerve). A skin incision is made 2 to 3 cm inferior and parallel to the peroneal tendons on the lateral calcaneal wall. A hemostat is used to spread bluntly to the periosteum. Sharp periosteal dissection is made. A small drill is used to make a unicortical entrance site. Round curettes are...
used to scoop out the bone. The desired amount of graft is harvested. Care is taken not to enter the subtalar joint or opposite side calcaneal wall. A bone-void filler such as allograft bone chips or a calcium ceramic may be used at the harvest site. The periosteum is closed, followed by the skin closure. Do not close subcutaneous tissue, so as to not inadvertently entrap the sural nerve.

The medial calcaneus may also be used as a harvest site. In this case, a medial posterior instep incision is made (Fig. 22.9A). Care must be taken to avoid the medial neurovascular bundle, and specifically the medial calcaneal nerve. This approach is useful if less bone is needed via a small 1- to 2-cm incision. The author does not fill this with bone-void filler and closes only skin (Fig. 22.9B).

OTHER SOURCES OF LOCAL BONE AUTOGRRAFTS

Other sources of bone autografts include the phalangeal heads from digital joint arthroplasties, the medial eminence after a resection of an accessory or hypertrophic navicular tuberority. Sometimes it is useful to harvest hypertrophic bone formation following a Charcot foot dislocation or subluxation. Most of the usefulness of these applications is limited by the amount of bone that may be harvested. In most cases, when resecting large Charcot exostoses or the dorsal medial eminence of a hallux valgus deformity or other deformities, the bone quality is marginal, with a significant amount of soft periosteal tissue and mixed fibrous tissue. Often the bone is marginally viable from an intraoperative standpoint. However, if the fresh bleeding bone is visualized intraoperatively, this bone could be used directly into the prepared fusion sites or as an overriding onlay graft to help facilitate fusion. It is highly considered preoperatively, especially in Charcot foot and ankle reconstruction or during significant deformity correction and when the local bone is of high enough quality to be applied directly to the fusion or repair sites. The main advantage to the use of these types of bone graft is that typically they are harvested from local sites that are already being operated on or close by and have minimal associated morbidity.

ORTHOBIOLOGICS

The orthobiologics group of graft or graft type implant materials has been redefined, reinvented, and reapplied over the last 20 years. For this reason, bone grafting cannot be simply talked about in terms of autografts, allografts, and xenografts. For the purpose of this chapter, orthobiologics includes osteoconductive materials that are bone allografts, enhanced bone allografts, calcium ceramics, including calcium phosphate, calcium sulfate, and calcium composite materials, HA products and collagen materials, including polymeric bone replacement (2,3,7,8,18,21–24,46–51).
The use of osteoinductive materials, including the combinations of osteoconductive material mentioned, platelet gel concentrates, DBM, and BMP is also discussed (11,23,24). There has been an explosion of different companies, manufacturers, and laboratories, and there has been an equal number of confusing mixtures of both osteoconductive and osteoinductive materials. To understand the use by application of these materials, one needs to have a working knowledge of basic properties and general applications, which will allow optimal use translating into optimal surgical results for complex reconstructive cases.

OSTEOCONDUCTIVE

Allograft

Allografts and associated alloimplant materials are excellent for most applications in foot and ankle reconstructive surgery. Many times, unless they are coupled with a significant amount of osteoinductive agent or combined with autologous bone graft, their usefulness for diabetic reconstructive surgery can be limited. Because of variable processing with allografts, they also carry some additional risk of immunologic reaction. The most common methods for processing allografts are freeze-drying, liquid nitrogen freezing, and demineralizing. The closest type of graft to one’s own bone is through the fresh-frozen technique; however, these also have the most associated immune reactions. The main advantage to fresh-frozen grafts is their retention of some osteogenic potential and properties (12,29,34,46,52).

Applications

For most diabetic foot and ankle reconstructive surgery, the additional threat posed by fresh-frozen bone grafts by an immune reaction, when other viable and predictable graft options are available, has limited the use of this particular type of grafting. The author has limited the use of fresh-frozen bone grafts for patients where a large amount of osteoconduction with osteogenic properties is needed and in which the author is hesitant to harvest this from a separate site, such as the iliac crest or tibia. These allografts have mostly consisted of tricortical fresh-frozen iliac grafts, which have been applied to midfoot and rearfoot osteotomies and some large osteomyelitic defects; however, these are some of the exceptions and not the rules. In addition, these grafts can be particularly useful when other methods are either unavailable or have failed. Most facilities will have a freezer and cold storage available for these types of grafts.

Freeze-Dried Allografts

Freeze-dried allografts, excluding DBMs, do not contain the same osteogenic potential as do bone autografts. These types of bone products are excellent for autograft bone extenders (to extend the amount of the graft harvested beyond the amount procured). They are also excellent in combination with other osteoinductive agents. Included in this is DBM independently when containing a high concentration of BMP. The main fear in the late through mid 1980s and 1990s was the transmission of disease through a same-species donor. Human immunodeficiency virus (HIV), hepatitis C, and other prions and infectious processes were feared. This created significant restrictions in the acceptance of donors and also standardized guidelines for tissue banks. This has all but eliminated the fear for most surgeons and in most patients. In almost all cases, the benefit of graft application outweighs the extremely low likelihood of any disease transmission or antigenic reaction (12,29,34,46,52,53).

Applications

Freeze-dried allograft has mainly been used during reconstructive surgery for large bone voids. The author has found it particularly useful in filling the graft harvest site in the distal or proximal tibia or even the calcaneus. In large resolved osteomyelitic voids or nonunions, freeze-dried allograft in combination with DBM gel or autograft is sometimes used. Rarely, unless no other choice remains, freeze-dried allograft is used alone across a fusion site or a revision fusion site in which bony union across the site is anticipated and needed for the reconstruction. Large fracture voids may be filled with cancellous allograft in vascular areas of bone (Fig. 22.10). Lateral column procedures such as the Evans calcaneal osteotomy are also good application sites for tricortical iliac crest allografts (Fig. 22.11A–C).
BONE FIXATION DEVICES

Bone fixation devices have found some usefulness in reconstructive surgery. Difficult fusion and revision fusions of toes and even larger screw fixation and pin fixation devices made from cortical bone have been available on the market. Their minimal antigenicity has made them an option for some reconstructive surgeries. The main limitations have been their variable strengths, slow incorporation, and lack of strength when compared with standard rigid internal fixation. The benefit of these devices has mainly been the lack of need for removal, density, and strength equal to the bone that they are being placed into and their general availability (11,23,24,34,46,53–55).

The author has found limited use in diabetic reconstructive surgery, especially major reconstructive cases in which other options have shown clinically repeated excellent results such as standard internal/external fixation or adjuncts of both. This will continue to be an emerging market in which great expectations may lay in the future.

Hydroxyapatite

Hydroxyapatite (HA) grafts are considered xenografts, as they are comprised of Gonioptera coral species. These grafts are purely osteoconductive bridges that may be used to fill minimally load-bearing or protected voids in bone. HA come in a 200- and 500-mcg pore size. This approximately mimics cortical and cancellous bone, respectively (ProOsteon 200R and 500R, Interpore Cross, Irvine, CA). The structure of HA makes it excellent for large bone voids and cysts—and its use may be widened when mixed with a DBM autograft or osteoinductive agent.

Figure 22.10  Allograft cancellous bone chips for calcaneal fracture void.

Figure 22.11  A. Tricortical iliac crest allograft for Evans calcaneal osteotomy. B. Allograft DBM putty applied around the tricortical iliac crest allograft and within the osteotomy site. C. Internal fixation at the surgical site with the tricortical iliac crest allograft and DBM putty.
Figure 22.12  A. Preoperative radiographs of a diabetic neuropathic distal tibia malunion. B. Preoperative clinical picture of the distal tibia varus malunion. C. Intraoperative distal tibia osteotomy and deformity correction. D. HA bone graft wedge with allograft bone cancellous chips and DBM paste. E,F. Postoperative radiographs. G. Postoperative clinical picture after correction.
HA is useful as a building block or structure to add to, in large voids after pilon fractures, severe calcaneal void fractures, and after resecting large tibia defects (Fig. 22.12A–G). It is also good for filling the void at the majority of autograft harvest sites. At most sites, the application of HA must be rigidly protected by both surrounding bone and fixation. The slow osteoclastic breakdown of HA prevents any significant usefulness at fusion sites (8,12,15,47,56–61).

**CALCIUM CERAMICS**

**Calcium Phosphates**

Calcium phosphates have use in their various forms in filling large voids. The main drawback of calcium phosphate, as with other ceramics, is that they are clearly osteoconductive. These are best used to fill large bone voids and autogenous harvest sites; however, when applied into larger defects, the author prefers to do this in deeper tissue where the periosteum can be oversewn or a cortical cap can be placed. It is also useful in tumor voids when mixed with allograft (Fig. 22.13). The other drawback with calcium phosphate is that when it does get into soft tissue it can create a soft tissue sterile abscess that can go on to dehiscence. The author has seen this many times when not careful and has gotten some of the pellets or paste into the soft tissue. There have also been studies in which calcium sulfate mixtures have been useful in calcaneal fracture repairs, allowing early weight-bearing and mobilization (62). In the author’s own practice, it was not found to benefit most calcaneal fractures, fusion, or reconstructive surgeries outside of the noted purpose for large applications of calcium phosphate or calcium sulfate paste (8,16,18,23,51,56,61,63–70).

**Calcium Sulfate**

Calcium sulfate does come in many forms. The most common are pellets. These also have been very useful in filling large bone voids, large defects, and donor sites in the proximal distal tibia and pelvis. These, like calcium phosphates, are even worse when they leak into the soft tissue or are left in the soft tissue, as they seem to melt and have spontaneous sterile abscess within the site itself. The author rarely if ever uses any form of calcium sulfate, calcium phosphate, or other ceramic material at any fusion site or other site where cyclical loading and bone repair would be expected to occur to any reasonable extent beyond the conductive bridge they provide (11,16,18,23,24,51,71,72).

**Applications**

The author has used antibiotic-impregnated calcium sulfate in large soft tissue defects with underlying osteomyelitis, but tends to avoid leaving these in any soft tissue or periosteal regions where they can possibly leak out given their tendency to discharge and dehisce at the wound sites, and thus create a non-healing environment. They have been applied to large defects after resection of osteomyelitis; however, the author does not rely on them to rid the bone of osteomyelitis or bridge or span the bone to facilitate bone healing. These properties are usually indicated for autogenous or another bone allograft mixture in combination with other bone growth factors or BMP. Common forms include OsteoSet pellets (Wright Medical Inc, Arlington, TN), Jax (Smith & Nephew Inc, Memphis, TN), calcium sulfate, and many other variances (Fig. 22.14A,B).
Collagen has been combined with multiple other materials to help create a better bone graft supplement. Collagen is an excellent carrier of other materials, including calcium phosphate and calcium sulfate, but its use seems more applicable to irregular defects since it may be shaped, cut, and packed into a variety of situations, especially when combined with an osteoinductive material (11,18,23,24,48,51,73).

Applications

The main applications in reconstructive surgery have been as bone graft extenders, packing bone voids, and non-weight-bearing structural defects of the tibia and calcaneus. They have been used for supplementary overlay grafts in addition to autogenous bone grafts, but they are still combined with DBM or other osteoinductive materials. Two common and available agents on the market today are Healos (DePuy, Warsaw, IN) and Collagraft (Zimmer, Warsaw, IN). Healos is a bovine collagen and HA material. Collagraft is HA and tricalcium phosphate mixture.

OSTEOINDUCTIVE AGENTS AND MATERIALS

There are a variety of osteoinductive agents. This chapter includes DBM, platelet gel concentrates, BMP, and MSCs. Marshall Urist’s isolation of BMP in the 1960s led to advancements in isolated growth factors and other osteoinductive agents. Over the last decade research and technology have caught up to one another to allow an explosion in the number of materials available for surgical use. This will continue to be a merging market, as further biological stimulant and growth factors are isolated through progressive research (2–4,6,10,11,13,21,22,24,49,74,75,77–80).

Demineralized Bone Matrix

DBM has been used for many years, since residual properties of bone morphogenetic proteins were originally discovered. In addition to BMP, other growth factors continue to be isolated, and many of these have been shown to be beneficial in bone healing. These include insulin-like growth factor, osteocalcin, osteonectin, and transforming growth factor beta. Most of the carriers with DBM are a glycerol-type gel similar to some of the delivery systems with calcium pellet products. Most of the DBM products vary only in the concentration of protein gels or BMPs (2,6,24,81–83).

DBM is a mixture of cortical and cancellous bone organic material. Because of the different techniques and processing of DBM it is likely and significant that many products contain variable amounts of different types of BMP. The benefit and ideal properties of various BMPs described are not fully known or realized; however, it is generally accepted that almost all BMPs create a rich environment for osteoinduction, which is beneficial for bone healing (6,18,24,82,83).

Applications

DBM is very useful across fusions and nonunions, and in Charcot reconstruction. These have been found both in gel and paste bases to be very useful at fusion and fracture sites to fill in or smooth out small residual voids and irregularities before fixation is added. It is easily taken off the shelf and applied as a primary graft or more commonly in combination with allograft bone.

DBM is readily available and may also be added to combine with calcium ceramic and other materials to give them some osteoinductive capabilities. DBM has been proved in patients undergoing complex arthrodesis and nonunions to be compatible to autograft. They have been found particularly useful in simple fusions in the forefoot and midfoot, and more complex in the rearfoot and ankle as well as nonunions of the tibia, fibula, and foot. They are particularly useful in Charcot reconstruction applications and deformity corrections. The author does not use them alone, but most often mixes them with an autogenous bone graft. The main disadvantage is their lack of structural integrity; however, the author finds DBM the most useful of all the osteoinductive agents on a regular consistent basis (Fig. 22.15).

Platelet Gel Concentrate

These factors include a variety of growth features that have been isolated out and should be beneficial in wound, bone, and tissue healing. The most commonly appreciated ones today are platelet-derived growth factor (PDGF), vasculoendothelial growth factor, insulin-like growth factor, epithelial growth factor, and transforming growth factor. Each of these agents has the variable ability to progress the process of bone, wound, and soft tissue healing in various ways, including stimulation of osteoprogenitor cells (which can be thought of as a jump start) and reviving the normal wound-healing process (20,22,49,74,75,84,85).

There have been various platelet aggregate and gel concentrate systems. A commonly used device is the Symphony platelet concentrating system (DePuy, Warsaw, IN). The main difference in most of these systems is the amount of blood drawn from the patient and the variable amount of yield of platelet growth materials. The platelets become two main materials as

Figure 22.15 Medial calcaneal displacement osteotomy in a patient with diabetes mellitus and osteopenic bone augmented with DBM.
they are separated. The first is platelet-rich plasma. This material is typically mixed with a thrombin-like material and used with an additional grafting agent or directly on the wound bed.

The next is a platelet-poor material. This continues to have fibrinogen and other clotting materials. This material has been found to be beneficial in reconstructive surgery, when a residual Charcot defect or wound remains. It is applied directly to the wound area, either prior to closure or by applying this to this region after débridement if there is an ulcerative site that is going to granulate in by secondary intention.

The use of these materials is becoming more widespread as the benefits of adding them to an osteoconductive bridge or material or as a boost to autogenous or allografted bone material are seen (20,22,49,84,85).

**Figure 22.16**  
A. Intraoperative view of a nonunion at the first metatarsophalangeal joint (MTPJ) in a patient with diabetes mellitus and peripheral neuropathy.  
B. Short first metatarsal with void at the prepared arthrodesis site after nonunion resection.  
C. MSCs at the arthrodesis site to fill the bone void.  
D. MSCs packed into bone void.  
E. Rigid internal fixation with incorporated bone graft.
BONE MORPHOGENIC PROTEIN

More than 16 varieties of BMP have been isolated; however, many of these are investigatory and it is simply unknown how much influence many others have on healing. Most are not readily available in their isolated forms for commercial use.

BMPs serve as the osteoinductive portion of DBM. In tandem with a bone scaffold, BMPs are powerful inducers of new bone formation. They stimulate osteoblast to form and lay down new bone at fusion and fracture sites. The use of BMPs truly is an example of applied science in bone healing and repair (2,6,21,24,76–81,86,87).

The most commonly used today are BMP-2 (Infuse, Medtronic Sofamor Danek, Memphis, TN) and BMP-7 osteogenic Protein 1 (OP-1, Stryker Biotech, Hopkinton, MA). This is mainly approved for spine use; however, it has been limited use with foot and ankle surgeons in complex revisions on a limited basis mainly because of the cost and not necessarily because of its effectiveness.

Mesenchymal Stem Cells

MSCs have recently seen a widespread application in bone grafting. MSCs are attached to an allograft scaffold, usually in the form of cancellous bone. MSCs contain separated cells from adult bone marrow. These precursor cells convert into osteoblasts, osteocytes, and hematopoietic stem cells. New bone is formed directly and indirectly. Osteogenesis occurs through osteoid and matrix production by these osteoblast and osteocytes. Osteoinduction occurs by signaling host cells to produce more bone and causing further expression of BMPs (3,4,7,10,49,73,75).

It is commercially manufactured and available for use by Osiris Therapeutics (Baltimore, MD) under the trade name OsteoGel. Its size is consistent with autograft cancellous bone. The main drawbacks are its cost and that it must be thawed from its storage temperature of ~80°F.

The author has found a wide variety of applications in lower extremity reconstruction, and has used this extensively in and across fusions, nonunions, and complex fresh fractures with large voids. This product may be mixed with other products to extend its osteogenesis properties. This is also an excellent product for extending your autograft. This product has been especially useful in large angular corrections and Charcot reconstruction. It is a close second to autograft applications and has alleviated the need for an autograft harvest in many diabetic patients (Fig. 22.16A–E).

CONCLUSION

Understanding the variety of bone grafting and orthobiologic options is an essential component of diabetic lower extremity surgery. Appropriate internal, external or a combination of both fixation methods may be necessary to the overall success rate of bone grafting and/or orthobiologics. The surgeon and patient need to be aware of all the risks and benefits of these major procedures and have an astute knowledge of the bone and wound healing process in the presence of diabetes mellitus and peripheral neuropathy (Fig. 22.17).

REFERENCES


Figure 22.17 Mixed MSC, DBM paste, and allograft bone chips for an ankle fusion in a patient with diabetes mellitus and peripheral neuropathy.

**RECOMMENDED READING**

INTRODUCTION

Electric, electromagnetic, combined magnetic field, and pulsed low-intensity ultrasound have all been shown to be beneficial in bone healing. These modalities have been used to assist in bony repair and their use has increased tremendously over the last decade (1–5).

Multiple studies suggest that these devices assist in bony repair across nonunions, fractures, failed arthrodesis, and fractures secondary to Charcot neuroarthropathy. This chapter discusses the indications, roles, and uses of bone growth stimulators, including both electrical bone stimulation and pulsed low-intensity ultrasound (PLIUS) (1–8).

These modalities have been suggested to help regulate and increase the synthesis of collagen and proteoglycans, thereby influencing the endochondral ossification. There is shown to be an increase in union rates across fusion sites and bones that have shown potential to be delayed or declared nonunions clinically and radiographically. There has also been an increase in specifically callus formation, visualized radiographically, when compared to controlled subjects with the use of PLIUS (9–13).

Although the role of bone growth stimulation has not been specifically delineated in complex diabetic reconstructive surgery, it is recognized that when patients have multiple risk factors and comorbidities that bone growth stimulation is a useful adjunct to help facilitate and increase fusion rates (4–6,13–15).

ELECTRIC STIMULATION IN BONE HEALING IN THE HIGH-RISK PATIENT

Increase in bone healing has been shown through a variety of electric and electromagnetic bone-stimulating techniques. These techniques include direct current (DC), capacitative coupling (CC), combined magnetic field (CMF), and pulsed electromagnetic fields (PEMF or inductive coupling.) Each of these techniques differs on the type of electronic magnetic field, application at the fracture or nonunion site, i.e., implantable or nonimplantable and the frequency of use (Fig. 23.1) (1,4,5,17–19).

Bone repair has been shown to be increased through multiple studies. Most of these studies show effectiveness of both electric and electromagnetic energy in assisting with bone repair. In these studies it has been shown that both electric and electromagnetic fields via DC or CC and inductive coupling or PEMF to have approximately the same effectiveness. The fusion rates for specifically long bone fractures and other nonunited fractures have been anywhere between 70% and 90% and more. Most of these studies do not separate or delineate the higher-risk patients from the typical nonunion (4–6,14,15,20–22).

Electrical bone stimulation in foot and ankle surgery has been useful, although many of these studies are not profoundly ideal. One study compared PEMF with nonstimulated hindfoot fusions and found there was no significant radiographic fusion rate among subtalar joint fusions. It should be noted that most of these studies are compromised inherently by the comorbidities, whether or not they have had previous surgery, and most are not randomized. In talonavicular arthrodesis, the fusion control group was 17.6 weeks compared with 12.2 weeks in the PEMF-treated group. In the calcaneocuboid joint fusions, the arthrodesis time was 17.7 weeks in the control group and a little over 13 weeks in the PEMF group (4,5,14,15).

Implantable electric stimulation has also been used in higher-risk patients for foot and ankle arthrodesis. Success rates >90% have been seen in several studies. Although it is clear that both implantable or DC bone stimulation is useful in high-risk patients, these implantable stimulators (a) increase the operative time for a secondary procedure, (b) give the possibility of needing a secondary procedure or implant removal, (c) carry additional risk for pain and irritation, and (d) carry the additional risk for implant load or infection. However, they do confer some benefits, providing continuous stimulation, availability of placing the anode leads exactly at the necessary locale at the attempted fusion sites or bony repair site, and have been shown in multiple studies to increase both fusion and union rates (5,15,18).
ACTIONS OF ELECTRICAL BONE STIMULATOR FOR OSTEOSYNTHESIS

There have been multiple reports both in vivo and in vitro, which demonstrate up-regulation through precursor cells and osteoblast-like cells to increase both growth factors and bone morphogenetic proteins (BMPs). These factors include insulin-like growth factor II, BMP-2, BMP-4, transforming growth factor beta-1, and prostaglandin E2 levels. Many of the actions formed to up-regulate the messenger RNA (m-RNA) to the formation of each of these growth factors are BMPs (14,17,19,23–26).

Electrical bone growth stimulators in theory influence bone healing through the cell membrane itself and the specific up- and down-regulation of necessary receptors and regulators at the cellular level. This occurs through transmembrane signaling and gene expression thereby stimulating structural and signaling proteins. This allows differentiation of different cell lineages, thereby allowing new bone formation. Although a multitude of papers have been written both in theory and delineating mechanisms for this new bone formation to happen, this at first confusing multitude of up-regulation and bone formation can be summarized with the realization and appreciation that indeed new bone does form and progress on toward an increased fusion rate and fracture healing rate (14,17,19,23–26).

PULSED LOW-INTENSITY ULTRASOUND FOR BONE HEALING

Pulsed low-intensity ultrasound (PLIUS) has been shown to be useful in multiple in vivo and in vitro studies. Most of these studies confirm the effectiveness especially in fresh fractures, nonunions, and other bony defects. Osteotomies also have been shown to have increased healing potential when PLIUS is applied. Although the exact mechanism by which this happens is not distinct, it is clear that PLIUS is beneficial in bone healing (2,7,10–13,20,21,29–38).

The clinically effective and FDA-approved ultrasound consists of a 1.5-MHz ultrasound wave pulsed at 1 kHz with a 20% duty cycle and an intensity of 30 MW/cm², a 1 cm² spatial average temporal average (SATA). The ultrasound signal is transferred via a water-based gel. These ultrasound waves are passed through a process known as conversion as the wave encounters different materials, i.e., bone versus soft tissue.

Several studies have shown benefit without toxicity toward soft tissue and bony structures. The effects of ultrasound have also been shown not to be specifically influenced by metallic internal fixation (6,14,39).

The effects of ultrasound have been shown to be beneficial through multiple studies in increasing enchondral ossification, thereby promoting fracture healing. It should be noted that there have been two separate studies that have indicated that PLIUS does not have a profound positive effect in fracture healing. In tibia fractures, multiple studies have shown that fracture healing is promoted when the fractures have been declared as nonunions and also fresh fractures themselves. A tremendous benefit has not been seen with intramedullary nail fixation, specifically when tibia fractures are noted. Healing of distal radius fractures, scaphoid fractures, and specifically Jones fractures has been shown to be increased when compared with placebo and control groups with multiple studies. There have been reports of increased union rates with patients with specific comorbidities such as smoking, diabetes, and other high-risk comorbidities; however, there have also been reports of PLIUS not being influenced profoundly by the presence of comorbidities such as diabetes or infection. In fact, one specific study via Cook and colleagues did demonstrate that there was acceleration in healing because of PLIUS greater than the control group. This compared a subset of smokers versus nonsmokers (10–13,16,22,33–38,40–42).
Skeletally immature bone when looked at specifically in animal studies was not found to be affected, as was the enchondral or fracture sites in animal models, suggesting that treatment of fracture in the vicinity of growth plate may be possible or appropriate; however, this has not been proved in vivo studies (39).

The confusing and confounding number of control groups such as those treated with surgery, those that have not had surgical intervention and those with multiple comorbidities have made specific control arms of studies confusing to say the least. However, it should be noted, in large studies PLIUS stimulated a fusion rate >80% of nonunited fractures. These studies are consistent with other studies that show fusion rates all 80% or above with nonunited fractures and delayed unions. Specifically, combined studies showed that patients had higher risks that included substraight groups of substance abuse, diabetes, corticosteroid use, and vascular insufficiency. This suggested that there was no significant change in the effectiveness of PLIUS based on these comorbidities (8,10,30,43–45).

In the face of multiple studies it seems that regardless of comorbidities, fracture location, or age of fracture, it is evident that early intervention with PLIUS has been shown to increase the effectiveness of the treatment with about a higher success rate (Fig. 23.2).

MECHANISM AND ACTION FOR PLIUS

The exact mechanism and action for PLIUS is not specifically delineated or known. It has been shown that accelerated enchondral ossification occurs with PLIUS in addition to an increase in proteoglycan synthesis and a progression of fracture healing through each phase: initial, middle, and late. There have also been evaluations on the quality of the enchondral ossification, i.e., a softer versus harder callus in relation to the quality of the new bone formation, which has been shown to be of adequate quality as fracture healing progresses, even when PLIUS speeds up the fracture healing. Chondral sites have been demonstrated to show increased proteoglycan synthesis through the m-RNA response to PLIUS. There has also been an increased response to ultrasound through stimulation of undifferentiated mesenchymal marrow cells that in vivo have progressed these lineages or cell types to lay down and form new bone. Periosteal cell tissues have reacted to PLIUS by increased cell differentiation into osteoblastic lineages. Osteoblast cells themselves show progressive differentiation and progression in response to PLIUS and thereby accelerate both soft and hard callus formation (mineralization of the soft callus). Progressive research has been performed in the transduction process to sort out cellular pathways that regulate response to PLIUS. It is through these pathways that it is theorized that many of the osteoblastic cells are up-regulated in response to PLIUS. As we learn more in regard to transduction pathways and increase in the osteoblastic cell lineage, we will see further progression in the field of bone growth acceleration; in other words, as we can delineate each specific process by which PLIUS works, we will be able to sort out the positive and negative effects of cell transduction and possibly the ideal pulse and sequence of pulsed ultrasound (8–10,41,42).

CLINICAL USE OF BOTH PULSED ELECTRIC MAGNETIC FIELDS AND PULSED LOW-INTENSITY ULTRASOUND FOR HIGH-RISK PATIENTS

CHARCOT NEUROARTHRPATHY

Use of both PLIUS and electrical stimulation in high-risk Charcot patients has been beneficial in our practices. If patients are diagnosed early, bone stimulation may be a useful adjunct along with immobilization. When these patients are diagnosed in the initial phase, adjuncts such as bisphosphonates coupled with cast immobilization and bone stimulation have shown promising results. In patients with further joint disruption and progress to bony fracture and in need for Charcot reconstruction, including fusion and surgical fracture repair to prevent limb loss, both modalities of stimulation have been useful. We have found that electrical bone stimulation is particularly useful over the fracture or fusion corrective surgical site when applying a cast over the top of
the surgical correction or an immobilization splint. When using electrical bone stimulators over the top of external fixation devices, one has to be cautious about the distance from the surgical location(s) and presence of any open wounds. PLIUS is particularly useful when there is not an overriding wound or defect that has to heal by secondary intention (i.e., a Charcot rockerbottom foot wound that has to heal in the postoperative period) (14).

We typically combine cast immobilization with bone stimulation or in the surgical patient some form of internal or external fixation (or both) along with bone stimulation. In diabetic patients with compound and profound deformity secondary to Charcot neuroarthropathy, these patients are the highest risk for limb loss and long-term complications secondary to nonunion. Because of this extreme risk for limb loss, any adjunctive therapy that can be beneficial to progressing on to a faster union, a more solid union, or just increasing the percentages of not going on to nonunion are beneficial (Fig. 23.3).

**OSTEOTOMIES**

The authors have seen particular use of implantable bone stimulators in tibia osteotomies and distal tibia malunions that necessitate osteotomy for severe angular deformities. The implantable bone stimulators are more beneficial as they can be “tucked” into the posterior leg compartments with minimal discomfort in the deeper subcutaneous intramuscular tissues and rare neurovascular insult. Most of the time, the authors rarely find the need to remove these stimulators (Fig. 23.4).

When osteotomies are made in the distal tibia and or fibula or when nonunited fractures remain in the midfoot or forefoot, often an external electric bone stimulator is used to help facilitate bony union. This is especially pertinent when reconstructive surgery takes place to excise a nonunion/malunion and even more so when bone graft interposition is applied (Fig. 23.5). This assists and gives the surgeon one more way to ensure adequate fracture healing in an already high- and at-risk limb. This is especially pertinent when risk factors such as smoking, diabetes, peripheral vascular disorders, rheumatoid arthritis, alcoholism, or substance abuse run concurrent on an already at-risk limb (Fig. 23.6).

**FUSIONS**

The authors use both electrical (implantable and external) bone stimulators and also PLIUS to the prepared fusion sites in high-risk patients. The majority of those adjunctive devices are external electrical bone stimulators. The main reason for this is the

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**Figure 23.3** A-C. Postoperative radiographs of a Lisfranc fusion and a calcaneal displacement osteotomy with an external bone stimulator covering the fusion and osteotomy sites in a high-risk patient.
Figure 23.4  A. Painful nonunion of a tibia fracture with no evidence of a radiographic callous formation.  
B. Postoperative radiograph after resection of nonunion, bone grafting, spanning of the lower extremity with external fixation, and implanted electrical bone stimulator.  C. Implanted electrical bone stimulator at 4 months follow-up with the patient being asymptomatic.

Figure 23.5  A,B. A lateral and anteroposterior (AP) view of a trimalleolar ankle fracture in a 65-year-old diabetic patient with peripheral neuropathy. (continue)
Clinical Use of Both Pulsed Electric Magnetic Fields and Pulsed Low-Intensity Ultrasound for High-Risk Patients

Figure 23.5 (Continued) C. Four-week postoperative visit. Note: purulence and medial hardware exposed. D. Four-week postoperative visit. Note: Lateral dehiscence and screw heads visualized. E. Four-week postoperative AP radiograph. Note: Loose/inadequate 4.0-mm syndesmotic screw. F. Clinical picture after hardware removal and placement of antibiotic beads. G. Clinical picture after application of external fixation for fracture stability and PLIUS bone stimulator. H. Clinical picture of the PLIUS bone stimulator. Note: Uneventful healing after 2 months.
ease of application. Following the time of the operative procedure, the bone stimulator can be placed on over the postoperative splint and/or around the external fixator. It becomes more challenging to apply PLIUS in the operating room site while pin or wire tracts remain open and operative incisions are in their early healing phases, which often takes several weeks to several months in high-risk diabetic patients to heal. We use these devices extensively for midfoot and/or rearfoot fusions, ankle fusions both revisional and primary, and specifically when some of the following criteria are present: (a) previously operated limb; (b) history of cured osteomyelitis and significant bone loss; (c) history of avascular bone necrosis; (d) history of Charcot neuroarthropathy fracture; (e) at risk bone for avascular necrosis such as talus and navicular; (f) history of tobacco abuse; (g) history of nonunion (Fig. 23.7) (4,5,8,18,29,30,33,35,40,43).

FRACTURES

Fresh fractures and nonhealing fractures are assisted greatly by both electrical stimulation and PLIUS. These devices are used regularly with problematic fractures known to have a high complication or nonunion rate. In particular Jones fractures, talar body/neck fractures, navicular, comminuted metatarsal fractures, complex pilon, ankle and tibia/fibula fractures (Fig. 23.8). These devices are useful in bones that are delayed in their healing, however, often a bone stimulator will be used preemptively in the face of a high risk patient with diabetes. The decision towards stimulation is especially strong if the patient has accompanying neuropathy, lending towards more active unguarded weight bearing that would be avoided in the sensate patient (Fig. 23.9) (2,3,8,10–13,16,19,20,30,33–38,41–46).

Whether a bone stimulator is applied for a fusion, nonunion, fresh fracture, or Charcot progressive neuroarthropathy, we will strongly recommend that the patient use the device 3 to 6 months past the clinical and radiographic union (Fig. 23.10).

CONCLUSION

Both electrical bone stimulation and PLIUS have been shown to be beneficial in numerous models in multiple patients both in vivo and in vitro. Their role in bone healing is clear in that in patients with high risk factors and arthrodesis sites they have been shown to be useful in multiple studies. What is not clearly delineated is what specific fusion sites are most benefited, and the timing and application of bone stimulation. It seems prudent that patients with extreme high risk such as diabetic limb reconstruction should have any and all adjuncts that are capable of decreasing the likelihood of going on to amputation or further need for surgical intervention. It can be delineated from multiple studies that when patients have multiple and high-risk factors that they do benefit from each of these modalities. This should not be overrun by judicious use of bone stimulation in patient populations. Although the authors recognize that there is need for future studies to delineate specific bone stimulation use in high-risk populations, having a double-blind medically controlled study is a difficult feat to say the least.

The authors’ belief and experience would suggest that although we must be judicious in the use of bone stimulation, electrical, combined magnetic field and ultrasound stimulation are useful modalities in fracture healing and specifically in complex arthrodesis and nonunion reconstructions in the high-risk diabetic patient. Having had a personal experience of bone stimulators and as anyone who has had profound experience in diabetic reconstruction, it should be noted that no two patients or surgeries are alike. In our quest for the optimal surgical response and result, we must always keep in mind that the end goal is a pain-free, functional as possible, and of course attached limb to the diabetic patient. When bone stimulation is used as an adjunct to excellent and meticulous surgical technique, rigid internal and/or external fixation combined with autogenous grafting and/or orthobiologics, and overall excellent clinical
Figure 23.7  A,B. Preoperative radiographic and clinical views of a severe forefoot/midfoot deformity in a patient with diabetes mellitus and rheumatoid arthritis.  C. Postoperative radiograph after surgical correction with a panmetatarsal head resection, first metatarsophalangeal and first metatarsal-cuneiform fusions. The external electrical bone stimulator was used for 6 months postoperatively.  D. Postoperative external bone stimulation over the lower extremity cast application. E,F. Postoperative radiographic and clinical views at 2 years follow up.
Figure 23.8  A. Preoperative AP radiograph of a severe tibia and fibula intra-articular fracture with communication in a 40-year-old male with a history of diabetes mellitus. B. Computed tomography (CT) scan to assess the extent of the fracture and preoperative planning. C. Postoperative radiograph showing the use of rigid internal fixation, stabilization, and neutralization with a multiplane circular external fixator. D. Post-trauma reconstruction with the adjunctive therapy of an external electrical bone stimulator.
Figure 23.9  A,B. Preoperative AP and medial oblique (MO) radiographic views showing the ankle fracture with a widened ankle mortise and valgus rotation in a diabetic patient with dense peripheral neuropathy C. Intraoperative view of the shortened fibula. D. Intraoperative fluoroscopic view showing the internal fixation and bone grafting on the fibula with the anatomic reduction at the ankle joint E. Postoperative radiograph showing the diabetic ankle fracture repair and the insertion of the syndesmotic screw which was removed at 6 months follow-up. F. Postoperative clinical picture showing the external bone stimulator at the surgical site.
Figure 23.10  A–C. Radiographic and clinical pictures of a failed tibia/fibula open reduction and internal fixation (ORIF) with severe nonunion wound complications and exposed hardware at the tibia fracture repair in a patient with diabetes mellitus and peripheral neuropathy. D–F. Intraoperative application of a uniplane monolateral lower extremity external fixation for stability and fixation and after the hardware removal. (continued)
and surgical management, it will assist the reconstructive surgeon in the best possible outcome for the patient.

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REFERENCES

CHAPTER 24

Revisi onal and Reconstructive Surgery for the Diabetic Foot and Ankle

INTRODUCTION

Revisional surgery for the neuropathic lower extremity is often indicated for the management of failed internal fixation from previous trauma and/or elective surgery. These case scenarios are often complicated by the presence of broken or loosened hardware, surgery-induced Charcot joints, infection, osteomyelitis, malunions, nonunions, avascular bone necrosis, unstable deformities, bone loss, osteopenia, and ulcerations. The use of external fixation and especially the Ilizarov apparatus, with its diversity of application, provide a very efficient surgical method to address complex reconstructive procedures for the neuropathic lower extremity. Circular ring fixation is truly a minimally invasive technique providing adequate bone stabilization while protecting the soft tissue envelope. In addition, plastic surgery, which is often needed for revisional cases with a soft tissue loss, combines very efficiently with external fixation. The authors discuss a rational approach to functional limb salvage with surgical techniques that are aimed at achieving anatomic alignment, long-term osseous stability, and adequate soft tissue coverage. Emphasis is placed on the timing and staging of soft tissue and osseous surgical procedures, joint preparation(s) for an arthrodesis procedure, and application of external fixation.

DECISION MAKING

The goal of revisional operative treatment for the neuropathic lower extremity is to eradicate infection if present, resect all nonviable bone and soft tissues, decrease the deformity, provide soft tissue coverage, and finally, perform an adequate osseous stabilization throughout the postoperative course to minimize further complications. Deciding which patients are proper candidates for revisional and reconstructive surgery depends on multiple factors. The basic question that the authors answer prior to deciding if revisional surgery is indicated and worth pursuing is the following: Is the proposed revisional surgery a high-risk factor that will significantly compromise the patients’ ability to ambulate and/or increase the likelihood of infection and amputation? If the answer is no, then the authors tend to proceed with an extensive perioperative protocol to revise the previous failed surgical outcome.

Revisional surgery on the diabetic neuropathic lower extremity is often indicated for failed open reduction and internal fixation (ORIF) fracture cases. Broken or loosening of retained hardware associated with an unstable or malunited fracture with gross deformity in the neuropathic lower extremity is an indication for revisional surgery (1). The presence of infection or soft tissue loss may necessitate urgent surgery followed by staged surgical procedures to achieve functional limb salvage (2,3). In addition, the development of Charcot neuroarthropathy is a major causative factor for failed operative fracture care in the diabetic patient with dense peripheral neuropathy. It is difficult to determine if the presence of a Charcot joint was the result of the initial trauma, trauma associated with surgery, insufficient fixation and stability, and early or unprotected weight-bearing. In our practice, we have also seen a select group of patients who developed Charcot neuroarthropathy after partial foot amputations (4). For this reason, it is important to try to determine when in the postoperative course the acute Charcot process began.

Surgical intervention is often indicated with unstable Charcot joints that result in deformity and bony prominences that can lead to future ulceration, infection, and amputation (5). Our experience has been that Charcot neuroarthropathy of the midfoot is more amenable to conservative management, whereas Charcot neuroarthropathy of the rearfoot and ankle results in deformity that ultimately requires surgical intervention. The acute Charcot process associated with erythema, acute edema, and warmth is a relative contraindication for revisional surgery (5). The exception to this would be an acute Charcot joint with gross dislocation that may benefit from stabilization with external fixation until the acute inflammatory stage resolves to facilitate later reconstruction (6). However, applying external fixation in the acute phase can increase the time a patient requires an external fixator and the potential for complications associated with the external fixator can also increase. The authors prefer to wait until the erythema subsides, skin lines are present, and the skin temperature is within 1°F of
the contralateral extremity before proceeding with revisional surgery. The acute inflammatory process is an indicator of bone proliferation and may be present for 6 to 9 months. Radiographs and computed tomography (CT) scans may be used during this phase to determine the presence of bone proliferation and eventual consolidation. The authors do not classify the Charcot process as acute, coalescence, and remodeling according to radiographs, as this has very little clinical relevance. Rather, the radiographs and CT scans are used to determine the apex of the deformity and if bone proliferation and osseous bridging across the affected joints and/or fracture fragments is present providing stability. If osseous bridging is evident, the deformity is then evaluated clinically to determine if it is stable. Noninfected stable deformities without ulceration or preulcerative lesions are not amenable to revisional surgery and should be treated conservatively with appropriate shoe gear and bracing for the patient to remain ambulatory.

The timing of surgery and the strategies employed are paramount and should be understood and agreed upon by both the surgical and nonsurgical disciplines managing the diabetic patient. The overall strategy for revisional surgery is as follows: The first step is eradication of infection and osteomyelitis if present through adequate surgical débridement and parenteral antibiotics and infectious disease consultation; the second step is a comprehensive vascular assessment with possible vascular surgery if warranted; and the final step is soft tissue and skeletal reconstruction to obtain wound closure and functional limb salvage. Unfortunately, the determination of limb salvage cannot always be made until the reconstructive surgeon begins to progress down this treatment algorithm to adequately determine if limb salvage is a realistic option. A consistent stepwise surgical approach combined with sound surgical principles is paramount for successful surgical revision for the complicated neuropathic lower extremity.

PREOPERATIVE PLANNING

Initially, a thorough history of the previous surgeries is required. The initial traumatic event, associated injuries, and previous course of operative and conservative treatment if applicable are obtained. The presence of previous infections, Charcot events, open fractures, and compartment syndrome should be documented. Focus is placed on the time frame of the previous surgeries in relation to the pathology. The authors always make a point to inquire about previous preoperative and/or postoperative infections. Emphasis is placed on identifying the severity of the infection, superficial localized skin infection, ascending cellulitis, abscess formation, draining sinuses, infected hardware, osteomyelitis, and/or necrotizing fasciitis. Previous culture and antibiotic sensitivity results, laboratory studies, and imaging modalities are requested for review and can be used for future comparison if needed. Swab cultures should not be performed or relied on because they offer little clinical relevance and often misguide the overall treatment and prognosis. Previous oral and parenteral antibiotic usage and duration of treatment along with the clinical outcome is reviewed and documented. Diagnosing a soft tissue infection is relatively easy clinically even in the face of a Charcot process. Erythema is clinically present with both a soft tissue infection and an acute Charcot process but it only dissipates with elevation of the lower extremity above the heart level when associated with an acute Charcot neuroarthropathy event.

Unfortunately, difficulty arises in diagnosing osteomyelitis in a Charcot foot. Osteomyelitis may be present in a Charcot foot with a deep ulceration probing to bone or previous postoperative infections. Technetium 99m sulfur colloid bone marrow scan is our imaging modality of choice with good sensitivity and specificity results to decipher between osteomyelitis and Charcot neuroarthropathy (7). This incorporates a combined evaluation using leukocyte scintigraphy and bone marrow imaging to diagnose osteomyelitis with underlying neuroarthropathy. However, in equivocal cases, bone biopsy with deep intraoperative cultures should be obtained after stopping all antibiotics for three drug half-lives (3). Bone biopsy and deep intraoperative cultures provide a definitive diagnosis and the appropriate administration of antibiotics if there is a question of underlying osteomyelitis to plan the staging of surgical procedures.

Physical examination includes close evaluation of joint range of motion about the lower extremity, identification of contracted joints, and associated and compensatory deformities, as well as the integrity of the soft tissue envelope. On clinical examination, the lower extremity deformity is evaluated in a non–weight-bearing phase, stance, and during the patient’s gait if possible. Emphasis is placed on functional limitations during ambulation and the presence of soft tissue compromise that is present or at risk secondary to an underlying osseous deformity.

Determining the placement of new incisions is essential to consider the condition of the soft tissue envelope with respect to previous skin incisions, scar contractures, edema, and neuropathic ulcerations. Incision placement is paramount in preventing wound healing complications in revisional surgery. New incisions should be planned to allow direct access to retained hardware, resection of nonviable or infected bone and associates soft tissues, and finally, access the joints that should be prepared and realigned for the arthrodesis procedure(s). Hardware removal may be straightforward with plates and screws. On the other hand, intramedullary nails that are broken or involve broken screws may require the planning of separate incisions and bone windows for removal.

Smaller incisions may seem optimal for reconstructive procedures with the rationale of preserving the vasculature. However, we found that longer incisions that are curvilinear offer excellent surgical exposure, minimize tension to the soft tissues preventing wound healing complications, and permit proper joint preparations for arthrodesis procedures. Smaller incisions may require excessive skin tension and inadequate joint preparation leading to wound healing complications and nonunions, respectively. In addition, we prefer a direct plantar incision to approach an osseous reconstruction when plantar neuropathic ulcers are present. This direct approach minimizes surrounding soft tissue trauma and allows easy access to underlying osseous deformities. Often, a local random or pedicle flap is designed and incorporated for soft tissue coverage of the pre-existing plantar ulcer.

Weight-bearing radiographs if feasible, consisting of foot, ankle, tibia-fibula, and calcaneal axial views, are performed. A mechanical axis series is useful if a limb length discrepancy or suprastructural deformity is suspected. The physician should evaluate each joint for deformity and arthrosis. Computed tomography or magnetic resonance imaging (MRI) are used to
better evaluate joint arthrosis, Charcot neuroarthropathy, avascular necrosis, osteomyelitis, malunions, delayed unions, and/or nonunions.

Noninvasive vascular studies are performed preoperatively if there is a question of arterial insufficiency based on history or physical examination. A vascular surgery consult should also be obtained preoperatively if studies are equivocal to prevent further arterial compromise and surgical complication. We advise not to rely on the assumption that the patient who healed surgical incisions from previous surgery has adequate arterial sufficiency to heal future surgical incisions. This is particularly true when there is a time frame of 12 months or greater, given that the progression of peripheral vascular disease among diabetic patients could have significantly worsened. In addition, revisional skin incisions are more difficult to heal and are associated with higher wound healing complications secondary to previous scar formation and local tissue ischemia. For this reason, the authors obtain preoperative baseline noninvasive vascular studies on all diabetic patients with dense peripheral neuropathy whose previous surgery was >6 months from the initial surgery.

The authors also evaluate the extent of venous insufficiency and the presence of lower extremity edema preoperatively. Edema should be controlled preoperatively through compression stockings or the use of Unna boots when casting techniques are required. Edema can be monitored through circumferential measurements. Our preference is to continue with edema control preoperatively until skin lines are present and the surgeon is able to perform a “pinch test” over the proposed incisions.

Determining the type of fixation preoperatively is an essential part of preoperative planning. The type of fixation chosen is dependent on the soft tissue envelope, previous infection, bone density, bone loss, retained hardware, and the patient’s body weight. If soft tissues and bone quality permit, internal fixation can be used. Intramedullary rods, plates, and screws to be used should be planned with radiographic templates. If internal fixation is to be used, our preference is to supplement lag screw fixation with locking plates to provide further stability. Circular external fixation can be used with compromised soft tissues, previous infection, decreased bone density, retained hardware, and in obese patients (8). External fixation can also be used in combination with internal fixation if needed. We have found this to be needed with very obese patients who undergo revisional surgery.

If external circular fixation is to be used we prefer to have majority of the frame prebuilt preoperatively to save valuable operating time. In addition, it offers the advantage of being able to size the frame on the patient’s lower extremity and make any modifications that may be needed prior to surgery. The frame is built in a static fashion without hinges. A typical circular frame for the foot and ankle is constructed with two tibia rings, a foot plate, and a half ring fastened to the foot plate and the distal tibia ring. If bone docking is needed, additional circular rings are placed proximal. The frame should allow room for postoperative swelling while maintaining biomechanical stability. Postoperative swelling tends to occur in the region of muscle bellies and for the lower extremity, the posterior and lateral aspect of the leg needs to accommodate for most of the postoperative edema. The circular frame is constructed in such a way to permit access for the placement of planned smooth wires and/or half pins. The order and placement of transosseous wires and half pins should be considered preoperatively to expedite the application of the circular external fixator.

**JOINT PREPARATION FOR LIMB SALVAGE ARTHRODESIS: SURGICAL TECHNIQUE**

Revisional surgery for deformity correction, unstable fractures, joint dislocations, and/or nonunions in the neuropathic lower extremity is best managed with joint realignment and arthrodesis. Often, multiple joints require arthrodesis to achieve the required stability of the extremity for ambulation. If it is questionable whether an adjacent joint should be incorporated into the planned arthrodesis, we favor on the side of performing an arthrodesis of the adjacent joint in the same setting. Extended joint arthrodesis procedures are our preferred way of salvaging osseous pathology about the neuropathic lower extremity. The notion of preserving motion by forgoing an extended arthrodesis procedure could lead to a future Charcot event and deformity about an adjacent joint requiring further surgical intervention.

The authors rarely perform an isolated arthrodesis procedure in the neuropathic lower extremity. Our preferred technique is to perform a pantalar, tibiotalocalcaneal, or tibialcaneonavicular arthrodesis for deformity about the ankle and rearfoot; a triple arthrodesis for deformity about the rearfoot, and an entire medial and/or lateral column arthrodesis for deformity about the midfoot. Even if Charcot neuroarthropathy deformity or arthritis only involves one joint, permitting motion at the adjacent joints can lead to additional stress at the arthrodesis site and therefore increase the chance of a delayed and/or nonunion in the neuropathic lower extremity.

The first step in achieving joint preparation is to remove retained or broken hardware from previous failed surgeries. Hardware removal after a Charcot event can be daunting as a result of excessive bone proliferation and hardware failure. We use preoperative CT to obtain a 3D picture and intraoperative triangulation with radiographs to localize the hardware for the most direct access permitting removal. At times, bone windows or tunnels should be created to extract broken hardware. The removal of intramedullary nails can be difficult when complicated with broken poorly sized screws and/or a broken intramedullary rod. Bone windows must be created to remove the threaded portion of the broken screws. The distal portion of a broken intramedullary nail can be removed with the use of two guidewires. First, an olive guidewire is passed through the nail, and then a guidewire without an olive is passed to lock the olive portion of the first guidewire distal to the tip of the nail. Retraction of the olive wire usually removes the nail. If removal is still unsuccessful, a bone window can be made and the distal portion of the nail is tamped out. The surgeon should also refrain from removing deeply embedded hardware that is not interfering with joint preparation, planned fixation, or causing soft tissue irritation.

Prior to a preparing any joint for an arthrodesis, any presence of osteomyelitis or avascular bone must be first surgically debrided. Our approach is to stage the reconstructive arthrodesis procedure until there is no clinical evidence of infection and the final culture and sensitivity results are reported and until the appropriate long-term antibiotic is initiated. We typically remove
all nonviable bone to the level of good bleeding corticocancellous bone. Resection of osteomyelitis should be performed without a tourniquet or if the tourniquet is used, it is released after bone resection to appropriately evaluate the viability of the remaining bone. The use of methylene blue can also be used in determining the level of bone resection that needs to be performed. Methylene blue is very useful for resection of the distal tibia but offers little benefit with resection of the midfoot and rearfoot, as this is usually performed on the intraoperative clinical appearance of the bone.

Large bone voids may be present after surgical débridement that will require shortening of the bone segments for successful arthrodesis, bone block distraction arthrodesis, or bone transport. Large bone voids that leave considerable dead space are best managed with either antibiotic impregnated beads or an antibiotic impregnated cement spacer until the second procedure is performed. We use antibiotic beads if the extremity is relatively stable after bone resection with splinting or if an external fixator is applied. Larger antibiotic cement spacers can be fashioned to fill a void while simultaneously providing additional stability if needed, after performing large bone resections, by acting as a temporary strut graft. This is typically used when a takedown is performed along with resection of the distal tibia for osteomyelitis. It is important to prevent motion about the lower extremity during the interval between staged procedures to decrease the overall inflammatory response. The antibiotic spacers are typically removed anywhere from 6 to 12 weeks depending on the clinical presentation of the lower extremity (Fig. 24.1).

A decision has to be made whether a shortening arthrodesis of the foot and ankle is acceptable or bone grafting and/or bone distraction is needed to restore length. Our experience has been that midfoot deformities that require arthrodesis do well with shortening of the foot and allogenic bone grafting with bone morphogenic proteins is used to augment the arthrodesis site and not for structural support. In the presence of large bone voids about the rearfoot and ankle as a result of a takedown and/or aggressive resection of the distal tibia, bone grafting or bone transport may be indicated. Bone graft of choice is usually autogenous iliac crest from the contralateral extremity. We do not advise an allogenic bone strut in this patient population secondary to longer healing times to union and higher nonunion rates. In addition, a pseudoarthrosis may be acceptable if stable in a neuropathic lower extremity, but if a nonviable allogenic bone strut remains this can serve as a nidus for infection. Bone transport is indicated for large segmental tibia defects ≥2.5 cm. Bone transport can be difficult in the neuropathic lower extremity, as the regeneration may be weak, requiring longer periods that the patient may remain in the external fixator. For this reason, bone transport is only used when the bone graft will not suffice the arthrodesis procedure but does include a high complication in the diabetic neuropathic patient. Most often, any limb length discrepancy can be easily accommodated with protective shoe gear and heel lifts.

Incision placement to access the proposed joints is vital to the patient’s potential of wound healing without complications. For a pantalar arthrodesis, we use a 10-cm incision placed directly (text continues on page 322)
Figure 24.1 (Continued) The patient was admitted and eventually brought back to surgery for a total takedown (D-G) and application of a large antibiotic cement spacer shaped in a talus formation (H). (continued)
The initial bone cultures were positive for osteomyelitis. This was followed by a hybrid frame application for skeletal stabilization, observation of the wound, and simultaneous offloading (I–K). The patient was eventually discharged from the hospital on proper IV antibiotics and returned 7 weeks after the second surgery for removal of the antibiotic spacer and intraoperative cultures to rule out any persistent osteomyelitis (L). The patient eventually underwent a tibiocalcaneal arthrodesis with the use of an autogenous iliac crest (M) and allogenic bone grafting (N). (continued)
The use of autologous platelet-rich plasma was also used to enhance the arthrodesis site (O). Note that the external proximal tibial circular fixation block was never changed throughout the whole period (P) and that the hybrid frame was modified into a circular external fixator with the foot plate and compression arthrodesis (Q-S). (continued)
over the lateral aspect of the fibula that extends over the sinus tarsi to the base of the fourth metatarsal. This incision allows resection of the fibula for bone grafting and permits access to the ankle, subtalar, and calcaneal-cuboid joint for joint preparation. After the skin is incised, full thickness flaps are then created that include the periosteum from the lateral aspect of the distal fibula. Next, the peroneal tendons are retracted posteriorly and inferiorly, and the fibula is then transected with a sagittal saw just above the level of the ankle joint in an oblique fashion from proximal lateral to distal medial. The distal portion of the fibula is then excised and morselized for later bone grafting if needed. An acetabular reamer can also be used to resect the fibula while simultaneously creating morselized corticocancellous bone graft. At this point the incision is then carried full thickness over the floor of the sinus tarsi and just inferior to the extensor digitorum brevis muscle belly. The extensor retinaculum and the anterior subtalar joint capsule are then incised vertically, allowing the proximal aspect of the extensor digitorum muscle belly to be reflected dorsally and distally after being reflected off the floor of the sinus tarsi and the anterior process of the calcaneus. It is important to leave a cuff of tissue over the sinus tarsi for later closure rather than completely excising the sinus tarsi components. Subcutaneous coverage of bone graft to this area is essential in preventing wound dehiscence. Next, remnants of the

Figure 24.1 (Continued) An external bone stimulator was also applied and attached to the circular fixator to further enhance the arthrodesis site (T). Note the deformity correction and healed wounds at 9 months follow-up (U–W).
ankle. If there is an ankle varus deformity we prefer to resect a random flap is needed for soft tissue coverage of a pre-existing ulcer to the lateral or medial malleoli region. If there is a postoperative guidewires if needed. We begin with the tibia cut first and then proceed with the talus cut after the foot is properly positioned in the sagittal plane. Common mistakes with ankle joint resection is to neglect positioning of the foot in the sagittal plane during the talus cut and to perform a lateral to medial resection with a pre-existing valgus deformity. We have found that joints prepared with resection of the fibula tend to drift into valgus and when joint resection is performed from lateral to medial with a pre-existing valgus ankle deformity it becomes difficult to obtain the necessary correction. The remaining joints are prepared by denuding the articular cartilage with osteotomies and curettes or through minimal and careful joint resection with a sagittal saw. A sagittal saw with a longer and narrower blade is useful to further denude well-exposed cartilage to expedite joint preparation. The remaining joints can become difficult to align if large resections are performed. For this reason, we attempt to maintain the anatomy of the joint and rely on repositioning for deformity correction.

When performing a tibiotalar or tibiotalocalcaneal arthrodesis, incision placement is similar to the pantalar arthrodesis. The exception is that the lateral incision only extends to the floor of the sinus tarsi and the medial incision is shortened and only performed for resection of the medial malleolus and possible ankle joint resection. Dissection and joint preparation of the ankle and subtalar for arthrodesis is performed in the same manner as in the pantalar arthrodesis (Figs. 24.2 to 24.4). When performing a triple arthrodesis, the incision begins laterally at the distal tip of the fibula and extends to the fourth metatarsal base. Medially the incision begins at the tip of the medial malleolus and extends to the navicular tuberosity. Surgical dissection and joint preparation are similar to the pantalar arthrodesis with the exception of not exposing the ankle joint or malleoli.

A medial column fusion is a very useful procedure to correct triplanar deformity about the midfoot most commonly associated with a Charcot neuroarthropathy. Incision placement is curvilinear to facilitate the exposure while minimizing the tension on the skin. We base our incisions according to the apex of the deformities and the location of the bony prominences. The incision usually begins just dorsal to the posterior tibial tendon and ends at the midportion of the medial aspect of the first metatarsal base. The incision should pass directly over the deformity and the joints that are deformed. After the skin incision is made we tend to perform a blunt dissection between the superficial and deep fascia, creating skin flaps that are tagged with a suture to minimize further soft tissue handling. The subcutaneous tissues are then incised in line with the skin incision, creating a full-thickness flap with the periosteum. Creating this layer is very important for closure to prevent migration of bone grafting material and wound dehiscence. In addition, we have found it easier to transect the anterior tibial tendon to facilitate exposure of the navicular cuneiform joint at its insertion and tagging it with a whip stitch for later repair. Postoperatively we have not experienced any ruptures to the anterior tibial tendon with this approach. The joints to the medial column are then identified and opened with a sharp curved or straight osteotome. At this point an attempt is made to reposition any dislocated or subluxed joints prior to joint resection. Joint resection of the first metatarsal cuneiform joint and the navicular cuneiform joint are...
Figure 24.2 Preoperative radiographs (A–C) and clinical pictures (D–G) of a severe left Charcot foot/ankle dislocation and nonunion. The patient had multiple minor debride-ments and was unable to bear any weight on the left lower extremity. The patient was initially brought to the operating room for an intraoperative bone biopsy along with deep soft tissue cultures. There was no evidence of osteomyelitis and the patient was eventually brought back to the operating room for a tibiotalocalcaneal arthrodesis (H–L) with a circular external fixation device. Please note the two incisional ap-proach and temporary fixation before the application of the static circular external fixator (M–Q). Final postoperative radiographs (R–T) and clinical pictures (U–X) and 8 months follow-up. (continued)
Figure 24.2 (Continued)
Figure 24.2  (Continued)
Figure 24.2 (Continued)
Figure 24.3 Preoperative radiographs (A,B) and clinical appearance of a severely deformed and dislocated Charcot foot and ankle (C,D). After extensive preoperative clearance, the patient was brought to the operating room for a one stage subtotal takedown and a tibio-calcaneal-naviculo-cuboid arthrodesis with allogenic bone grafting (E-I). Postoperative radiographs (J,K) and clinical picture of the circular external fixator with the adjunctive external bone stimulator (L). Final postoperative radiographs (M-O) and clinical appearance and 8 months follow-up (P,Q). (Continued)
Figure 24.3 (Continued)
Figure 24.4 Preoperative ankle fracture radiographs (A,B) on diabetic neuropathic patient who underwent ORIF (C,D). The patient was referred 8 days after the initial surgery for pus and drainage from the bilateral incisions. The patient was admitted and brought to the operating room for hardware removal and intraoperative bone biopsy and soft tissue cultures (E-G). No tourniquet was used during the hardware removal and it was noted that was minimal bleeding intraoperatively. A vascular consult was initiated followed by a lower-extremity angioplasty. The bone cultures were positive for ankle osteomyelitis and the patient was then brought back to the operating room for insertion of antibiotic cement beads and application of a hybrid offloading external fixator (H-M). Please note that the external fixator immobilizes the lower extremity, allows for direct visualization of the multiple wounds and simultaneously offloads the affected extremity. The patient was eventually discharged with IV antibiotics and strict non-weight-bearing status. After 7 weeks, the patient was brought back to the operating room for removal of the antibiotic beads and external fixator. Intraoperative bone cultures were negative for osteomyelitis and the patient underwent a tibiotalocalcaneal arthrodesis with a locking plate because of her severe osteopenia and morbid obesity (N-P). Postoperative radiographs at 5 (Q,R) and 12 weeks (S,T). Clinical appearance at 4 months follow-up (U-W). (continued)
Figure 24.4 (Continued)
Figure 24.4 (Continued)
Figure 24.4 (Continued)
performed with a sagittal saw. Resection is typically performed with a plantar based wedge so as to plantarflex the first ray to restore the height to the medial longitudinal arch. The surgeon needs to be cautious of the distal perforating artery off the dorsalis pedis in the first interspace when joint resection is performed of the first metatarsal medial cuneiform joint. Also, the surgeon has to appreciate the natural curvature of the navicular cuneiform joint to prevent overzealous joint resection. At times the articular cartilage to the navicular and the medial and intermediate cuneiform are resected first and a lamina spreader is placed to denude the cartilage of the lateral cuneiform and the lateral aspect of the navicular with an osteotome/curette. The cartilage to the talonavicular joint is prepared for arthrodesis as described previously for the pantalar arthrodesis.

Lateral column fusions are often needed either in combination with a medial column fusion for a Charcot midfoot deformity or in isolation for the management of a plantar lateral ulceration with lateral column collapse (Fig. 24.5). The approach for the

Figure 24.5  Preoperative clinical (A,B) and radiographic pictures of a failed Charcot midfoot arthrodesis with inadequate internal fixation (C–E). (continued)
The patient had an unstable deformity with recurrent ulcerations. The patient underwent a one-stage revisional midfoot arthrodesis (F-J) with a two-incisional approach (medial and plantar). Please note the use of allogenic bone grafting to enhance the arthrodesis sites (J). (continued)
Figure 24.5  (Continued) The broken hardware was removed and the entire tarsometatarsal joint complex was fused with the use of the Taylor spatial frame (K-O). (continued)
Figure 24.5 (Continued) Final radiographic (P–R) and clinical pictures at 1-year follow-up (S,T). Please note the complete bony union at the entire tarsometatarsal joint complex.
lateral column fusion is a direct plantar approach through a clean previously excised ulcer. Often a random or pedicle flap may be raised in conjunction to obtain soft tissue coverage. Full-thickness flaps are raised after a direct subcutaneous incision overlying the calcaneal-cuboid joint and the fourth/fifth metatarsal-cuboid articulation is made. After verification of the joints with a curved osteotome, retraction is placed and the joints are resected with a sagittal saw from plantar to dorsal. Attention is made to create a plantar base wedge so that the lateral column can be raised to prevent further skin breakdown. Taelectomy is a powerful procedure to manage severe fixed deformities about the ankle and rearfoot. A taelectomy can be performed from either a medial or lateral incision as described for the pantalar fusion. We tend to carry the incision distally over the head of the talus, which is often dislocated at the talonavicul ar joint. Whether a medial or lateral incision is made the surgical technique to remove the talus in toto is to place a bone hook posteriorly on the dome of the talus and a curved osteotome into the posterior facet of the subtalar joint. As the talus is lifted, the bone hook is pulled distally and the talus is extruded in toto. Often dislocation is evident at the talonavicular joint and dissection at this level is minimal if at all to remove the talus. A medial incision is typically used when the talus is displaced medially as in severe acquired pes plano valgus deformities. A medial incision beginning just proximal to the medial malleolus and extending distally along the talus allows for easy extrusion of the talus and permits joint preparation of the tibia and calcaneus for arthrodesis. It is easier to resect the medial malleolus prior to extrusion of the talus. As the talus is lifted from the subtalar joint with the curved osteotome and the bone hook pulled distally the talus is extruded while performing meticulous dissection of any remaining soft tissue attachments. In revisional surgery secondary to scar contractures it is not unlikely to have the neurovascular bundles adhered to the talus, and caution should be taken when resecting these remaining soft tissue attachments. After the talus is removed from a medial incision, the fibula can easily be resected at the level of the tibia, eliminating the need for an additional lateral incision. A lateral incision as described for the pantalar arthrodesis is indicated for a taelectomy when the talus dislocates laterally as in a severe acquired equinocavovarus deformity. The fibula is resected from the lateral incision prior to removing the talus. A large portion of the talus is articular cartilage and often the remaining bone is very avascular, so we rarely use the talus after being extruded for bone grafting in the neuropathic lower extremity. If bone grafting is needed we prefer to use autogenous iliac crest bone graft for additional stability when performing a tibiocalcaneal arthrodesis. After the joints are appropriately positioned they are stabilized either with Steinman pins that are later incorporated into the circular external fixator or with guidewires for large cannulated screws to supplement the external fixation.

**CIRCULAR EXTERNAL FIXATION: SURGICAL TECHNIQUE**

The authors believe there is an obvious learning curve for the use of circular external fixation. Attention to surgical detail, cross-sectional anatomy, and a thorough understanding of the biomechanics of circular external fixation to achieve frame and osseous stability are paramount to prevent postoperative complications. The first step in application is proper positioning of the prebuilt circular external fixator to the lower leg. The use of surgical towels positioned on the posterior aspect of the lower leg and knee allows excellent positioning of the lower extremity prior to wire insertion. Anatomic landmarks should be evaluated to ensure appropriate positioning unless a gradual correction is needed to achieve anatomic alignment. The anterior crest of the tibia should align with the second metatarsal and second toe assuring that the foot is neither internally nor externally rotated. Laterally the foot should be positioned 90 degrees to the lower leg. Often, a surgical assistant or an additional member of the surgical team is needed to hold the foot in this position while the initial transosseous wires are placed. At this point, the circular external fixation frame is provisionally stabilized with one transverse transosseous wire for each ring and bone segment. Proper surgical technique for tensioned transosseous wire placement and half pin placement is essential in preventing associated skin irritation and infection. Tensioned transosseous wires offer great stability to their respective osseous segment. Transosseous wires should always be placed through bicortical bone. The authors prefer to hold the transosseous wires with an alcohol- or saline-soaked gauze during insertion to minimize cross-contamination, increase manual wire stability, and decrease the temperature across the wire during insertion. Tension should be initially applied to the skin while the wire is manually placed onto the bone segment percutaneously. The wire should be driven with steady and even pressure, avoiding thermal necrosis. Wires should not deviate from their anticipated course. Deviation of wires is often present when uneven pressure is administered to the wire driver during insertion or inadequate soft tissue tension was placed during initial wire insertion. Transosseous wires that are inappropriately placed often result in wire tract irritation, infection, and/or wire breakage. In addition, the wire can be tamped through with a mallet after bicortical purchase is achieved, minimizing soft tissue irritation and thermal necrosis. If thermal necrosis occurs during insertion, the wire is removed, the area is cooled with a saline-soaked gauze, and a new wire is inserted in a different position.

After placement of the transverse transosseous wires, reassurance of positioning is performed clinically and radiographically if needed. At this stage, it is easy to translate the frame if needed prior to tensioning and dynamization. If frame alignment is not adequate, the surgeon should remove the initial transosseous wires and reposition the external fixator. After appropriate positioning, the transosseous wires are tensioned with a dynamometric wire tensioner. Transosseous wires in the tibia are typically tensioned to 110 to 130 kg of force, whereas transosseous wires in the foot are typically tensioned to 70 to 90 kg of force. The second step is to further stabilize each bone segment and level of the external fixator with additional tensioned transosseous wires and/or half pins. The placement of oblique transosseous wires are placed on the opposite site of the ring in which the transverse transosseous wires were placed to increase stability to the ring and to prevent wire interference on insertion. In addition, these wires should be tensioned from the opposite side that the previous transverse transosseous wire was tensioned. Angular placement of the transosseous wires and appropriate staggering of the half pins are essential in frame stability. The angle that transosseous wires are placed are often predicted by the anatomy, but
should be placed as large as possible to achieve adequate frame stability and control of the respective bone segment. Transosseous wires placed at an angle of <30 degrees tend to offer little additional stability and should be avoided. Crossed olive wires offer the advantage of additional stabilization by preventing translation. In addition, olive wires when tensioned allow the movement of bone segments and should be placed opposite the corrective forces to achieve correction. The third step is to provide additional stability between the external fixation rings and foot plate with additional threaded rods and connection plates. Finally, the circular external fixator and every connecting part is inspected for stability and rigidity and is then prepared for distraction osteogenesis, bone transporta-
tion, and/or joint arthrodesis. Distraction osteogenesis and bone transportation are performed either through gradual distraction of two segments of the external fixator or gradual tension of crossed olive wires through a pulley mechanism.

Compression across joints prepared for arthrodesis is achieved through compression of two segments of the circular external fixator or by applying tension through a "prebent" transosseous wire. If the prebent wire technique is used, each end of the wire is brought toward the joint requiring compression, resulting in a bend that when straightened by manually tensioning the wire from each end simultaneously transmits tension across the transosseous wire and compression across the arthrodesis site. The surgeon should be aware that when performing an arthrodesis of multiple joints as in a medial column arthrodesis to begin compression with the prebent wires proximally and continue distally to avoid distraction of joint after it was previously compressed. Placing too much bend to the prebent wire can place significant tension on the soft tissue when manually tensioned resulting in skin ischemia and eventual necrosis. For this reason, after tensioning this wire the underlying skin is assessed for tissue ischemia and if evident tension to the skin is released by incising the skin at the skin wire interface. If ischemia is still present the wire should be repositioned and re-tensioned. The skin between frame segments that are either compressed or distracted should also be evaluated for signs of ischemia. If the area is cyanotic, then compression or distraction between the frame segments should be reduced and then reinstated gradually postoperatively. Our preference is to use segments of the external fixation frame to achieve compression of the ankle and subtalar joint and rely on manually tension to prebent smooth wires for compression across the midfoot and forefoot. After compression is achieved, provisional percutaneous Steinman pin fixation that was used can be either removed or incorporated into the external fixation frame for additional stability if needed.

POSTOPERATIVE MANAGEMENT

The postoperative management of the diabetic neuropathic patient that has undergone revisional lower extremity reconstruction will require compliance, patience and close monitoring for a successful outcome. All these patients require hospitalization ranging from days to weeks depending on the staging of procedures and how they respond to surgery. Postoperative management for this patient population varies greatly and often entails the management and repetitive evaluation of many critical aspects. The overall medical management of these patients is far beyond the scope of this chapter, but emphasis should be placed on the fact that this should be coordinated and managed by a diabetic multidisciplinary team. Attention by the surgeon must be made if present to open wounds, deep infection, pre-existing osteomyelitis, surgical incision healing, interval osseous healing, pin sites, split-thickness skin grafts, and flaps along with their associated donor sites.

Typically, these patients are bedridden for the first 48 to 72 hours. Vascular checks are performed every 6 to 8 hours during this period. Clinical signs of ischemia may warrant a frame modification to decrease the amount of compression or distraction that was performed intraoperatively. Evaluating the neurologic status of a patient with peripheral neuropathy can be difficult and offers little clinical relevance. Since the patient is bedridden, the authors recommend all mechanical and medical measures be initiated for deep vein thrombosis prophylaxis. We also recommend a compression stocking to the contralateral lower extremity, the patient to be instructed on the first postoperative day to perform leg lifts and limited exercise while in bed to prevent blood stasis, and prophylactic pharmacological therapy as instructed by the medical team.

The patient is usually instructed on transfers from bed to chair beginning on the second or third postoperative day, and physical therapy for gait training to be non-weight-bearing on the affected lower extremity begins on the third or fourth postoperative day. The assumption to mobilize these patients earlier may create lower extremity edema and wound healing complications. We have found that the first 72 hours are critical to decrease postoperative edema through elevation of the lower extremity above the heart level. In the neuropathic diabetic patient the vasomotor response is compromised and edema control through limb elevation is essential. Many surgeons support the notion that when the Ilizarov apparatus is applied, the patient can be permitted to weight-bear immediately. We do not support this notion as the Ilizarov apparatus and technique are typically used for limb lengthening or deformity correction in an otherwise healthier patient population, and these principles may not necessarily be applied to diabetic patients with dense peripheral neuropathy.

Transosseous wires and half pins in the diabetic patient with neuropathy should be evaluated by the surgeon only. We prefer to place nonadherent dressing with Betadine solution to the wire/pin sites that are then covered with sterile compressive "fluff" dressings that are enclosed and sealed. The digits (if a pedicle flap or free tissue transfer was performed) are left uncovered for vascular checks. Shower privileges are restricted during the time that the external fixator is in place. Our preference has been not to allow the diabetic patient with peripheral neuropathy to perform local wire/pin care. The area is inspected 72 hours postoperatively by a member of the surgical team, then weekly thereafter, preventing contamination at the pin/wire skin interface from repetitive handling. Another advantage to controlling the management of wire/pin site care is to ensure that transosseous wires that display clinical signs of skin irritation are tensioned appropriately. The presence of localized erythema at the skin wire interface is often an indication that the transosseous wire is loose or tension across the wire has diminished. These wires should be re-tightened and tensioned to properly prevent further skin irritation that can lead to secondary infection.
Radiographs may be needed if motion is still apparent to determine if lucency around the wire/pin or unicortical placement is evident. In addition, at the time the wires/pins are inspected we evaluate the stability and position of the external fixator in relation to the lower extremity. Complications commonly associated with circular external fixation can be avoided by close observation during the postoperative period. A common mistake is removal of an external fixator early in the postoperative course if complications arise from the transosseous wires or half pins. Case scenarios in which the external fixator is removed early and further osseous stabilization is not achieved until successful arthrodesis or bone regeneration is apparent, often lead to devastating complications and at times major limb amputation. For this reason, the authors prefer to perform the necessary frame modifications that may be needed to extend the overall period of the external fixator until the necessary osseous interval healing is present. Often, broken wires and/or half pins should be replaced, additional external fixation segments may be added to a particular bone segment to provide additional stability, and the placement of additional olive wires may be needed to prevent unwanted motion and/or translation of a bone segment.

The time frame for which an external fixator is placed can range from 10 weeks to >1 year in patients that require extensive distraction osteogenesis. Radiographs are obtained 1 to 2 weeks postoperatively, then every 2 to 4 weeks to evaluate for internal bone healing at the arthrodesis or bone docking site. Radiographs are typically obtained at the fourth week on patients undergoing distraction osteogenesis to evaluate the early signs of bone regeneration. Particular attention is made to the central lucency among the visible callus that is apparent on radiograph to determine if a change in the rate of distraction needs to be made. Typically distraction is performed at a rate of 0.25 mm every 6 hours unless signs of premature consolidation or weak regenerate are apparent. A central lucency of >8 mm is indicative of excessive distraction that could lead to a fibrous union and the rate is decreased. A central lucency of <2 mm is indicative of premature consolidation and the rate of distraction should not be increased. In addition to radiographs, a CT scan may be needed prior to external fixation removal when it is difficult to evaluate an arthrodesis site with standard radiographs. Radiographs may be needed if motion is still apparent to determine if lucency around the wire/pin or unicortical placement is evident. In addition to radiographs, a CT scan may be needed prior to external fixation removal when it is difficult to evaluate an arthrodesis site with standard radiographs. For example, if it took 2 months to obtain the required bone regeneration, then the circular external fixation is removed at approximately 8 months postoperatively. The circular external fixation frame can be left in place to provide neutralization or can be compressed to achieve solid consolidation and simultaneous arthrodesis if needed.

Our preference is to remove all external fixation devices in the operating room. Returning to the operating room allows us to remove the external fixator, stress the arthrodesis site, address any remaining wounds if present, and apply a well-padded cast. Diabetic patients with peripheral neuropathy who undergo revisional reconstructive surgery typically experience wound-healing complications such as wound necrosis or dehiscence. If still present at the time the external fixator is removed, a formal débridement can be performed. A decision is then made to whether soft tissue coverage can be obtained at this setting or wound care or negative pressure therapy is indicated.

The most challenging aspect of the recovery process is the period after the external fixation is removed. Patients typically feel they are finished with the surgical process and want to ambulate as soon as possible. The surgeon needs to minimize early weight-bearing with the diabetic patient with peripheral neuropathy until a solid union or pseudoarthrosis is evident and the soft tissues heal completely. The surgeon also has to explain to the patient the need for continued bracing and shoe gear modifications with long follow-up visits to achieve long-term functional limb salvage.

### Complications

Complications in this high-risk patient population do occur and should be discussed with the patient and family preoperatively. Difficulties with wound healing, wire/pin tract infections, soft tissue infections, osteomyelitis, scpsis, nonunions, malunions, recurrent Charcot events, hardware failure, and iatrogenic stress or complete bone fractures from incorrect wire or pin placement account for most of the complications associated with revisional surgery on the neuropathic lower extremity.

**Wound healing complications** are frequently seen after revisional surgery in this patient population. Most commonly a superficial wound dehiscence and/or local tissue necrosis is experienced. Meticulous atraumatic soft tissue handling, creation of full-thickness flaps, subcutaneous coverage of bone graft and hardware, and strict postoperative limb elevation can minimize potential wound-healing complications. Wound dehiscence is best managed with avoidance of early suture removal, adequate tissue débridement, and appropriate antibiotic to prevent secondary infection. In more severe cases, negative pressure therapy may be needed after adequate débridement to promote granulation tissue. At times, split-thickness skin grafting, random or pedicle flap, or free tissue transfer is needed for soft tissue coverage.

**Deep infection** and the development of osteomyelitis is infrequent but should be managed with aggressive surgical débridement, management of the dead space, osseous and soft tissue stabilization, offloading, and a staged procedure to obtain soft tissue coverage.

**Nonunions** occur at a higher incidence in this patient population. We have found nonunions to occur more often with pre-existing avascular bone, large bone defects, inadequate joint preparation, insufficient fixation, and early weight-bearing. For this reason, meticulous joint and bone preparation along with stable fixation is paramount. The use of bone stimulation and orthobiologic agents such as bone morphogenic proteins and platelet-rich plasma can be used adjunctively to prevent or manage a nonunion. If evidence of nonunion is still present...
after 6 months, we continue with controlled bracing of the lower extremity supplemented with bone stimulation if the nonunion is stable. If instability persists, then revisional bone grafting with added fixation and extended non-weight-bearing immobilization is warranted.

Malunions can develop from intraoperative positioning of the prepared joints. It is imperative to confirm appropriate intraoperative alignment when performing major joint arthrodesis procedures about the foot and ankle. The development of a nonunion can also develop during the healing process in the postoperative period as a result of insufficient fixation that allows motion across the arthrodesis site. Also, patients who weight bear prematurely prior to solid union can result in a malunion. Malunions usually with <5 degrees of deformity can easily be managed with shoe gear modifications. The more severe deformities may require additional corrective osteotomies or a revisional arthrodesis to achieve a plantigrade foot suitable for functional bracing.

Charcot neuroarthropathy is a devastating condition that affects diabetics with peripheral neuropathy. At times, the reason for its development still remains unknown. Postoperative patients who develop Charcot neuroarthropathy or a recurrent event face one of the most challenging complications to manage. The most common reason for the development of neuropathic fractures and dislocations in the postoperative period that we have experienced resulted from early and/or unprotected weight-bearing. The diabetic patient with peripheral neuropathy who undergoes major reconstructive surgery about the lower extremity usually requires protective weight-bearing with bracing, orthosis, and/or shoe gear management for at least 1 year if not for life. If the development of Charcot neuroarthropathy is present the patient is immobilized until the acute phase subsides. A decision for revisional surgery or major limb amputation should not be made during the acute inflammatory phase. Conservative management is beneficial for stable deformities with no ulcerations or pre-ulcerative lesions. Unstable deformities that persist after the acute phase may require further revisional surgery for limb salvage. At this point, a decision has to be made between the surgeon and patient as to performing further revisional reconstructive surgery or major limb amputation.

CONCLUSION

This chapter reviews in detail the authors’ approach in revisional and reconstructive diabetic limb salvage surgery. We strongly believe that each patient has a different pathology and different demands and is handled accordingly. A vast knowledge of the external fixation biomechanics and management of any associated complications is a must to treat these deformities. Finally, the importance of a multidisciplinary team approach is crucial to the overall patient’s successful outcome.

REFERENCES

INTRODUCTION

According to the American Diabetes Association (ADA) in 2005, 1.5 million new cases of diabetes mellitus were diagnosed. The ADA also reported that the incidence of diabetes mellitus in the United States was prevalent among 20.8 million people, which accounted for 7% of the United States population. This disease has reached epidemic proportions in the United States as well as around the globe. The World Health Organization estimates that currently, there are 171 million people with diabetes mellitus, and it is projected that by the year 2030 the prevalence will escalate to 366 million people (1).

Peripheral neuropathy is a serious and significant complication of diabetes mellitus that affects >50% of patients with diabetes. The highest rates of peripheral neuropathy are among people who have had diabetes for at least 25 years, are >40 years of age, and have had poorly controlled glycemic levels as well as other cardiovascular risks, such as obesity and hypertension (1). In addition, those patients with diabetes mellitus and neuropathy are reported to have a reduced bone mass and severe osteopenia (2).

Peripheral neuropathy and peripheral vascular disease play a significant role in the development of surgical complications and can create significant limb-threatening scenarios if left untreated or misdiagnosed (3). Peripheral neuropathy alone is considered an indicator for unfavorable prognosis for lower extremity trauma. Patients with peripheral neuropathy are difficult to manage because of their loss of sensation and failure to sense infection secondary to trauma and/or soft tissue complications.

The neuropathic patient who experiences lower extremity fractures and/or dislocations presents a great challenge to the treating physician. Typically, trauma surgeons use external fixation to temporarily stabilize fractures until the soft tissue envelopes are ready for surgery (4). Open reduction internal fixation (ORIF) is then executed following the decrease in soft tissue swelling and the return of skin lines in the nonvascular compromised patient (5). This chapter discusses the use of external and/or internal fixation as a primary and definitive treatment for this difficult-to-treat patient population.

INDICATIONS/CONTRAINDICATIONS

External fixation is much less invasive to the soft tissue envelope when it is performed percutaneously. A methodical preoperative assessment of potential operative candidates will support the surgeon with suitable selection criteria. Supporting documentation reveals that medically compromised patients, such as those with diabetes mellitus, rheumatoid arthritis, extensive smoking history, vascular impairment, and morbid obesity do not fare as well with standard open surgery and are more appropriate type of patients for external fixation. One must also consider and evaluate anesthesia risks with external fixation. Two considerations need to be understood: External fixation typically requires a significantly longer operative time than typical AO techniques, and in most scenarios a second anesthesia is needed on removal of the external fixator.

Appropriate candidates for the use of external fixation in reconstructive foot and ankle surgery include and are not limited to patients who have experienced trauma (high-energy open or closed fractures resulting in significant soft tissue injury), need for temporary fixation or staged procedures, bilateral lower extremity trauma, patients with impaired upper extremities that will not allow their upper body to be supported with crutches or other walking devices and direct visualization to flaps and soft tissue envelope.

Options for open and/or closed treatment exist for the neuropathic trauma patient. The respect of the soft tissue envelope is vital while providing stable rigid fixation. Characteristically, this patient population requires extensive detail to the soft tissues. Surgical wounds related to osseous and soft tissue injuries in patients with neuropathy often heal unsuccessfully. Preoperative evaluation of these cases includes performing a history and physical with a thorough lower extremity evaluation. This evaluation should include a detailed physical assessment specifically evaluating skin integrity and quality. In the acute traumatic patient, reduction of bony displacement is mandatory to eliminate tension from the skin to minimize the danger of skin necrosis. A sensory evaluation is needed preoperatively to determine if the patient is neuropathic. Differentiating between
**SURGICAL TECHNIQUE FOR THE NEUROPATHIC FOREFOOT/MIDFOOT OSSEOUS TRAUMA AND DISLOCATIONS**

Surgical treatment of the neuropathic forefoot/midfoot osseous trauma and dislocations may be addressed with a traditional surgical approach with some additional steps needed to ensure healing and decrease complications. The initial clinical presentation is a valuable predictor of what additional surgical steps might be required. Radiographic examination of the pathologic foot is absolutely necessary any time a neuropathic patient describes a questionable event or related symptoms. Subtle dislocations should be further examined by radiographic comparison of the contralateral foot. A CT scan may also be obtained to confirm a diagnosis and determine the severity of pathology. Undiagnosed and improperly treated forefoot and/or midfoot osseous trauma and dislocations can rapidly progress into a Charcot joint collapse. The severity of peripheral neuropathy indicates that the patient will most likely weight-bear prematurely and has an extremely high risk of developing an acute Charcot event.

It is the author's opinion that these patients will better benefit with a primary arthrodesis of the affected collapsed joint(s) with multiple screws, multi-ring external fixation with a foot plate for additional stabilization and joint compression, and a possible percutaneous tendo-Achilles lengthening. A primary arthrodesis may not be necessary if the presentation of the trauma is more traditional to a patient in the early stages of diabetic neuropathy and who is unable to weight-bear secondary to discomfort. It is also the authors' opinion that the vast majority of diabetic neuropathic patients who sustain forefoot/midfoot osseous trauma and dislocations will benefit from external fixation. The deciding factor of whether a circular multi-ring or monolateral/hybrid external fixation system is used depends on the severity of the initial trauma presentation.

A wide variety of forefoot/midfoot trauma exists. Forefoot trauma may be classified and described by the Hardcastle tarsometatarsal joint injury classification (8). If the patient is able to have surgery performed within 3 to 5 days from the traumatic event, the likelihood of a percutaneous reduction and stabilization is acceptable. Beyond this time frame, it is likely that an open approach will be needed using a two to three dorsal incisional approach. The keystone of the metatarsal bases must be restored to anatomic alignment. Using bone reduction forceps, the fractured/dislocated metatarsals may be reduced and temporarily stabilized. The Lisfranc ligament must be recreated stabilizing the keystone by a 4-mm cancellous screw. Depending on what other tarsometatarsal fractures/dislocations have occurred, it will determine whether additional screw fixation will be needed. It is the authors' preferred technique for lesser metatarsal bases to be fixated with one 4-mm cancellous screw in each metatarsal that was dislocated. The first metatarsal should be fixated with two 4-mm cancellous screws. After internal fixation has reduced and stabilized the traumatic pathology, a decision on which external fixation modality arises. Pathology described as Hardcastle B1 and C1 involve the medial column and second metatarsal only. Therefore, a mini-external fixator is the preferred choice. However, pathology described as Hardcastle A, B2, C2 involve multiple metatarsals (Figs. 25.1 and 25.2). These types of fracture dislocations are much more traumatic and unstable. A tarsometatarsal multi-ring external fixator consisting of a proximal ring, ankle ring, and a foot plate is then recommended.

The tarsometatarsal external fixator is applied in the following fashion. The chosen configuration is similar to the ankle joint stabilization frame consisting of two full rings and a foot plate connected by four threaded rods. The distance from the foot plate to the ankle joint should place the ankle ring 2 to 4 cm above the ankle joint. The proximal ring distance from the ankle joint should be 150 mm from the ankle ring. The prebuilt external fixation is placed over the foot and lower extremity. The foot plate is placed to allow planter projection of the heel. A transosseous calcaneal wire is
Figure 25.1  Neuropathic technique for Hardcastle A, B1, and B2.
Figure 25.2 Neuropathic technique for Hardcastle C1 and C2.
placed medial to lateral and tensioned to 70- to 90-kg force. Two converging transosseous tibial wires are placed on the proximal ring and ankle ring and tensioned to 110- to 130-kg force. Once the proximal fixation block is stabilized, a second converging calcaneal wire is placed. The next wire is the midfoot wire. This wire serves two purposes. It stabilizes the midfoot and serves as a stable block that allows the metatarsal wire rebound force for compression of the Lisfranc’s joint. The midfoot wire is a transosseous wire placed from medial to lateral coursing from the proximal medial cuneiform and exiting at the cuboid. The olive must be abutting the cortex of the medial cuneiform. The midfoot wire is then tensioned to 70-kg force and secured to the foot plate. The metatarsal wire is next placed from lateral to medial serving two purposes. This wire stabilizes the forefoot and compresses the bases of the metatarsals against the cuneiforms and cuboid. The metatarsal wire is a transosseous wire placed from lateral to medial. This wire should course through the bases of at least three metatarsals with the olive abutting the lateral cortex of either the fourth or fifth metatarsal. After this wire is placed, make note of where the wire lies on the foot plate both medially and laterally. Secure the wire back toward the rearfoot by one to two foot plate holes. Loosely fixate the metatarsal wire in this position medially and laterally to the foot plate. A tensioner is then placed medially and laterally on the wire. Gently both tensioners are simultaneously tightened to about 20- to 30-kg force. The wire is then secured to the foot plate. The tarsometatarsal stabilization external fixator is now completed (Figs. 25.3 and 25.4).

Isolated midfoot and forefoot fracture/dislocations outside the Lisfranc’s joint in diabetic neuropathic patients also benefit from traditional surgical approaches with the addition of reduction and stabilization using a mini-external fixator. The mini-external fixator has the ability to aid in reduction and stabilization of the fracture pathology throughout the postoperative course. Reduction techniques may be used in fracture pathology involving bones of the medial cuneiform, navicular, and cuboid. By inserting two 3.5-mm fixator pins proximal and distal to the fracture bone, the external fixator is then adjusted by lengthening the distance between the proximal and distal fixator pins. This mechanism creates a reduction force using ligamentotaxis. Once the fracture is reduced, it needs stabilization and compression by one to two 4.0-mm cannulated screws. When dealing with a fractured metatarsal, the insertion of a Kirschner wire (Kwire) for stabilization and realignment can be performed. However, when multiple metatarsals are fractured, a mini-external fixator is added to the Kwire fixation for further stability. A size ranging from 2.5- to 3.5-mm mini-external fixator pins are positioned with two pins distal to the fracture and two pins proximal to the fracture. Distally, one pin may be placed in the base of the proximal phalanx and a second pin placed in the head/neck area of the corresponding metatarsal. Proximally, two pins are placed in the base of the metatarsal (Fig. 25.5).

SURGICAL TECHNIQUE FOR THE NEUROPATHIC HINDFOOT OSSEOUS TRAUMA AND DISLOCATIONS

It is the authors’ opinion that diabetic patients with dense peripheral neuropathy and severely comminuted intra-articular calcaneal fractures will better benefit with a primary arthrodesis of the subtal joint with the use of multi-ring external fixation and a foot plate for additional stabilization and joint compression. If the presentation of the trauma is more traditional and a CT scan shows an extra-articular calcaneal fracture in a patient with early stages of diabetic neuropathy, then a primary arthrodesis may not be necessary. It is also the authors’ opinion that the vast majority of diabetic neuropathic patients who sustain open or closed hindfoot osseous trauma and dislocations will benefit from external fixation. A wide variety of hindfoot trauma exists according to CT scan classifications. If the diabetic patient with dense peripheral neuropathy is able to have surgery performed within 3 to 5 days from the traumatic event, the likelihood of a percutaneous or mini-open reduction and stabilization with an external fixator is acceptable. Beyond this time frame, it is likely that an open approach will be needed for the calcaneal fracture repair or primary sub-talar joint arthrodesis.

The surgical procedure of either the calcaneal fracture repair or primary sub-talar joint arthrodesis begins by placing a large transfixing Steinmann pin through the calcaneus and simultaneous distraction of the sub-talar and ankle joint. Fluoroscopic imaging is paramount at this point and an intraoperative decision of a percutaneous versus mini-open incisional approach is made. It is recommended that the distraction is allowed for at least 10 minutes before the surgical procedure or even perform the entire procedure under the desired distraction technique described in the preceding. For the primary sub-talar joint arthrodesis, a 3- to 4-cm skin incision is made directly over the sub-talar joint and blunt dissection is performed to the level of the lateral wall of the calcaneus. Care is then taken to avoid injury at the peroneal tendons and sural nerve. It is the authors’ technique to reflect the lateral calcaneal wall and bluntly lift the sub-talar joint into anatomic alignment. At that time, if the articular joint cartilage is severely damaged, the joint is resected with a sagittal saw or aggressive curettage technique. Corticocancellous allogeneic bone grafting is also recommended for the primary arthrodesis. The sub-talar joint can then be temporarily stabilized with a large Steinmann pin and the skin is closed with a 3-0 nylon suture. The tourniquet, which is highly recommended during the procedure, is then released before the external fixation application.

The hindfoot external fixator is applied in the following fashion. The chosen configuration is similar to the neuropathic forefoot stabilization frame consisting of two full rings and a foot plate connected by four threaded rods. The distance from the foot plate to the ankle joint should place the ankle ring 2 to 4 cm above the ankle joint. The proximal ring distance from the ankle joint should be 150 mm from the ankle ring. The prebuilt external fixation is placed over the foot and ankle. The foot plate is placed to allow plantar projection of the heel. Two transosseous calcaneal olive wires are placed from lateral to medial and tensioned from the medial side to 70- to 90-kg force. This allows fixation and stabilization of the lateral wall of the calcaneus. Two converging transosseous tibial wires are placed upon the proximal ring and ankle ring and tensioned to 110- to 130-kg force. Once the proximal fixation block is stabilized, a third converging calcaneal wire is placed from medial to lateral and tensioned to 70- to 90-kg force.
Figure 25.3  Neuropathic forefoot stabilization frame technique.
At that point, if an extra-articular calcaneal fracture is being repaired an extra midfoot wire is placed from medial to lateral and tensioned to 70- to 90-kg force. The midfoot wire is a transosseous wire coursing from the proximal medial cuneiform and exiting at the cuboid. The olive must be abutting the cortex of the medial cuneiform (Fig. 25.6A–J). If a primary arthrodesis is performed, a talar wire is then placed from medial to lateral side and manually tensioned at both sides to cause compression and stabilization across the subtalar joint. A second talar wire is also recommended for extra stability. The midfoot wire is then followed from medial to lateral coursing from the proximal medial cuneiform and exiting at the cuboid. The olive must be abutting the cortex of the medial cuneiform and tensioned from lateral to medial side around 70- to 90-kg force (Fig. 25.7A–I).

It is paramount to complete all the parts of the external fixation by rechecking the levels of stability and rigidity, by counting the accessory parts, and by reviewing the intraoperative technique. For example, an extra bottom foot plate ring is added for the first 2 weeks for patient compliance and before dynamization and weight-bearing status. Final radiographic imaging is recommended at the end of the procedure.

(text continues on page 355)
Figure 25.5 Neuropathic technique for midfoot and forefoot pathology.
Figure 25.6  Extra-articular calcaneal fracture repair. Distraction technique (A,B) followed by 3- to 4-cm skin incision directly over the subtalar joint (C,D), and application of corticocancellous allogenic bone grafting (E). Two transosseous calcaneal olive wires are placed from lateral to medial and tensioned from the medial side to 70- to 90-kg force (F,G). (continued)
A midfoot wire is placed from medial to lateral and tensioned to 70- to 90-kg force and an additional bottom ring is also applied to the foot plate for the initial 2 to 3 weeks for “weight-sharing” status (H–J).
Figure 25.7  Intra-articular calcaneal fracture repair with primary subtalar joint arthrodesis. A 3- to 4-cm incision over the subtalar joint followed by the resection of the articular surface (A) and application of corticocancellous allogenic bone grafting (B,C). Please note the position of the talar wire for the subtalar joint arthrodesis and application of the circular external fixator (D,E). (continued)
Lastly, ORIF with primary subtalar joint arthrodesis might also be considered in younger individuals in the early stages of diabetes mellitus (Fig. 25.8A–F). The postoperative course may be a minimum of 10 to 12 weeks of cast immobilization and/or the use of external electrical bone stimulation.

**POSTOPERATIVE MANAGEMENT**

The estimated time for bony consolidation is approximately double the time normally estimated for a healthy patient. Prolonged stabilization is essential to prevent neuropathic fractures from progressing into an acute Charcot event.

The patient is kept in the hospital for 3 to 7 days postoperatively for glucose control, pain management, appropriate intravenous (IV) antibiotics, and to ensure that the patient is medically stable and able to rehabilitate before discharge. The patient receives 10 to 14 days of prophylactic low molecular weight heparin or other thrombolytic therapy, which is started 12 hours postoperatively and 7 to 10 days of oral antibiotics in accordance with the medical and infectious disease teams. The patient is seen weekly until the sutures and/or staples are removed at 3 to 4 weeks and then once every 2 weeks for the remaining months. Postoperative radiographs are obtained at 2 to 4 weeks and then once a month until healing is complete. Patient and family care education, home health services, and close and constant monitoring are absolutely imperative.

The pin or wire sites are covered with gauze that is soaked with povidone-iodine (Betadine) and the external fixator is kept dry throughout the postoperative course. Patients are instructed not to take showers and are educated on pin or wire site care that is to be done weekly if necessary. Patient compliance is strongly emphasized and strict pin or wire site care must be maintained. Stability is also of the utmost importance. The wires and pins must be checked at each visit to guarantee that the tension has not been lost. Retensioning can be achieved using the manual tensioning technique.

**LISFRANC/FOREFOOT**

The patient is kept non-weight-bearing for 10 to 14 days. The patient is then encouraged to be full weight-bearing as tolerated with assistance. A patient with diabetic neuropathy generally has consolidation at 8 to 14 weeks. The frame may be dynamized by loosening the tension from the wires. The patient is full weight-bearing for 2 weeks. If no problems occur,
the frame may be removed. The patient then progresses into a walking device for 4 to 6 weeks. After complete consolidation has occurred the patient requires custom molded inserts and/or ankle foot orthoses for extra support and to prevent future breakdown or collapse.

REARFOOT/MIDFOOT

The patient is kept non–weight-bearing for 10 to 14 days and then after this point the patient is encouraged to be full weight-bearing as tolerated with assistance. In a normal patient, bony consolidation normally takes 6 to 8 weeks. A patient with diabetic neuropathy generally has consolidation at 12 to 16 weeks. The patient is then encouraged to walk full weight-bearing for 2 weeks. If no problems occur the frame may be removed. The patient then progresses into a walking device for 4 to 6 weeks. After complete consolidation has occurred, the patient requires custom molded inserts and/or ankle foot orthoses for extra support and to prevent future breakdown or collapse.

CONCLUSION

The use of circular external fixation demands a great amount of surgical experience and training. The principles and techniques applied by circular external fixation are paramount to the management of complex neuropathic lower extremity trauma and dislocations. However, extreme caution needs to be taken throughout the patient care. Postoperative complications are avoided by vast knowledge and training on external fixation and careful patient selection.

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REFERENCES

INTRODUCTION

The surgical treatment of the neuropathic pilon and ankle osseous trauma and dislocations may be accomplished with a traditional surgical approach with some additional steps needed to ensure healing and decrease complications. The initial clinical presentation is a valuable predictor of what additional surgical steps might be required. Radiographic examination of the pathologic ankle and distal tibia is absolutely necessary any time a neuropathic patient describes a questionable event or any related symptoms. Subtle dislocations should be further examined by radiographic comparison of the contralateral ankle and distal tibia. A computed tomography (CT) scan should also be obtained to confirm a diagnosis and determine the severity of pathology. Undiagnosed and improperly treated ankle and distal tibia osseous trauma and dislocations can rapidly progress to a Charcot joint. If the fixation is inadequate or the fixation is being minimally protected, the severity of peripheral neuropathy has an extremely high risk of developing a Charcot joint at the affected or the adjacent fractured site(s).

SURGICAL TECHNIQUE OF NEUROPATHIC DISTAL TIBIAL EXTRA-ARTICULAR FRACTURES

The complexity and level of the distal tibial fracture pattern are the determining factors for surgical planning. Distal tibial fractures can be described as intra-articular and extra-articular. Muller et al. have described the AO/ASIF distal tibial fracture classification, which is divided into categories A, B, and C (1). AO/ASIF type A fractures are defined as fractures occurring above and not involving the distal tibial articular surface. The distal tibial fractures not involving the articular surface are the focus of this section. If the mechanism of injury is secondary to a crush injury, hyperbaric oxygen therapy may also be considered.

Surgical correction may be performed at the closest time possible from the traumatic event. Extended surgical treatment timing reduces chances of anatomic alignment. To execute a proper reduction and stabilization of the distal tibia, the appropriate external fixator construct must be built preoperatively. A multi-ringed Ilizarov type external fixator is the authors’ preferred choice. Long tibia and fibula views consisting of anterior-posterior, medial oblique, and lateral views should be assessed routinely when evaluating this pathology. If there is any secondary fracture line that may appear to extend into the ankle mortise, a CT scan should be ordered and assessed because it will affect the external fixator ring construct and surgical reduction. Also, if a multisegmental and/or comminuted fracture is suspected, a CT scan should be ordered and thoroughly reviewed.

The external fixator construct should always consist of a minimum of two ring fixation blocks above and below where the fracture lies on the tibia. These blocks are called the proximal fixation block and the distal fixation block. Each fixation block is comprised of two full rings connected individually by four threaded rods. Two different ring constructs exist for distal tibial fractures. The proximal fixation block remains consistent by connecting two rings with four fully threaded rods with a distance of 150 mm between the two. However, the distal fixation block may vary depending whether or not two rings can fit on the distal tibia remaining above the ankle joint and below the distal aspect of the tibial fracture. If two rings will not fit, the distal fixation block will be modified and consist of a foot plate and an ankle ring. Once the distal and proximal fixation blocks have been constructed, the two blocks are then connected using four fully threaded rods. The distance between the two blocks should span just above and below the distal tibial fracture (Fig. 26.1). It is highly recommended that all transosseous wires be olive wires for additional stability.

During intraoperative anesthesia, the contralateral limb malleolar position is examined. Most of the time, the surgeon will observe an external rotation of the fractured limb and a varus ankle. However, this is not always the case, and examination of the fractured limb with the normal limb is necessary to better understand the rotational and angulated deformity. In the event of an open distal tibial fracture, the wound should be cleansed and débrided appropriately depending on the open...
nature of the wound. If indeed an open fracture is being treated, operating time should be performed within the “golden period” of 6-hour time window in conjunction with intravenous (IV) antibiotics correlating with the contamination level and nature of the wound. The surgical team should re-gown and drape following open fracture protocol before continuing with the external fixation application and fracture reduction. Intraoperative soft tissue and bone cultures are also imperative throughout the procedure.

Tibial fracture reduction techniques are next performed systematically. The preconstructed four-ringed external fixator or three ringed and a foot plate is placed over the leg. Under fluoroscopy, the foot and ankle are manually distracted and rotated, allowing reduction of the tibial fracture. Manual side-to-side compression may be applied at the level of the fracture to aid in reduction. Manual distraction of the foot and ankle should correct varus/valgus, procurvatum/recurvatum, and axial shortening. Clinically, the patella, anterior tibial crest, and the second ray should line up. The lateral fluoroscopic view should show the proximal and distal tibia lined up parallel without anterior or posterior translation (Fig. 26.2). The anteroposterior (AP) fluoroscopic views should show the ankle joint perpendicular to long axis of the proximal and distal tibia. Once reduction is confirmed, the external fixator is attached to the proximal tibia with a transosseous wire to the high proximal ring of the proximal fixation block. This wire is tensioned to 110- to 130-kg force and secured. Maintaining the triplane reduction, a distal transosseous wire is placed on the most distal ring of the distal fixation block. This may be the foot plate or ankle ring depending on what kind of fracture presented. This wire is tensioned between 70- to 90-kg force and secured. At this point, the fracture should be “out to length” and there should be no center of rotational angulation. If a slight varus/valgus, procurvatum/recurvatum, and shortening/over lengthening exists, the threaded rods connecting the proximal and distal fixation block can be adjusted.

Next, focus is aimed at stabilizing and compressing the fracture site. This is performed by a dual olive tensioning technique. The leading edge of the fracture is examined. If there is anatomic alignment, this step can be cut short by simply placing a transosseous olive wire from the proximal fracture ring and a transosseous wire from the top ring of the distal fixation block. With these olives opposing each other, a tapping technique should then be performed until they abut the cortex; then, tension and secure. If the leading edge of the fracture has a “step-off,” a transosseous olive wire is used to reduce the fracture. Correlating with the step off, a proximal transosseous olive wire is placed from the proximal fracture ring. The olive must be abutting either the lateral or medial cortex.

![Figure 26.1](image1.png)  
**Figure 26.1** Neuropathic distal tibial extra-articular fracture external fixator construct.

![Figure 26.2](image2.png)  
**Figure 26.2** Neuropathic distal tibial extra-articular fracture closed reduction.
If the distal tibia is laterally deviated as depicted in Figure 26.3 of the AO/ASIF A1 treatment pathway, the proximal olive wire should be against the medial proximal tibial cortex. The distal olive should be against the lateral distal cortex of the distal tibia. These olive wires may be strategically loosely secured to the ring one to two holes backward or forward depending on their orientation. This movement in the ring holes is to create a sagittal plane compression moment. This is called “walking back” the wire technique. Once these olive wires are in place, a tensioner is placed over the two wires opposite the olive. After a tensioner is over the distal olive wire and the proximal olive wire, the tensioner is gently tightened, pulling the distal and proximal tibia together. The end of the wire opposite to the olive is tightly fixated to the ring. The tensioner is loosened and re-tightened between 110- to 130-kg force. The olive should not move upon the second tensioning. If a large “butterfly” fragment is displaced, a third transosseous olive wire can be placed and tensioned as per the previously mentioned technique. Once the tibial fracture has been reduced and stabilized, the proximal and distal fixation block should be completed. Respecting the lower extremity anatomic “safe zones,” three converging transosseous wires or two transosseous wires and a half pin should be placed per ring. If a foot plate was utilized, it is fixated by a second converging transosseous olive wire through the calcaneus and two converging transosseous olive wires on the forefoot/midfoot region (Figs. 26.3 and 26.4).

The surgical technique of neuropathic distal tibial extra-articular fractures is depicted in diagrams. The surgical technique diagrams are not implying that all AO/ASIF A1, A2, and A3 can be treated as depicted. However, one should keep in mind the methods and apply as deemed appropriate.

**SURGICAL TECHNIQUE OF NEUROPATHIC DISTAL TIBIAL PERIARTICULAR FRACTURES**

The complexity of the articular disturbance inherent to the distal tibial periarticular fracture makes anatomic fracture reduction extremely challenging. Not only is the pilon fracture a severe intra-articular pathology, but it also produces severe soft tissue pathology. The distal tibial periarticular fracture zone of injury is notorious for dictating when and what kind of surgery can be performed. Depending on the severity of the...
intra-articular fracture pattern, realistic surgical outcomes must be thoroughly discussed with the patient. The neuropathic patient is projected to have a much poorer surgical outcome than the non-neuropathic patient. The goal of surgery is restoration of the distal tibia anatomic alignment. A more traditional pilon surgical approach involves initial stabilization and distraction with a monolateral external fixator. A second surgery is then performed approximately 2–3 weeks after the traumatic event. This second surgery involves an open reduction and internal fixation (ORIF) combined with plating of the medial tibia. The neuropathic limb is at risk with this procedure. Open reduction and internal fixation of a neuropathic pilon fracture increases chances of infection and wound dehiscence. A modification of this technique is required to minimize postoperative complications. This technique revolves around immediate closed reduction, percutaneous fixation, and a stable strategic application of a multi-ring external fixator. As with most complex fracture patterns, no one technique exists; however, a combination of techniques with underlying principles remains.

A high-energy pilon at the authors’ institutions is treated similar to a crush injury. Surgery is performed as soon as possible to the traumatic event. Surgical planning is correlated with radiographs and CT scans. Hyperbaric oxygen therapy is implemented when necessary. If surgery is delayed, hyperbaric oxygen may begin preoperatively and continue postoperatively. If an open distal tibial periarticular fracture is observed, it is a surgical emergency and is treated using an open fracture protocol.

Ruedi-Allgower classification of pilon fractures and the AO/ASIF distal tibial fracture classification can be used to generally describe radiographic pathologic anatomy of pilon fractures (1,2). The goals of distal tibial periarticular fracture surgery are to restore anatomic distal tibia alignment to set the stage for a functional ankle joint. If a distal fibular fracture and/or syndesmotic rupture and diastasis injury coexist, they must also be anatomically aligned. The tibia is the major load bearer and the fibula plays a minor role. Historically, distal tibial periarticular fracture surgery methods focused on plating the fibula regardless of the fracture pattern and location. If the fibula is brought to length and plated, certain postoperative measures should be taken before weight-bearing to prevent a varus ankle mortise by removing the distal plate screws before weight-bearing. If a fibula fracture is about 4 cm above the ankle mortise and there is no syndesmotic diastasis injury, it

Figure 26.4 Neuroarthropathic distal tibial extra-articular fracture technique for AO/ASIF A2.
usually does not need fixation. However, if the fibular fracture occurs with a concomitant syndesmotic diastasis injury, a syndesmotic screw and/or plate should be applied. A fibular fracture at the level of the ankle joint should be fixated using plating and screws in most cases. The premise is that a correctly aligned articular surface of the distal tibia, medial malleolus, and lateral malleolus is the only outcome that will restore the architecture for a functional ankle joint.

The authors' preferred choice is to use a multi-ringed circular type external fixator consisting of a foot plate and three circular rings. The foot plate and each of the three rings are connected by four threaded rods. Avoid using long threaded rods connecting multiple rings because they will limit postoperative adjustments. The frame construct should be planned preoperatively from true anatomic AP, calcaneal axial, and lateral long view radiographs from the foot to proximal tibia. The frame construct should consist of two fixation blocks called the proximal and distal fixation block. The four rings are designated as foot plate, ankle ring, proximal fracture ring, and high proximal ring (Fig. 26.5). The proximal fracture ring and the high proximal ring should be connected by four threaded rods with a distance spanning the tibia of at least 150 mm for an optimally stable block (3). The two fixation blocks are then connected by four threaded rods. The distance from the ankle ring and the proximal fracture ring is dictated by how high the pilon fracture lines extend into the proximal metaphyseal portion of the tibia. This distance may range from 60 to 110 mm. A common treatment pathway exists for similar type pilon pathological anatomy (Fig. 26.6). Once the patient is under anesthesia, distraction of the foot and ankle is performed allowing ligamentotaxis to reduce the pilon. The distraction maneuver is performed to bring the fibula and distal tibial peri-articular fracture out to length and attempt to acutely reduce frontal, sagittal, and transverse plane rotation associated with the traumatic event.

AO/ASIF B1, B2, and Ruedi-Allgower I type pilon injuries are described as the least destructive to the articular surface with minimal fracture displacement (2,3). Primary percutaneous fixation can be performed. The fracture orientation and plane determines the screw(s) orientation. CT scan correlation is very helpful. Using 4.0-mm cannulated partially threaded screws, the fractures can be compressed and stabilized. It is important to examine the fracture pattern preoperatively to be sure the cancellous portion of the screw will pass the fracture site maximizing screw lag technique. Once the distal tibial peri-articular fracture has been fixated, the fibula may be addressed. A fibular fracture below or at the level of the ankle joint with >2 mm of displacement should be fixated. A combination of a plate and screws may be used combined with a percutaneous technique. The tibia and fibula syndesmosis should always be stressed. If a syndesmotic ligament rupture has occurred, it must be reduced and stabilized. The syndesmotic screw insertion should be held until the tibial articular surface has been

Figure 26.5 Neuropathic distal tibial peri-articular external fixator construct and terminology.

Figure 26.6 Neuropathic distal tibial periarticular treatment algorithm.
restored and fixated. The syndesmosis is addressed by one to two 4.0-mm cannulated fully threaded cancellous screws applied to the lateral aspect of the fibula through the lateral aspect of the tibia, and anchoring in the medial cortex of the tibia. The screw should stop just before exiting the medial aspect of the tibial cortex. A transosseous olive wire may be used as an alternative syndesmosis reduction and stabilization technique. The wire is placed just above the ankle joint going through the fibula and tibia in the frontal plane with the olive wire abutting the lateral cortex of the fibula. The tensioner is placed over the wire opposite the olive and gently tightened under live fluoroscopy visualizing reduction of the tibia and fibula diastasis. Fibular fractures above the level of the ankle joint by 4 cm that do not have a concomitant syndesmotic rupture do not need plate and screw fixation. Intraoperative view should confirm correct placement of the olive wire(s) and the fibular should be stressed to confirm reduction and stability.

A prebuilt multi-ring external fixator is placed on the leg. This frame is applied to serve as a force neutralizer and joint stabilizer. The first wire is placed across the calcaneus allowing 1- to 1.5-cm plantar fat pad projection plantarly. The frame is then grasped and pulled distal from the patient, serving to distract the ankle joint and fracture fragments. While distracting, a tibial wire is placed parallel to the calcaneal wire to the high proximal ring. After checking for anterior and posterior spacing of the tibia and calf, the rest of the frame wires can be completed. Each of the three circular rings should be fixated to the tibia with three transosseous olives or two transosseous wires and half pin. All tibial wires should be converging consistent with the lower extremity safe zones and tensioned to about 110- to 130-kg force. The foot plate is fixated by two converging transosseous olive wires through the calcaneus and forefoot. The foot plate wires are tensioned to 70- to 90-kg force (Fig. 26.7).

AO/ASIF C2 and Ruedi-Allgower type II are described as multifragmental intra-articular minimally displaced distal tibial fractures (1,2). These fractures can resect into an anatomic realignment with traction and closed reduction techniques if performed as soon as possible to the traumatic event. However, there are times when these types of fractures do not respond to traction and a percutaneous manipulation combined with opposing olive wire reduction technique must be used.

Initially, the foot and ankle are distracted while an assistant stabilizes the knee. While distracting, the surgeon is waiting for a “deep click” that can be felt and sometimes heard. Distraction may continue for a continuous 5-10 minutes and fluoroscopic views will confirm that the joint has been reduced. Sometimes anatomic and other times percutaneous manipulation is needed to further align the articular surface. After the closed reduction, surgery may begin. Fluoroscopy determines the appropriate next steps. If ankle joint alignment has been restored, percutaneous screws may be placed to hold the reduction and compress and stabilize the fractures. This technique was previously described in the treatment of AO/ASIF B1, B2, and Ruedi-Allgower type I.

In the event that the AO/ASIF C2 and Ruedi-Allgower type II do not respond to percutaneous manipulation, a more aggressive reduction technique must be employed. The prebuilt three ring and foot plate external fixator is placed over the leg. A calcaneal wire is place from medial to lateral and anchored to the foot plate allowing 1 to 1.5 cm of plantar fat pad projection plantarily. The external fixator is then grasped while an assistant stabilizes the knee and pulled away from the patient pulling the calcaneus in aggressive traction. If this maneuver does not reduce the joint, a percutaneous introduction of a periosteal elevator may used to free and reduce fragments. This is a maneuver aimed at pushing plantarly the articular fragment of the joint that has become lodged in the metaphyseal portion of the tibia. Sometimes, multiple strategically placed tibial stab incisions anterior lateral and anterior medial are necessary to locate and reduce fracture fragments. Once the fragment has been reduced, large reduction forceps are used to reduce the anterior and posterior widened tibia. The proximal fixation block must be stabilized by placing two to three transosseous olive wires anchored and tensioned to the high proximal ring and the proximal fracture ring. After the proximal fixation block has been stabilized, percutaneous 4-mm cannulated partially threaded screws are then placed from anterior to posterior or posterior to anterior correlating with the fracture pattern anatomy of the CT scan. The sagittal plane of the pilon has been stabilized. The frontal plane is the next focus. Large medial and lateral pilon fracture fragments meet in the articular surface forming an “articular gap.” This articular gap must be reduced. One transosseous olive wire is placed from medial to lateral tibia just above the ankle joint, not coursing through the fibula with the olive abutting the medial tibial cortex. A second transosseous olive wire is placed from lateral to medial tibia 2 to 5 cm above the ankle joint, also avoiding the fibula abutting the lateral tibial cortex. A tensioner is placed on the wire opposite to the olive. Simultaneously, both tensioners are tightened under live fluoroscopy visualizing bone reduction. Once the articular
gap reduction has been confirmed, the transosseous olive wires are fixated to the ankle ring. The end of the wire opposite to the olive is tightly fixated to the ankle ring. The tensioner is loosened and retightened between 110 to 130 kg force. The olive should not move upon the second tensioning. Next, the distal fixation block is to be completed. The foot plate is fixated by a second converging transosseous olive wire through the calcaneus and two converging transosseous olive wires at the forefoot/midfoot region. The foot plate wires are then tensioned between 70 to 90 kg force (Fig. 26.8).

AO/ASIF B3, C3, and Ruedi-Allgower type III are described as the most destructive of the distal tibial periarticular fractures because of the severely comminuted intra-articular displaced distal tibial fractures (1,2). These injuries generally have a poor functional outcome. The goals remain restoring the ankle mortise, correcting the varus or valgus distal tibia, and fixating the fibula appropriately. By holding to the original goals of pilon surgery, a plantigrade tibia will be the outcome capable of a later joint destructive procedure such as an arthrodesis. If a primary arthrodesis is decided upon, the definitive surgery should be performed no earlier than 21 days after the traumatic event. The details of a primary arthrodesis are outside of the scope of this chapter.

AO/ASIF B3, C3, and Ruedi-Allgower type III are initially manually distracted and reduction of the tibia and fibula is attempted. The fibula fracture is examined, and as mentioned,
may need stabilization and fixation. This stage of pilon fracture can be highly variable. The surgical example has a high fibula fracture and a syndesmotic injury. The fibula is brought out to length and stabilized using a combination of plate screws or an intramedullary wire coursing from the distal fibula to proximal fibula. The preconstructed external fixator consisting of three rings and a foot plate is placed over the leg. A calcaneal wire is placed from medial to lateral and anchored to the foot plate allowing 1 to 1.5 cm of plantar fat pad projection plantarly. The external fixator is then grasped while an assistant stabilizes the knee and pulled away from the patient pulling the calcaneus in aggressive traction. Multiple fluoroscopic views should be taken to ensure the gross alignment in the frontal, sagittal, and transverse plane and correction to a rectus position. Once this is confirmed, the proximal fixation block is stabilized using previously mentioned techniques. A percutaneous introduction of a peristoeal elevator or blunt instrument may be used to free and reduce fragments of the articular surface lodged proximally in the metaphyseal bone. The comminuted metaphyseal portion of the tibia should be structurally and biologically augmented using a combination of cancellous bone chips and an orthobiologic rich in growth factors. The surgical technique case example shows a syndesmotic ankle injury. The distal tibia must be reduced and stabilized in the frontal plane. A transosseous olive wire is placed from the lateral fibula parallel to the ankle joint and at the level of the syndesmosis with the olive against the lateral cortex of fibula. A second transosseous olive wire is placed just above the most proximal medial distal tibial periartricular fracture line. This wire is also parallel to the ankle joint, with the olive abutting the medial cortex of tibia. The distal olive wire is temporarily fixated to the ankle ring and the proximal olive wire is also temporarily fixated to the proximal fracture ring. These wires may extend from their ring by fixation posts. A tensioner is placed on the distal wire opposite the olive. A second tensioner is placed on the proximal wire on the side opposite the olive. The tensioners are gently tightened at the same time, pulling the respective olive wires toward one another under fluoroscopy. Once there has been adequate reduction of the distal tibia in the frontal plane, the end of the wire opposite to the olive is tightly fixated to the ankle ring. The tensioner is loosened and re-tightened between 110 to 130 kg force. The olive should not move upon the second tensioning. If a medial malleolar type fracture exists in an area of heavily comminuted bone, a transosseous olive wire can be directed in the frontal plane from distal tibial medial tibia to proximal lateral tibia. A washer can be placed in combination with the olive wire to increase reduction surface area against a comminuted medial malleolar fracture component. This wire should exit the lateral tibia above the distal tibial periartricular fracture. The wire is anchored to the proximal fracture ring and gently tensioned under fluoroscopy, watching medial malleolar fracture reduction. Once reduced, the wire is attached to the foot plate and attached to the proximal fracture ring extending from a post without any added tensioning. The foot plate is fixated by a second converging transosseous olive wire through the calcaneus and two converging transosseous olive wires through the forefoot/midfoot region. The foot plate wires are tensioned between 70 to 90 kg force (Fig. 26.9).

A final important point should be stressed. After the reduction olive wires have been placed and reduction has been attempted, it is not uncommon that fracture reduction does not become aligned much as one would hope. Many times, a rotational component may be revealed and counter productive wires are noted. These wires may be moved or replaced while correcting the rotational fracture component.

**SURGICAL TECHNIQUE OF NEUROPATHIC ANKLE FRACTURES**

Surgical repair and successful outcome of the neuropathic ankle fracture lies solely on the patient’s healing potential. Each and every ankle fracture has a different presentation that must be recognized and treated appropriately. As with any ankle fracture, the goal of surgery is restoration of the anatomic joint alignment. The neuropathic ankle fracture has a much higher complication rate. Complications include but are not limited to infection, nonunion, malunion, dehiscence, osteomyelitis, hardware failure, and development of a Charcot foot/ankle. The surgical techniques that follow are aimed at the anatomic reduction and stabilization of the neuropathic ankle fracture by minimizing postoperative complications. Dense peripheral neuropathy alone makes the postoperative outcome more challenging and one may expect early patient weight-bearing because of their inability to sense pain and feel their lower extremities.

In the situation of the neuropathic ankle, soft tissue viability and surgical wound coverage are of equal importance, as are the fracture pattern and pathoanatomy. Open reduction and internal fixation provide the best fracture fixation; however, the neuropathic limb demands additional fixation and stability consisting of circular external fixation stabilization. Not all neuropathic ankle fractures need this approach, but many of the patients’ risks of noncompliance, surgery-induced Charcot neuroarthropathy, multiple comorbidities, dense peripheral neuropathy, and peripheral vascular disease are heavily considered candidates for additional fixation with external fixation. Primary ankle arthrodesis may also be considered in severely comminuted intra-articular tibial plafond and ankle fractures.

Treatment of the neuropathic ankle fracture begins immediately upon presentation to the physician. Dislocation of the ankle joint needs relocation immediately with application of a mildly compressive type of dressing and temporary splinting. This alone can prevent avoidable fracture blisters and skin necrosis. The sooner the surgery can be performed to the traumatic event, the better the outcome will be. The soft tissue envelope must be addressed and protected immediately. Stabilizing the fracture will in return stabilize the soft tissues if a minimally invasive technique is used properly. If massive edema exists, mild compression and immobilization must continue until the skin lines return to normal. This may take 7 to 21 days for the zone of injury to clearly define itself. Radiographs will dictate the size of the external fixator chosen. The authors’ choice is a foot plate with two circular rings. The foot plate and rings are attached using three levels of four threaded rods (Fig. 26.10). The construct is designed for joint and fracture stability. Fracture reduction will be dependent on a percutaneous open reduction and internal fixation. Several methods have been described to use external fixation and transosseous wires for ankle fracture stabilization as well as permanent fixation. It is the authors’ opinion that this method may be avoided. Better longer-term outcomes are obtained when an element of internal fixation is simultaneously used.
Fibular fractures are the first to be addressed. Under fluoroscopy, a gentle reduction of the ankle can be visualized. If a medial malleolar fracture is present with the medial gutter preventing distraction of the fibula, it must be percutaneously moved from inside the gutter by using a periosteal elevator with the belly against the medial malleolar articular surface. The level of the fibular fracture and bone quality dictate reduction techniques and hardware to be used. A short spiral distal fibular fracture at the level of the ankle joint lacking comminution can be addressed more traditionally. While manually distracting the ankle and under fluoroscopy, bone reduction forceps are placed laterally perpendicular to the fracture with the fibular out to length and proper sagittal plane alignment piercing the skin to the bone. A small stab incision is made that is no bigger than the head of the screw to be used. A small hemostat is used to free up...
deep tissue to bone. A cannulated interfragment screw is placed from proximal anterior to distal posterior perpendicular to the fracture. Once the screw is tightened and if a good bicortical purchase is achieved, the bone reduction forceps can be removed. A one third semitubular plate is next chosen to allow two screws below the fracture and two to three screws above the fracture. Depending on the degree of comminution or osteoporosis, a locking plate option should be considered. The plate must be bent to the anatomy of the fibula. A longitudinal full-thickness incision no bigger than 1 cm is made just at the distal lateral aspect of the fibula. A peristeal elevator is then used to create a layer for the plate beneath the deep tissue and ideally beneath the periosteum. The plate is gently slid from distal to proximal against the fibula. The plate is checked for alignment under fluoroscopy for length and appropriate number of screw holes proximal and distal to the fracture. The first screw will be cortical and located just above the fibular fracture. A longitudinal full-thickness incision is made just over the hole in the plate no more than the size of this cortical screw to be placed. A small hemostat is introduced into the incision to free up any soft tissue surrounding the plate hole to allow the screw head to obtain a direct contact to the plate. The next screws to be placed are just below the fracture. The previous incision that the plate was introduced through will allow adequate exposure while inserting the cancellous screws. If the fibula remains at length and reduced at this point, the rest of the available screws may be placed. Before placing the last proximal cortical screw in the plate, the syndesmosis must be stressed. Gently pulling on the distal fibula under fluoroscopy with a bone hook, the ankle fracture is checked for a diastasis injury. If indeed a diastasis injury exists, a fully threaded cortical screw is placed using the minimal incision technique in the most proximal hole of the fibular plate.

The next focus is the medial malleolar fracture. An incision no bigger than 1 cm is made at the distal aspect of the medical malleolus fracture. Blunt dissection is carried down to the periosteum. A bone hook is then placed grasping the distal tip of the malleolus. The bone hook is then pulled proximal, at-tempting temporary fracture reduction. If a rotational component or soft tissue entrapment appears to inhibit reduction, the following technique may be employed. A small stab incision is made at the medial gutter of the ankle joint. The ankle fracture is carried down to the joint. A small periosteal elevator is then introduced through the incision. A sweep of the fracture site is performed. The bone hook at the tip of the medial malleolus is pulled proximal while rotating the periosteal elevator against the fracture fragment. Once the fracture has been reduced, it is then fixed using two parallel cannulated 4-mm partially threaded screws. If a posterior malleolar fracture involves 90% of the distal tibial articular surface, a percutaneous anterior to posterior or anterior to posterior cannulated 4-mm partially threaded screws may be placed. Depending on the stability of fixation, patient condition/physiologic status, a decision to apply an external fixator should be considered (Fig. 26.11).

A severely comminuted fibular fracture at the level of the ankle joint can pose a challenging task of obtaining stable fixation and reduction. A percutaneous approach may be used in the following manner. A 1-cm incision is made longitudinally at the distal aspect of the fibula. Blunt dissection is carried down to the level of bone. A periosteal elevator is then used to create a layer for the plate beneath the deep tissue and the periosteum. A plate is chosen and contoured in the previously mentioned fashion. The plate length is chosen, not modeled after the presently shortened fibula, but instead to an “ideal” fibula out to length. The plate is then slid through the incision so that two to three screw holes are proximal to the comminuted portion of the fibula. The plate is placed lateral to the fibula and a lateral fluoroscopic view is taken to make sure that the plate is directly over the fibula. At that time, the distal portion of the fibula can remain in a malaligned position which will be addressed later in the procedure. Once views confirm appropriate plate position in the sagittal plane, a cortical screw is placed in the most proximal plate hole. Simultaneous manual distraction of the ankle and distraction of the distal fibula using bone reduction forceps is performed. Once the first screw is placed, a second cortical screw is placed just below the most proximal screw. While the second screw is tightened, the plate will reduce the fibula from its valgus position, buttressing the comminuted portion and distal fibula. The distal fibula may need manipulation with the bone forceps to recreate the lateral gutter. One to two cancellous screws are placed in the distal portion of the fibula. Fluoroscopic views should be taken to confirm fibular length as well as sagittal and frontal plane alignment. Bone graft should be placed in the comminuted fibula through the distal incision. The syndesmosis must be stressed and treated appropriately. If the medial malleolus is noncomminuted, it should be reduced and fixated as previously mentioned. However, if a comminuted medial malleolus is encountered, an olive wire reduction technique may be performed. This technique is performed after the ankle joint external fixator is applied. The distal tip of the medial malleolus is pierced by a transosseous olive wire without crossing the fracture site. It is then manipulated by rotating the fragment with the olive wire assisted by a peristeal elevator. Once alignment of the medial gutter is obtained, the olive wire is advanced from distal medial to proximal lateral. The goal is for the olive wire to abut the distal medial malleolar fragment and the end of the wire to exit the proximal lateral tibial cortex. Once the olive exits the lateral tibial cortex, it is then loosely fixated to the ring to its closest to whether it is the ankle or more proximal ring. A tensioner is placed over the wire opposite to the olive. Gently under fluoroscopy, the wire is tensioned reducing the fragment and providing compression across the fracture site. The olive wire is then secured to the foot plate and circular ring. A second olive wire may be applied in a similar way as well.

Severely comminuted and unstable neuropathic ankle fractures benefit from a multi-ringed external fixator. The external fixator may function to further stabilize the ankle or add to fracture reduction and stabilization. The chosen configuration is two full rings and a foot plate connected by four threaded rods. The distance from the foot plate to the ankle joint should place the ankle ring 2 to 4 cm above the ankle joint. The proximal ring distance from the ankle joint should be 150 mm from the ankle ring. The external fixator is applied after percutaneous fracture reduction and stabilization is performed. A prebuilt external fixation is placed over the foot and ankle. The foot plate is placed to allow plantar projection of the heel. A transosseous calcaneal wire is placed medial to lateral and tensioned between 70 to 90 kg force. While grasping the foot plate, manual traction distally is performed. This is done to attempt ankle joint arthrosis and aid in ligamentotaxis fracture reduction. A transosseous tibial wire is placed, avoiding the fibula parallel to the calcaneal wire and tensioned to about 110 kg force. Once foot and ankle alignment is confirmed in the frame, a second converging
A transosseous tibial wire is then placed and tensioned. A second converging calcaneal wire is then placed and followed by two converging metatarsal wires that are tensioned in a similar way. Next, two converging proximal tibial wires are placed and tensioned to about 110 kg force. It is recommended to use all olive wires. The ankle stabilization frame is now complete (Fig. 26.12).

POSTOPERATIVE MANAGEMENT

The estimated time for bony consolidation is approximately double the time normally estimated for a healthy patient. Prolonged stabilization is essential to prevent neuropathic fractures from progressing into a Charcot deformity. The worst case scenario should always be assumed.

The patient is kept in the hospital for 3 to 7 days postoperatively for glucose control, pain management, appropriate IV antibiotics, and to ensure that the patient is medically stable and able to rehabilitate before discharge. The patient receives 10 to 14 days of prophylactic low molecular weight heparin therapy, which is started 12 hours postoperatively and 1 week of oral antibiotics in accordance with the medical and infectious disease teams. The patient is seen weekly until the sutures and/or staples are removed at 3 to 4 weeks and then once every 2 weeks for the remaining months. Postoperative radiographs are obtained at 2 to 4 weeks and then once a month until healing is complete. Close and constant monitoring is absolutely imperative.

The pin or wire sites are covered with Betadine-soaked gauze and the frame must be kept dry. Patients are instructed not to take showers and are educated on pin or wire site care that is to be done weekly. Patient compliance is strongly emphasized and strict pin or wire site care must be maintained. Stability is also of the utmost importance. The wires and pins must be checked at each visit to guarantee that the tension has not been lost. Retensioning can be achieved using the manual tensioning technique.

**Figure 26.11** Neuropathic ankle fracture technique of noncomminuted fibula.
DISTAL TIBIA EXTRA-ARTICULAR FRACTURES

The patient is kept non-weight-bearing for 10 to 14 days. After this point the patient is encouraged to be full weight-bearing as tolerated with a walker and/or crutch assistance. In a normal patient bony consolidation normally takes 14 to 16 weeks. A patient with diabetic neuropathy will generally have consolidation at 16 to 24 weeks. The frame should be dynamized when signs of consolidation appear, usually around 10 to 16 weeks postoperatively. The patient is then encouraged to walk full weight-bearing for 2 to 3 weeks. If no problems occur the frame may be removed in the hospital setting. The patient then progresses into a walking device or pre-tibial brace for 4 to 6 weeks. After that, the patient may progress into a custom molded diabetic shoe as tolerated. A final postoperative visit is done at 6 months. Patient education is paramount throughout the postoperative course (Figs. 26.13 and 26.14).

DISTAL TIBIA PERIARTICULAR FRACTURES

The type of injury will dictate the postoperative care. A rotational or low-energy pilon fracture will be treated like a distal tibia fracture. A high-velocity pilon fracture is much more complicated. Because of the high forces involved with severe pilon

Figure 26.12  Neuropathic ankle fracture technique of comminuted fibula.
fractures, these injuries are considered the same as crush injuries. Inpatient treatment may include the use of hyperbaric oxygen therapy. The patient is kept non-weight-bearing with a walker or crutch assistance for 6 to 8 weeks. If radiographs show signs of consolidation, the patient is encouraged to be partial weight-bearing with assistance after this point. It is important to maintain arthrodiastasis across the ankle joint during this time.

The frame should be dynamized when signs of consolidation appear, usually around 10 to 12 weeks postoperatively. The patient is then encouraged to walk full weight-bearing for 2 to 3 weeks. If no problems occur the frame may be removed. The patient then progresses into a walking device for 1 to 2 months. After that, the patient may progress into a custom molded diabetic shoe as tolerated. A final postoperative visit is done at 6 months. Patient education is paramount throughout the postoperative course (Fig. 26.15).

Figure 26.13  A neuropathic distal tibia extra-articular fracture (A) treated with a circular external fixator and percutaneous internal fixation (B,C). Final postoperative pictures at 6 months follow-up (D,E).

ANKLE FRACTURES

The patient is kept non-weight-bearing for 6 to 8 weeks. After this point the patient is encouraged to be full weight-bearing as tolerated with assistance. In a normal patient bony consolidation normally takes 6 to 8 weeks. A patient with diabetic neuropathy will generally have consolidation at 12 to 16 weeks. The frame should be dynamized when signs of consolidation appear, usually around 10 to 12 weeks postoperatively. The patient is then encouraged to walk full weight-bearing for 2 to 3 weeks. If no problems occur the frame may be removed. The patient then progresses into a walking device for 4 to 6 weeks. After that, the patient may progress into a custom molded diabetic shoe as tolerated. Ankle bracing is encouraged for 6 to 8 months (Figs. 26.16 and 26.17).

(text continues on page 374)
Figure 26.14  A case example of an extra-articular ankle fracture with a simultaneous severely comminuted intra-articular calcaneal fracture (A,B), treated by an ORIF for the ankle fracture and a primary subtalar joint arthrodesis using a multiplane circular external fixation device for better rigidity and stability (C,D). A final 10-month postoperative outcome (E,F).
Figure 26.15  A high-velocity pilon fracture (A,B), treated immediately by a delta distraction frame to allow consolidation of the soft tissues and provide immediate reduction and stability (C,D), followed by a primary ankle arthrodesis by using a multiplane circular external fixation device (E,F). Final 10-month postoperative outcome (G,H).
Figure 26.16 Preoperative clinical and radiographic pictures of a bimalleolar diabetic neuropathic ankle fracture with skin blisters and necrosis (A,B), treated with a multiplane circular external fixator (C), followed by an early limited weight-bearing (D). Final postoperative outcome (E).
Figure 26.17  A severe bimalleolar ankle fracture-dislocation in a diabetic neuropathic patient (A,B), followed by an immediate reduction (C) and further stabilization with a multiplane circular external fixation device (D,E). (continued)
CONCLUSION

Neuropathic pilon and ankle fractures are very challenging to the reconstructive surgeon. Sound principles and techniques of external fixation are necessary to minimize postoperative complications. Timing of surgery, soft tissue monitoring, proper surgical and offloading techniques, as well as an understanding of the bone and wound healing in a patient with dense peripheral diabetic neuropathy, are paramount for a long-term successful outcome. Additional adjunctive therapies including but not limited to electrical bone stimulation, orthobiologics, and postoperative shoe and brace therapy are beyond the scope of this chapter.

ACKNOWLEDGMENT

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REFERENCES


Figure 26.17  (Continued) After 8 weeks the patient underwent a primary ankle arthrodesis with a circular fixator (F,G), which was kept for an additional 12 weeks. Final 8-month postoperative outcome (H,I).
Surgical Management of Postoperative Infections and Complications

INTRODUCTION

Surgery of the diabetic lower extremity presents with a unique set of preoperative considerations, intraoperative issues, and postoperative complications. These unique complications are a direct result of the disease process of diabetes mellitus, and the effects the disease has on the patient’s anatomy and physiology. These effects on the patient require the foot and ankle surgeon to approach diabetic foot and ankle surgery differently than surgery on the nondiabetic patient. This may be especially true in revising postoperative complications. Armstrong et al. proposed a diabetic foot surgery classification: elective, prophylactic, curative, and emergency. The classification helps surgeons identify potential risks in diabetic surgery. As the class increased, so did the risk of ulceration and re-ulceration, infection, and amputation (1). In another study by Mendicino et al., they compared tibiotalocalcaneal arthrodesis with a retrograde nail in diabetics and nondiabetics. In their study, the diabetic patients had all the major complications, and 14 of 20 combined major and minor complications (2). The surgeon must take into consideration the comorbidities that present with diabetes. Vasculopathy, neuropathy, neuroarthropathy, and nephropathy all contribute to the patient’s final outcome.

Diabetic patients have abnormal soft tissues and bone. Charcot reconstruction requires significant stabilization of the abnormal osseous structures. The combination of internal and external fixation, for adequate fixation constructs, has become an accepted protocol. The addition of external fixation to the reconstruction of the diabetic foot helps resist collapse and provides superior compression when used in conjunction with internal fixation (3). Complications following surgical reconstruction in the diabetic patient can often lead to disastrous failure of fixation usually secondary to abnormal weight-bearing forces on the fixation device as seen in Figures 27.1 to 27.4.

The necessity of increased fixation creates its own complications. External fixation creates pin and/or wire tract infections, irritations (Fig. 27.5), and broken hardware (Fig. 27.6). Reconstruction of postoperative complications also becomes more difficult because of the retained or broken hardware. Beaming the medial and lateral columns can make removing hardware very challenging.

It is recommended in revisional Charcot reconstruction that the reconstructive surgeon thoroughly evaluate the patient’s vascular and endocrine status. The vascular evaluation is covered in another chapter, but it should not be assumed that the previous surgeon has evaluated the patient or that the status of the patient has not changed. The endocrine status must be evaluated to identify any deficiencies that may be present with aggressive optimization of the patient’s blood glucose with the assistance of the internist or endocrine specialist. It is recommended that a 24-hour urine calcium, 25-hydroxyvitamin D, as well as both thyroid and parathyroid hormone testing be obtained prior to surgery. Even when all endocrine and vascular parameters are satisfactory, healing complications can still occur; therefore, it is recommended to consider the use of orthobiologics during the reconstruction of postoperative complications. Demineralized bone matrix, autologous platelet-derived growth factors, bone marrow aspirate, and bone morphogenic proteins have all been used in the reconstruction of postoperative complications to help facilitate bone healing. Implantable or external bone stimulators have also been used to help facilitate bone healing in these patients, but may contribute to higher complication rates (4). Removing enough bone to create healthy bleeding surfaces will often create a significant defect of bone, as all devascularized Charcot bone must be removed and may not be used as bone graft or filler. In revision surgery, there is also bone loss from removing the previous fixation. These factors create the necessity for bone grafting. The foot and ankle surgeon should be prepared preoperatively for this bone loss and how to deal with the use of autogenous, allogenic, or a combination of both bone grafts.

The nutritional status should also be considered in the diabetic patient, especially if there has been a surgical failure the first time. Without the proper nutritional status, the patient will either delay healing or will not heal at all with a potential of a postoperative infection. This sets the patient up for a postope-
Figure 27.1  A lateral radiograph of a Charcot fracture-dislocation at the midfoot/rearfoot joints.

Figure 27.2  Surgical reconstruction and multiple attempted joint arthrodesis procedures with the use of internal and external fixation.

Figure 27.3  Postoperative lateral radiograph demonstrating failure of both the internal and external fixation devices.

Figure 27.4  Final outcome followed with a more complex Charcot deformity and multiple joints with malunion and nonunion.

Figure 27.5  An acute wire tract irritation and infection with an inflammatory process.

Figure 27.6  External fixation failure of the tensioned wires.
ative infection. Nephropathy, especially in those patients on dialysis, can be a contributing factor to malnutrition. The patient should be checked for serum albumin and total protein levels. The total lymphocyte count as well as the hematocrit and hemoglobin must also be taken into consideration before proceeding with surgical management of a complication (5).

The increased complication rate of surgery on the lower extremity of the diabetic patient is not limited to Charcot reconstruction. Several articles have described increased complication rates with open reduction and internal fixation (ORIF) on diabetic patients. This increased rate of complications seems to be especially true of those patients who have comorbidities (6–9). The diabetic patient may deteriorate into neuroarthropathy even with complete patient compliance and ideal treatment. They can require prolonged immobilization and non-weight-bearing, sometimes twice as long as the nondiabetic patient (10).

Postoperative infections in the diabetic patient can be even more disastrous than in the nondiabetic patient. Diabetic patients have an increased risk of developing infections and getting osteomyelitis (11). The patient may have a reduced host response. This can increase the spread of infection. The absence of leukocytosis in severe foot infections has been well documented in the literature (12–15). The reduced host response can also diminish the typical signs and symptoms of an infection. This can make clinical decision making more difficult, especially in the immediate postoperative period. The diminished signs and symptoms in combination with neuropathy, that prevents the patient from feeling the pain associated with the infection, delays the recognition of the infection. This creates a delay in the subsequent initiation of treatment (16,17).

Close monitoring by the patient or their family to notice either the drainage on the dressings or the odor is of great importance, as these infections may quickly become out of control, spreading rapidly through the tissues and creating significant and irreversible damage. The infection may also be discovered during a “routine” dressing change (Figs. 27.7 and 27.8). Diabetic foot infections are usually polymicrobial (12,18,19), and can include aerobes, anaerobes, and fungus. The common infecting organisms in diabetic patients are listed in Table 27.1.

At the time of identifying an infection, both aerobic and anaerobic cultures must be taken. Consideration of a fungal and acid-fast culture must also be entertained. Superficial swabs of the wound have a poor correlation with the microbiology of deep infections (18,20,21). It is advised to get a deep culture and if there is bony involvement a bone culture should be obtained as well, if possible. The patient may also have nephropathy; this can make the proper dosing of the antibiotics more of a challenge and may preclude the use of certain antibiotics altogether.

The postoperative infection in the diabetic patient requires a well defined medical and surgical team approach. An infectious disease consultation is recommended if available, as well as initiation of broad spectrum empiric antibiotic therapy at the treating facility. Medical management of the patient may also be required to control the impending hyperglycemia and other systemic manifestations of infection.

Appropriate imaging studies, including radiographs, and when necessary, computed tomography (CT), magnetic resonance imaging (MRI), and white blood cell labeled bone scans may be ordered. The imaging studies are helpful in determining the extent of the infection both in the soft tissue and bone. Once the appropriate diagnostic tests have been obtained and evaluated, the patient should be taken to the operating room.

**TABLE 27.1**

**Common Infecting Organisms in Diabetics**

<table>
<thead>
<tr>
<th>Organism</th>
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<tbody>
<tr>
<td>Methicillin Resistant Staphylococcus Aureus (MRSA)</td>
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<tr>
<td>Group B Streptococcus</td>
</tr>
<tr>
<td>Enterococcus</td>
</tr>
<tr>
<td>Escherichia coli</td>
</tr>
<tr>
<td>Proteus mirabilis</td>
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<tr>
<td>Proteus vulgaris</td>
</tr>
<tr>
<td>Klebsiella</td>
</tr>
<tr>
<td>Serratia</td>
</tr>
<tr>
<td>Enterobacter cloacae</td>
</tr>
<tr>
<td>Acinetobacter</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
</tr>
<tr>
<td>Bacteroides fragilis</td>
</tr>
<tr>
<td>Clostridium perfringens</td>
</tr>
<tr>
<td>Peptococcus species</td>
</tr>
<tr>
<td>Peptostreptococcus species</td>
</tr>
<tr>
<td>Candida</td>
</tr>
<tr>
<td>Fusarium</td>
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</tbody>
</table>

**Figure 27.7** Local signs of a postoperative wound infection showing the erythema, edema, and ascending cellulitis.

**Figure 27.8** Other signs of a postoperative wound infection showing the re-ulcerations, excessive drainage, and purulence from the surgical site.
as quickly as possible for drainage of any abscess, débridement of necrotic tissues, and deep cultures. All potential deep spaces that are contiguous with the infection should be explored, and the tissues should be lavaged with an antibiotic solution. Bone biopsies should be taken if osteomyelitis is suspected. It is difficult to differentiate among Charcot bone, postoperative changes, and osteomyelitis in the postoperative patient. The bone biopsy makes the definitive diagnosis of osteomyelitis. Antibiotic beads are often used to help reduce the local bioburden. It is recommended to repeat surgical débridements, with adequate pulsed lavage, irrigation, and antibiotic bead exchange every few days until the infection is controlled. The tissues can be loosely approximated at the end of the procedure to allow drainage, while retaining the antibiotic beads and preventing wound retraction (Fig. 27.9).

Intravenous antibiotics and aggressive local wound care is paramount at this phase. The use of negative pressure wound therapy (NPWT) with the large wounds is often obtained after treating the postoperative infection and is helpful in managing the exudate while dilating the arterioles and enhancing local circulation. In addition, the use of external fixation to stabilize the bony deformity may also be helpful. Once the local infection is resolved, usually following serial negative bone and soft tissue cultures, a revisional reconstruction can then be considered. When the infection only involves soft tissue, then the revisional reconstruction may be performed with a combination of both internal and external fixation. However, when osteomyelitis is involved it is not recommended to use internal hardware; the reconstruction should be performed primarily with the use of external fixation, so that there is no remaining internal fixation upon completion of healing. Leaving any internal fixation in place when osteomyelitis is present only leaves the surgeon with a much higher risk of recurrence, and makes advanced imaging studies such as CT and MRI much less helpful in the future.

Following successful revisional reconstruction the surgeon can follow certain laboratory tests that will provide helpful indicators that the infection has resolved. These labs may include sedimentation rate and C-reactive protein levels.

Postoperative complications can be disastrous regardless of whether the patient is diabetic or not, but the sequela of a major complication on a diabetic patient is more disastrous and potentially more lethal than the patient without diabetes. This combined with the increased complication rate of surgery, has made surgical management of postoperative complications one of the most demanding aspects of foot and ankle surgery. The advances in surgery with improved vascular reconstruction techniques, more predictable surgical reconstructive techniques, as well as advances in orthopaedic hardware and a new array of antibiotics has allowed the foot and ankle surgeon to better deal with the postoperative complications of surgery on the diabetic lower extremity.

The following illustrative cases provide a guide for the foot and ankle surgeon when approaching the high-risk complications and postoperative infections in the diabetic neuropathic patient. The illustrative case studies highlight both osseous and soft tissue complications in the diabetic trauma and Charcot patient, as well as disastrous postoperative infections and management.

CASE STUDIES

CASE ONE: THE NEUROPATHIC TRAUMA PATIENT WITH OSSEOUS AND SOFT TISSUE DEFORMITY

A 55-year-old male with a history of diabetes mellitus and dense peripheral neuropathy suffered a fall from a ladder from a height of 25 feet and sustained a severe open pilon and fibula fracture and dislocation. He underwent an initial surgical temporization of his injury, followed by aggressive local wound care and fixation of his fibular fracture. The tibial fracture was reduced with external fixation only, without the addition of internal fixation secondary to the ankle wound that failed to heal with local treatment, including NPWT and split-thickness skin grafting (STSG). A local advancement flap was also attempted with failure. Four months postoperatively, the tibia had failed to heal and the anterior ankle wound remained open. Multiple cultures were obtained from the open wound and, with the exception of skin contaminants, there was no soft tissue or bony infection diagnosed.

Prior to revisional correction of this case, a very thorough preoperative plan was initiated to address the patient’s soft tissue coverage and the sustained nonunion. Consultation from internal medicine to assess the patient’s blood glucose levels, renal function, and nutritional status were all obtained. In addition, vascular consultation to assess the blood supply to the lower extremity, including arteriography, was obtained. From a soft tissue healing standpoint, in the absence of infection, adequate blood flow, and failure of previous local wound care, STSG and local flap, a muscle or free flap, would be the best possibility for soft tissue coverage. From a bone healing standpoint with a nonhealing fracture across the joint, interruption of the cartilaginous surface is a certainty and merely addressing the nonunion would
not provide a feasible long-term result, given the articular damage at the ankle joint. The surgeon must consider what is in the best interest of the patient and therefore address the articular damage and the nonunion. A fusion with an intermedullary nail would allow the surgeon to realign the foot and ankle, address the articular deformity at the ankle joint, and maintain alignment of the tibia while addressing the nonunion. Adding the appropriate orthobiologics, and an osteoinductive bone stimulation device is yet another consideration in such a complex case.

For this patient the surgery was performed in two stages. The bony procedure was performed first with repair of the nonunion and fusion of the rearfoot and ankle with a 30-cm hindfoot and ankle arthrodesis nail, with use of an implantable direct current bone growth stimulator across the nonunion site as well as demineralized bone putty. This was followed by short hospital admission, and then a return to the operating room for an aggressive excision of the soft tissue surrounding the nonunion site followed by a gracilis free tissue transfer. During the procedure, exposure of the anterior portion of the tibia and a portion of the arthrodesis nail required the use of an osteoconductive calcium phosphate as a bone void filler to cover the deficit. The patient remained non-weight-bearing for 8 weeks, followed by guarded weight-bearing for another 4 weeks, and then with satisfactory fusion obtained, he was progressed to full weight-bearing in a custom molded diabetic shoe with a double upright lower extremity brace. He has had a long-term satisfactory result of over 2 years with no further complications (Figs. 27.10–27.19).

(text continues on page 384)

Figure 27.10  A lateral preoperative radiograph showing the severe lower extremity injury in the patient with diabetes mellitus and neuropathy.

Figure 27.11  A–C. Clinical and intra-operative fluoroscopic views illustrating the temporary stabilization and reduction of the comminuted distal lower extremity fractures with good alignment in all planes and restoration of the ankle joint articulation.
Figure 27.12  A,B. ORIF of the fibula to maintain length and lower extremity stability.

Figure 27.13  A,B. Failure of local wound care with NPWT, STSG, and local soft tissue flap.
Figure 27.14  A,B. Nonunion of the tibia and irregularity of the tibiotalar articulation.

Figure 27.15  A–C. Illustrates the arthrodesis nail and the clinical result immediately after surgery.
Figure 27.16  Immediate postoperative radiographs of status-post ankle and hindfoot arthrodesis with repair of the nonunion.

Figure 27.17  Photos depicting the exposure of the anterior tibia after excision of the nonhealed soft tissue flap and skin graft with placement of calcium phosphate and free tissue transfer.
Figure 27.18  A–C. Clinical and radiographic views 8 weeks after the tibio-talo-calcaneal (TTC) arthrodesis and 7½ weeks status post free tissue transfer and STSG.

Figure 27.19  A–C. Radiographic and clinical views at 18 months postoperatively with a successful revisional reconstruction, complete healing, and consolidation of the tibia nonunion and arthrodesis sites. There was an interval removal of the implantable bone stimulator and shrinkage of the free flap.
CASE TWO: NEUROPATHIC CHARCOT FOOT FRACTURE DISLOCATION WITH A CHRONIC PLANTAR ULCERATION AND SOFT TISSUE INFECTION

A 62-year-old female with a history of a neuropathic Charcot foot with a fracture and dislocation of >1 year duration had undergone numerous soft tissue débridements and local wound care with a stagnant and nonhealing ulceration. The patient subsequently developed a soft tissue infection consistent with MRSA. The most important issue of this patient with the long history of the Charcot foot collapse and with the diagnosis of MRSA was the presence or absence of concomitant osteomyelitis. Although this patient had undergone a number of surgical débridements, she had never been diagnosed with osteomyelitis. Serial radiographs along with an MRI were obtained to identify any bony changes that would indicate bone infection. The radiographs showed no local bony changes in the area of the ulcer, and the MRI showed soft tissue changes without any acute bony changes. In addition, a sedimentation rate and a C-reactive protein were obtained and not found to be consistent with osteomyelitis. Although further testing could have been performed including a bone biopsy, the clinical picture and progression was that of a soft tissue infection only. In addition, a vascular evaluation was performed and showed adequate blood flow for healing potential, and the patient was referred to an endocrinologist to optimize the blood glucose levels before surgery. The patient received a 2-week course of oral antibiotics and aggressive débridement. Following the resolution of the soft tissue infection, a bioengineered alternative tissue was used to obtain closure, followed by a bony reconstruction and fusion of the midfoot and rearfoot joints with a combination of internal and external fixation. In the absence of osteomyelitis, treatment of the soft tissue infection and obtaining closure of the ulcer are important in reducing complications with the formal bony reconstruction. Although wound closure prior to reconstruction is not always possible, it is helpful in reducing the postoperative complications (Figs. 27.20 to 27.23).

CASE THREE: NEUROPATHIC CHARCOT FOOT WITH CONCOMITANT OSTEOMYELITIS

A 60-year-old male with a history of diabetes mellitus and dense peripheral neuropathy who underwent >3 years of nonsurgical treatment of his Charcot foot deformity and local treatment of his diabetic wounds, developed an acute soft tissue and bone infection with abscess, ascending cellulitis, and sepsis. His radiographs identified a severe Charcot midfoot fracture dislocation. His laboratory tests revealed a sedimentation rate of 80 mm/hr, and a white blood cell count of 18,000 cells per cubic millimeter (cmm). He had an MRI that documented an abscess and increased T-2 signal to the midfoot. The patient was taken to the operating room for incision and drainage and intra-operative cultures. Infectious disease consultation was obtained and broad spectrum antibiotics were instituted. NPWT
Figure 27.21  A–D. Intra-operative pictures showing the reduction of the lateral and medial column, with placement of an allograft for structural support and removal of the avascular bones. Compression was obtained with cannulated screw beaming of the medial and lateral columns, followed by locking plates for neutralization and stability.

Figure 27.22  A,B. Immediate postoperative pictures showing the placement of a hybrid external fixator to maintain the correction and lower extremity alignment, yet allowing for guarded weight-bearing if needed in the postoperative period.
was initiated over the surgical wounds with necessary changes and until the ascending cellulitis had resolved. The patient was returned to the operating room for multiple soft tissue and bone débridements. Bone biopsy confirmed the diagnosis of osteomyelitis. Consultation was obtained for vascular evaluation, which was found to be sufficient for healing. In addition, endocrinology was consulted to optimize the patient’s blood glucose levels, which were stabilized greatly after controlling the infection and septicemia. After an extended hospital admission and when the local and systemic signs of infection were resolved, the patient was finally returned to the operating room for formal reconstruction. No internal fixation was used secondary to the previous osteomyelitis; therefore, all bony reconstruction was with external fixation. Two small monolateral rails were used for compression of the medial and lateral columns after reduction of the deformity. A large external fixator was used for additional compression and neutralization of the lower extremity. The patient was treated with intravenous (IV) antibiotics and NPWT to treat his medial, lateral, and plantar wounds. Unfortunately, the patient developed multiple pin and wire tract infections secondary to noncompliance and failure to return on all normally scheduled office visits, as well as excessive ambulation on the external fixation device. The initial tensioned wires were removed, cultures were taken, and the infection was treated with additional IV antibiotics to cover the MRSA that grew from the pin and wire tract infections. The patient’s external fixator was revised under anesthesia and new wires and pins were placed as well as a plantar foot plate for compliance issues. Further noncompliance just 4 weeks after the frame modification, with the patient getting into a car accident while driving with his fixator, led to half pin disruption, which required another external fixator revision, replacing the half pins in the tibia. Extensive time was spent with the patient and his family educating them about alignment of the lower extremity. The patient was treated with intravenous (IV) antibiotics and NPWT to treat his medial, lateral, and plantar wounds. Unfortunately, the patient developed multiple pin and wire tract infections secondary to noncompliance and failure to return on all normally scheduled office visits, as well as excessive ambulation on the external fixation device. The initial tensioned wires were removed, cultures were taken, and the infection was treated with additional IV antibiotics to cover the MRSA that grew from the pin and wire tract infections. The patient’s external fixator was revised under anesthesia and new wires and pins were placed as well as a plantar foot plate for compliance issues. Further noncompliance just 4 weeks after the frame modification, with the patient getting into a car accident while driving with his fixator, led to half pin disruption, which required another external fixator revision, replacing the half pins in the tibia. Extensive time was spent with the patient and his family educating them about
Figure 27.24  A–C. Wounds after multiple surgical débride-
ments, NPWT, and prior to the final Charcot reconstruction.

A,B

Figure 27.25  A,B. Foot and ankle, and lower extremity
stabilization, compression, and neutralization by using a
combination of both hybrid and minirail monolateral exter-
nal fixation to reduce the Charcot deformity.

proper care of the external fixator and the risks of amputation. Over the following 8 weeks, the patient remained compliant, and returned to the operating room for split-thickness skin grafting of the wounds, as well as final external fixator removal. The patient was eventually prescribed a custom made diabetic shoe with a double upright brace for ambulation. The patient obtained successful fusion with a plantigrade foot without recurrence of infection. This case illustrates the importance of close monitoring with daily attention while the patient is hospital-
ized and weekly visits for the Charcot patient during the post-
operative course after hospital discharge. In this case, despite the most severe of complications with vigilant and aggressive local wound care, IV antibiotics, and multiple frame revisions, we still obtained a satisfactory final result (Figs. 27.24–27.29).

(text continues on page 391)
Chapter 27 Surgical Management of Postoperative Infections and Complications

Figure 27.26 Development of wire tract infection with excessive bending secondary to complete patient noncompliance with the postoperative protocol with excessive weight-bearing and inappropriate follow-up and treatment of the external fixator.

Figure 27.27 Rebuilding the external fixator with replacement of the affected wires and addition of a plantar offloading fixation plate.

Figure 27.28 Illustrates continued noncompliance with the postoperative regimen and fracture of the tibial half pins.

Figure 27.29 Successful STSG of the open and granulating wounds despite the initial multiple complications.
Figure 27.30  A–D. Complete healing of the soft tissue and bone, without recurrent infection, 3 months after removal of the final modified external fixator.
Figure 27.31  A–D. Two-year follow-up with patient remaining free from osteomyelitis and soft tissue infection and solid consolidation of his Charcot reconstruction.
CONCLUSION

This chapter summarizes in great detail some of the most common complications encountered when dealing with reconstruction of the complex Charcot foot and ankle deformities. It also outlines the importance of patient education, multidisciplinary team approach with emphasis in diabetic limb salvage and vast experience, and knowledge in the treatment of the diabetic foot.

REFERENCES


RECOMMENDED READING

Amputation is defined as the intentional surgical removal of a limb or body part and to remove diseased tissue or relieve pain (1). Foot and ankle amputation or disarticulation can be painful and devastating for any individual. These procedures are performed to improve a patient’s quality of life; thus, amputation or disarticulation can frequently become life-saving procedure. Such procedures should not only be looked on as an end treatment for all, but as a reconstructive means in treating patients. Approximately 82,000 limb amputations are performed yearly among people with diabetes mellitus (DM); this is the highest number of nontraumatic amputations performed in the United States (2). The desired end result of any amputation is restoration of function with complete healing. It is important to remember that precise technique is required to heal an amputation. When performing an amputation, it is understood that there may be delay or nonhealing of the surgical site, leading to further proximal amputation. It can be physically, mentally, and emotionally draining for a patient. Every patient facing limb loss is keenly aware of former possibilities, and often fears the unknown more than the procedure itself. Frequently, re-amputation cannot be prevented or avoided, and its likelihood may be minimized by determining the patient’s healing potential in addition to using the most favorable surgical technique. Following is a list of many clinical examples that may lead to an amputation (3):

- Diabetic foot infection
- Osteomyelitis
- Peripheral vascular disease (PVD)
- Gangrene
- Frostbite
- Trauma
- Tumors
- Congenital deformity
- Intractable pain
- Failed surgery

Other than patients with severe PVD or DM-related manifestations, healing amputation traditionally has not been challenging. In former entities, during the initial stages of planning an amputation, it is important to determine the patient’s healing capacity at the level of amputation to be performed. In 1977, Wagner (4) reported a 90% healing rate for patients who underwent amputation with the ankle-brachial index (ABI) of 0.45. Dickhaut et al. (5) and Pinzur et al. (6) found that Wagner’s level of success could only be reproduced with a sufficient level of immunocompetence, tissue nutrition, and arterial inflow. These factors combined together better predict a patient’s local and systemic wound-healing capacity after an amputation.

**IMMUNOCOMPETENCE**

This is measured by a total (absolute) lymphocyte count $>1500$ cells/mm$^3$. The total lymphocyte count is calculated by multiplying the total white blood cell count by the percentage of lymphocytes in the most recent differential white blood cell count (6). A low total lymphocyte count in a patient may indicate decreased ability for a patient to fight infection.

**TISSUE NUTRITION**

For an individual, a minimum level of tissue nutrition required are serum albumin level $>3.0$ g/dL and a total protein level of 6.0 g/dL. Systemic factors such as hepatic or renal disease and even overhydration or dehydration has been shown to affect serum albumin and total protein levels. These nutritional indicators should be used in conjunction with other markers (7). A patient’s prealbumin level is another helpful diagnostic tool when there is question of nutritional competence. Normal serum prealbumin level should be between 16 and 35 mg/dL. Moderate to severe nutritional deficiency is diagnosed if the prealbumin level is $<10$ mg/dL. External factors do not influence prealbumin level, and thus it provides an accurate representation of nutritional deficiency. Prealbumin level has shorter half-life, so the level can be used to monitor the effect of dietary supplementation. It has been shown that the risk for wound complication is greatly increased in patients whose serum albumin is $<3.0$ g/dL or whose total lymphocyte count is $<1500$ cells/mm$^3$ (8).

**ARTERIAL INFLOW**

In patients with peripheral vascular disease, a noninvasive vascular workup is needed to either determine the amputation
level or if revascularization is needed prior to the amputation procedure. Adequate blood flow for healing is indicated by a palpable dorsalis pedis or posterior tibialis pulse; an ABI with 0.5 in patients with DM and 0.45 in patients without DM or a transcutaneous oxygen (TcPO2) tension measurement between 20 and 30 mm Hg with the patient breathing room air (8,9). Traditionally, the ABI was regarded as the most useful diagnostic tool in identifying patients with macrocirculatory disease that would benefit from a revascularization procedure prior to performing an amputation. The ABI can be falsely elevated from noncompressibility in calcified vessels and measuring the TcPO2 may eliminate the concern of this variable. TcPO2 is measured through the superficially applied sensors on the operative limb. The sensors are applied at multiple different sites to measure the oxygen-delivering capacity or perfusion to the skin in room air. These sites predict the arterial flow at various levels of amputation (7). Factors that compromise the validity of the TcPO2 are infected wounds with increased bacterial load that may suppress the transcutaneous oxygen tension value because of increased oxygen consumption by macrophages and invading organisms, operator error, improper device calibration, position of the limb, and room temperature (7,10). Careful control of the above variables can improve diagnostic accuracy significantly, making the TcPO2 one of the most valuable tools in preoperative screening (5,7).

Finally, it is important to remember that for any individual, the energy expenditure for walking is inversely proportional to the length of the remaining limb. In any circumstances, the key to foot-and-ankle amputation should be to ensure that the amputation is performed at the most distal level to offer a reasonable chance of healing and maximize function for any individual.

LEVEL OF AMPUTATIONS DISCUSSED IN THIS CHAPTER

- Terminal Syme
- Toe
- Ray
- Transmetatarsal
- Lisfranc
- Chopart
- Calcanectomy
- Syme

DIGITAL AMPUTATION

TERMINAL SYME AMPUTATION

In 1874, Hukill first described partial amputation of the distal phalanx of the hallux (11). In 1933, Lapidus revived the same procedure in which was performed the surgical resection of whole nail plate, nail wall, matrix, and resection of the distal half of the distal phalanx with skin closure using plantar skin flap from the end of the toe. This procedure shares the same name as Syme’s amputation through the ankle joint because of the similar reconstruction of the plantar flap for closure of the distal phalanx (12,13).

Indications

Indications for terminal Syme amputation include underlying phalangeal lesion with secondary toenail involvement, recurrent painful ingrown toenail with chronic paronychia, osteomyelitis, severe digital deformities, chronic nonhealing or infected distal tuft ulceration, traumatic avulsion injury to distal phalanx, or localized ischemia (11,12).

Technical Principles

Care must be taken to remove the entire matrix of the toe, especially laterally. If a small fragment of matrix is left behind, it may result in growth of a small toenail spicule that can lead to irritation and recurrent infection.

Operative Technique

First, the distal interphalangeal joint is palpated, and the dorsal incision is placed distally in transverse direction on the digit proximal to the nail matrix, taking care not to violate the joint capsule (13). The second incision is made to join the first incision to circumvent the digit distally just below the level of distal tuft of the distal phalanx in a fish-mouth fashion. The tissues isolated now with the incision include the nail, matrix, nail bed, contiguous soft tissues, and distal aspect of the distal phalanx. The plantar skin includes adipose tissue, which is thicker than the dorsal skin. Using a sharp blade, the distal phalanx is carefully underscored and lifted from the plantar flap. The power instrumentation or bone cutter is used to make the vertical bone cut a few centimeters (cm) distal to the distal interphalangeal joint. The plantar flap should be handled meticulously using skin hooks to maintain the tissue integrity, to prevent any dehiscence postoperatively, and to ensure the best closure. Remember that the adipose tissue of the plantar flap includes the neurovascular structures, interphalangeal joint retinaculum, residual proximal base of the distal phalanx, and half of the joint capsule as well as the long flexor tendon. The surgeon must be careful not to leave any extra redundant bulbous tissues from the plantar flap. Using 4-0 or 5-0 nonabsorbable suture, the remaining plantar flap is sutured to the dorsal flap (Fig. 28.1).

TOE AMPUTATION

Amputation of a single digit is preferably performed at the distal or proximal interphalangeal joints.

Indications

Like any other amputations, the digital amputation is indicated for infection, trauma, ulcerations, and tumor.

Technical Principles

In hallux amputation, preservation of the metatarsophalangeal joint (MPJ) results in a better gait and foot stability. To maintain stability in push-off and in the late-stance phase of gait, hallux amputation should be performed 1 cm proximal to the base of proximal phalanx distal to the insertion of flexor hallucis brevis (FHB) tendons, plantar fascia, and sesamoids (14).
Preserving the integrity of the FHB allows continued function of the sesamoidal apparatus; this in turn helps to preserve plantar weight-bearing with avoiding transfer pressure to the second metatarsal with increased risk of developing ulceration on the second MPJ (Fig. 28.2).

There are two main approaches to making a skin incision: medial to lateral and dorsal to plantar orientation. The former flap allows for ambulation on more durable plantar skin. The latter approach allows easier visualization of proximal tissues, but the scar is located dorsal to plantar, which may easily break down or cause pain when ambulating.

Second-digit amputations should be performed at the level of proximal phalanx to retain a stump at the base of the second toe to prevent subsequent hallux valgus formation (14).

Figure 28.1  A distal Syme amputation at the right fifth digit. Please note the surgical incision and preservation of the plantar flap (A,B).

Figure 28.2  A left hallux amputation preserving the base of the proximal phalanx and its soft tissue attachments (A,B). The extensor and flexor hallucis longus tendons are sharply transected before closure.
Operative Technique

The preferred incision in all cases for primary closure in digital amputation is a fish-mouth or “racquet-shaped” technique. The authors prefer to use the dorsal-plantar flaps by making the incision perpendicular to the skin. Next, in an attempt to preserve all soft tissue with the flap, the incision is taken full thickness down to the bone. Initially, the flaps are incised longer as the distal pathology permits, with the intent of shortening the flap for a tension-free closure. After stripping the periosteum from the bone, the osteotomy or amputation of bone is made through the midshaft of either distal or proximal phalanx. Then the phalanx can be further shortened, smoothed down to the base, taking care not to violate the MPJ. The long extensor or flexor tendons are distracted, sharply cut, and allowed to retract into the deeper soft tissues.

During the procedure, if faced with inadequate soft tissue for closure, either standard plastic techniques are used to mobilize the flaps further, or one can attempt to shorten the bone, i.e., excising the entire base of the phalanx. If disarticulation at the MPJ occurs, it is crucial to remove the articular cartilage to avoid necrosis and infection of this nonvascular tissue layer later. Prior to closing the skin, final débridement of the flaps can be performed, at this time the tourniquet can be released in any amputation procedure to determine the viability of flap. Once the surgeon is satisfied with the resection, skin is closed with 4-0 nonabsorbable suture in interrupted fashion (Fig. 28.3).

Postoperative Care

In both procedures, dressing is kept dry postoperatively until sutures are taken out. The sutures are removed usually 7 to 10 days after surgery. The patient is able to weight-bear immediately after surgery.

Complications

Some of the complications of terminal Syme and digital amputations include transverse deformity or deviation of digits, shortening of the digit, bulbous nature of the terminal stub, potential sloughing of the plantar flap, painful scar formation and nail spicule, and recurrent ulceration or infection (13).

Figure 28.3 A traumatic injury with a severe soft tissue compromise at the left hallux (A) in a diabetic patient followed by a disarticulation at the MPJ level (B) and a toe fillet flap for primary closure (C,D).
One main complication after hallux amputation is an apopulsive gait because of loss of plantarflexor function and windlass mechanism resulting in metatarsalgia of the second and third MTPs secondarily to the shift in weight to the lateral aspect of the foot (14). A study of digital amputations in neuropathic feet showed that 65% developed new ulceration after hallux amputation with 53% requiring further proximal amputation. The re-ulceration rate was only 10% in the lesser digit amputations (15). There may be an increased chance of developing hammertoe deformity to lesser digits after hallux amputation. As hammertoes develop, anterior displacement of the plantar fat pad occurs and increased pathology at the plantar metatarsal heads may arise.

RAY RESECTION

SINGLE RAY (OUTER TOE)

A “ray” is defined as the metatarsal and its corresponding toe. Those of the first and fifth toes are the most commonly performed single ray amputations.

Indications

A ray surgery is performed when there is plantar erosion of a prominent metatarsal head or ulceration with or without evidence of osteomyelitis over the metatarsal head, or if there is a necrosis or ulceration of the toe at or proximal to the level of the MTP.

Technical Principles

Amip (16) cautions against disarticulating at the MTP instead of performing a ray resection. He believes that leaving the metatarsal head does not improve foot function, but instead creates a potential pressure point that may predispose to recurrent ulceration and infection. The bulk of the articular cartilage and metatarsal head can make skin closure with minimal tension more difficult. Once the joint is disrupted, there is no synovial fluid to supply its nutrients to the cartilage. Therefore, there is no advantage in leaving the bony head over amputation of a distal portion of the metatarsal. It is important to leave the base of the fifth metatarsal because of the peroneus brevis insertion.

Operative Technique

A “racket-shape” incision is made at the MTP level of either the first or fifth toe. This incision consists of an elliptical cut around the base of the affected toe with a straight longitudinal incision beginning at the proximal end of the ellipse and continuing proximally along the outer edge of either the first or fifth metatarsal shaft. The exact outline of the incision can be modified to include the ulceration or necrosis of the toe, but an attempt must be made to preserve as much plantar skin and soft tissue as possible. It is recommended to use the elliptical incision first to disarticulate the toe at the MTP and excise the ulcerated or dead tissue from the incision site before proceeding with the deeper tissue exposure. The advantage of this technique is that after the toe has been removed, the metatarsal head is easier to visualize.

After disarticulating the toe, the joint capsule is completely separated from the bone and the metatarsal head is exposed. At the same time, care is taken to avoid entering the MTP of the adjacent ray or injuring the plantar soft tissues abutting the shaft of the metatarsal because the arterial supply to the plantar flap is located in these tissues (16). Once the head is free of any soft tissue attachments, the shaft of the metatarsal is exposed and marked where the osteotomy is to be performed. Using a sagittal saw, the osteotomy for the first metatarsal is performed in proximal-plantar-medial to distal-dorsal-lateral and fifth metatarsal is performed proximal-plantar-lateral to distal-dorsal-lateral, beveled toward the plantar side. The next step is to excise the remnants of the soft tissue structures, including joint capsule, tendons, ligaments, which in the case of the first toe, includes the sesamoid bones. The preceding dissection is done with a very sharp no. 10 or 15 blade, sparing the plantar fascia and other soft tissues.

Once all the devitalized tissues are removed and the wound is irrigated, the incision site is ready for closure. The surgeon must then assess the closure potential by reapproximating the dorsal and plantar flaps. At this time, if possible, any redundant skin is taken from the dorsal flap unless the plantar tissues are of poor quality. If there is too much tension with approximation of the flaps, the surgeon should consider taking away more metatarsal, debulking the flaps, leaving part of the wound open, or amputating the adjacent ray to mobilize more soft tissue. Once the surgeon is satisfied with the appearance of the flap, the closure is performed as described in the preceding section or with more advanced plastic surgical techniques (Fig. 28.4).

LESSER RAYS (INNER TOE)

The amputation of the inner or lesser rays (toes 2, 3, or 4) can be challenging to perform and may require modifications in technique because of constraints imposed by the adjacent rays. It is more difficult to perform isolated lesser ray resection and obtain a good closure.

Indications

The lesser ray resections are performed when there is MTP dislocation with associated plantar ulcerations, infection, or when infection spreads from a distal to proximal digit. Some surgeons prefer a second ray amputation than a disarticulation at the second MTP to avoid hallux valgus formation because of lack of buttressing support provided by the second toe. However, second ray resection results in narrowing of the forefoot.

Technical Principles

Because the base of the second metatarsal functions as a keystone, it is also important to retain the base of the second metatarsal. If three lesser ray amputations are performed, the remaining two toes are at greater risk for subsequent deviation, contracture, and ulceration. When three or more rays require amputation, it is recommended to perform a transmetatarsal or more proximal amputation (17).

Operative Technique

The similar racket-shape incision mentioned in the previous single ray section is used. Now the longitudinal handle extends from the dorsal end of the ellipse on the dorsal surface of the
lesser metatarsal shaft (16). This incision may be modified when plantar skin ulceration is present. Again, a skin incision is made in identical fashion down to bone as described in the outer ray resection and disarticulation of the toe at the MPJ is performed first. After freeing the joint capsule and soft tissue structures from the lesser metatarsal head, resection of the lesser metatarsal shaft is made using a sagittal saw. The osteotomy is made in the same manner as the outer rays. The fixed position of the adjacent rays makes lesser ray amputation more difficult, and it is nearly impossible to close the incision site with some skin tension (Figs. 28.5 and 28.6).

POSTOPERATIVE CARE

In both single and lesser ray amputations, in the first few weeks, mechanical offloading of the foot is necessary to prevent compromise in wound healing by elevating the foot to decrease pedal edema, avoiding prolonged foot dependency, and increasing relative bed rest. The skin sutures are usually left in place for 3 weeks or until complete healing is noted.

COMPLICATIONS

Hematoma within the dead space or skin tension from lack of bone resection could lead to failure of the surgery in both outer and inner ray resections. With a first ray amputation, there is a loss of the medial column and the foot can progress into a pes planovalgus deformity (18). A most common complication after any ray resection is transfer lesions. Especially after a lesser ray resection, there is increased chance of adjacent transfer lesion developing, causing further tissue breakdown. Also, adjacent metatarsal stress fractures are complications of a ray resection.

When leaving a fifth toe isolated after resection of the fourth exposes the fifth to possible injury and subluxation. If the base of the fifth metatarsal is removed and the peroneus brevis tendon is sacrificed, an adductovarus foot deformity will develop from the tibialis posterior muscle gaining mechanical advantage. The supinator forces will override the pronatory forces and may lead to plantar lateral breakdown of the foot (19).

TRANSMETATARSAL AMPUTATION

Transmetatarsal amputation (TMA) was first described in 1855 by Bernard and Heute to treat trench foot. The procedure was described as an amputation performed at the anatomic necks of the five metatarsals and was then popularized by McKittrick et al. in their series of diabetic patients in 1949. Their patients had TMA because of gangrene or infection limited to a toe or toes that did not extend into the web or onto the foot itself (20). TMA maintains function and reduce energy expenditure for a patient because of preservation of residual limb length. One study found that the 30-day mortality rate in transtibial amputations was 6.3% and 13.3% mortality rate in transfemoral amputations versus 30-day 3% mortality rate in TMA (21). Currently, TMA is performed at various metatarsal lengths.

Indications

The main indication for TMA is a nonviable distal forefoot. A surgery that requires multiple toes or ray amputation, diabetic
foot infection or ulceration with vascular insufficiency, trauma, failed toe and ray amputations, and embolic phenomena are the most common etiologies that may require TMA.

Technical Principles

When considering performing TMA, evaluating the patient for an equinus contracture is important. If the equinus deformity is not addressed during TMA, it is more likely that a pressure ulcer will develop on the plantar aspect of the stump or cause a delay in healing of the stump (21). Tendo-Achilles lengthening, gastrocnemius lengthening, or complete tenotomy of Achilles tendon in rare circumstances is recommended (21,22).

Operative Technique

The lengthening of Achilles tendon or gastrocnemius should take place before any forefoot incision is made. To prevent cross-contamination, the forefoot should be draped out initially to keep the surgical field clean. The authors recommend performing percutaneous triple hemisection of Achilles tendon lengthening using a no. 11 or 15 blade. The lengthening may be generous, because shortening of the tendon may occur during the period of immobilization.

A fish-mouth incision is made using a longer plantar flap than the dorsal flap so that the suture lies on the dorsal distal aspect of the stump to avoid being in the weight-bearing region. The dorsal skin incision is made curving from a distal-medial to proximal-lateral direction using the first and fifth metatarsal midshafts as landmarks. The corresponding plantar incision is made close to the bases of the toes as possible. Last, the dorsal and plantar incisions are connected by axial incisions made along the shafts of the outer rays. The incision of choice is a fishmouth type if the plantar flap is not violated. If there is an ulcer located plantarly or within the distal flaps, the surgeon may modify the flaps to provide adequate soft tissue coverage without tension to the skin. A single ulceration on the dorsal or plantar flaps can be excised in a triangular fashion, and next the flap is closed in a “T” fashion.

After the initial skin incision is made, full-thickness flaps are created by extending directly down to the level of the bone. A key elevator is used to elevate the soft tissue structures from the dorsal and plantar aspect of metatarsals. The dorsalis pedis artery or other small vessels can be dissected, cauterized, or tied off. All of the metatarsal osteotomies are performed using a sagittal saw from dorsal-distal to plantar-proximal direction and beveled plantarly to avoid bony prominences. Only the first and fifth metatarsal osteotomy includes beveling medially and laterally, as illustrated in the previous ray amputation section. Concurrently, care is taken to preserve the metatarsal parabola as well as peroneus brevis attachment. All of the nonviable tissue is débrided, and tractions are placed on the flexor and extensor tendons and transected as far proximally as possible. Any tendon that is infected should be followed proximally until the entire infected tendon is removed. It is imperative to remove other structures, such as plantar plates and sesamoids, which may interfere with closure. As débridement of the incision site is completed, the wound is irrigated, the tourniquet is released, and hemostasis is accomplished.

In some infected or traumatic TMA patients, the wound should be packed open with iodoform-packing soaked in saline dressed with sterile dry dressing and continue local wound care.
until there are no signs of infection. A repeat débridement may be performed in a minimum of 3 to 5 days after the initial TMA and may be closed. During revision surgery, the wound edges are excised sharply to create an acute wound. Lastly, the granulation tissue and bone margins are freshened by using a curette and pulsé lavage irrigation and prior to performing delayed primary closure. The TMA is closed with minimal skin tension dorsally and plantarly to prevent skin necrosis.

In primary skin closure of TMA, the edges are approximated to determine if there is any redundancy or tension. The redundant tissue is sharply excised to prevent hematoma formation. A drain can be used as needed. If there is excess tension, further bony resection or slight thinning of the flap may be necessary. The skin is approximated by either using staples or using interrupted nylon mattress suture to evert the skin edges. To prevent tension and dog ear formation, the skin sutures should be placed in the middle, medial, and lateral edges with subsequent sutures bisecting the adjacent sutures until the wound is closed. If local coverage is inadequate, negative pressure wound therapy (NPWT) and/or split-thickness skin grafting (STSG) may allow an open TMA to eventually heal. The patient is then placed in an extremely well-padded plaster splint dressing (Figs. 28.7 and 28.8).

**POSTOPERATIVE CARE**

In TMA, edema control postoperatively is crucial in preventing failure, leading to future skin breakdown. The foot should be elevated using folded blankets stacked on top of each other to support the entire lower leg with the foot hanging off the end. If a drain is used, the output is monitored and the drain is removed a couple of days after surgery. If a concomitant Achilles tendon lengthening was performed, the patient is placed in an

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**Figure 28.6** Open partial fourth and fifth ray amputations with remained fibrotic and necrotic tissues and tendons (A), followed by revisional surgery and application of a STSG (B), covered by a bolster dressing (C), and final clinical outcome (D).
extremely well-padded plaster splint to hold the ankle in neutral position. If there are no signs of sepsis, the dressing is left intact for 3 to 4 days.

The patient is kept non-weight-bearing until the incision is healed without draining. If the patient is debilitated and unable to strictly observe the non-weight-bearing order, touch-down on the heel is allowed to mobilize the patient. If an Achilles tendon lengthening was performed in conjunction with a TMA, the patient is immobilized for a minimum of 8 weeks and for as long as 12 weeks. The timing for removal of sutures is variable, but it is recommended to remove sutures 3 to 4 weeks after amputation. In diabetic patients or those who have delayed healing, sutures can be left in place for 6 to 8 weeks.

**Complications**

The main complications are delayed primary healing, failed primary healing with need for revision surgery, recurrent plantar ulceration or pain, ulceration or painful blisters on the distal stump, distal bone callus formation (21). Mueller reported that after 7 months of the Achilles tendon lengthening, the decreased peak plantar pressure on the forefoot may return to baseline value (23).

**MIDFOOT AND HINDFOOT AMPUTATIONS**

In the 19th century, midfoot and hindfoot amputations, also known as Lisfranc and Chopart amputations, were first introduced by French surgeons. In the United States, they were first used by battlefield surgeons in the Civil War. The preceding procedures are employed in patients who fail or are not eligible for TMA (16). The main disadvantage of both procedures is the loss of foot length, interruption of tendinous attachments, leaving plantar flexors unopposed and resulting in equinus or equinovarus deformity with shift of weight-bearing from calcaneus onto the stump, causing pressure and instability during gait. Even though technical modifications have been introduced to compensate for this imbalance of forces, these amputations have not gained favor.

**LISFRANC AMPUTATION**

A French surgeon, Jacques Lisfranc de St. Martin, developed a technique to treat forefoot gangrene by partial amputation of the foot through the tarsometatarsal joint. Not only is the amputation named after the French surgeon, but the tarsometatarsal joint is also referred to as Lisfranc joint (24).

**Indication**

The indication is extensive forefoot soft tissue loss, which prevents from performing TMA. The reason for this soft tissue loss can be because of DM, PVD, osteomyelitis, soft tissue infection, and trauma. Some argue that for a nonambulatory patient, instead of Lisfranc amputation a more proximal amputation is recommended. Lisfranc amputation is a viable option when distal forefoot procedures fail and one has adequate soft tissue coverage. Once again, this procedure pre-

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**Figure 28.7** Severe forefoot gangrene (A), followed by one-stage TMA (B) and after a lower extremity arterial reconstruction (C). Please note the amputation level and flap closure.
serves length of the foot and allows patients to ambulate in a modified shoe rather than a prosthesis.

**Technical Principles**

When a Lisfranc amputation is performed, one will encounter the tibialis posterior, tibialis anterior, and peroneal tendons. The tibialis posterior tendon has multiple inserts, the main insertion is to the base of the navicular, then to the bases of the second through fourth metatarsals and the three cuneiforms. This muscle inverts and plantarflexes the foot; the insertion to the navicular and cuneiforms should be preserved because it is not encountered during the procedure. The tibialis anterior tendon inserts into the base of the first metatarsal and medial cuneiform. Its main function is to dorsiflex the foot. If the insertion is disturbed, the detached portion should be reattached to the proximal aspect of the medial cuneiform to preserve the function. The peroneal tendons are the strong evertors of the foot, and if the insertion is lost the tendon can be reattached to the cuboid.

Because of the proximity of the amputation, the transverse arch is disrupted, with loss of peroneal and extensor tendons resulting in a varus deformity. When there is loss of function of the muscles described in the preceding, the Achilles tendon

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**Figure 28.8** A failed TMA with remained fibrotic and necrotic tissue (A), followed by revisional surgery with STSG (B) and final clinical outcome (C).
gains advantage and an equinovarus foot deformity can occur. An Achilles tendon lengthening or complete tenotomy may be performed in conjunction with various tendon transfers (25). Variety of tendon transfers and Achilles tendon lengthening have been proposed, but results still can be suboptimal.

**Operative Technique**

In Lisfranc amputation, the operative technique is virtually identical to TMA. A fish-mouth incision is used with disarticulation performed at the tarsometatarsal joints. DeCotiis believes in salvaging the bases of the second and fifth metatarsals because the peroneus brevis, peroneus tertius, and the lateral band of plantar fascia attach to the base of the fifth metatarsal (24). Early (26) recommends disarticulation of all the tarsometatarsal joints except the base of the second metatarsal because it plays a keystone position, providing stability to the medial cuneiform through the network of plantar ligaments. If the fifth metatarsal is disarticulated, the soft tissue structures are then reflected subperiosteally from the fifth metatarsal base to maintain the integrity of the soft tissue attachment of these tendons. Reattachment of these structures to the lateral aspect of the exposed cuboid and surrounding tissue to preserve some eversion control to the foot is highly recommended. The foot should be in a slightly everted, dorsiflexed position when securing the tendons to the cuboid. The peroneus longus and tibialis anterior tendons should be secured to surrounding soft tissue. It is important to remove as much articular cartilage as possible from the cuneiform and cuboid surfaces to avoid cartilaginous necrosis. Achilles tendon lengthening or complete tenotomy may also be performed (Fig. 28.9).

**CHOPART AMPUTATION**

François Chopart, a French surgeon, was credited with disarticulating the talonavicular and calcaneocuboid joints while performing an amputation (24,26,27). Now those joints bear his name and the joints are also known as transverse tarsal or midtarsal joints. After amputation, only the talus and calcaneus are left of the foot. Numerous surgeons soon abandoned this procedure because it invariably led to equinus deformity, resulting in distal stump ulceration, infection, and subsequent proximal amputation. MacDonald (27) in 1955 published a small series study of Chopart amputations treated successfully with modified prosthesis. Bingham (28) concurred with MacDonald in his result of Chopart amputation in a paper published in 1970; however, both believed that transfer of the anterior tibialis tendon to the talar neck was necessary to control deformity of the rearfoot.

**Indication**

Chopart amputation is mainly performed in patients with serious midfoot infection. When performing a definitive surgery, Chopart amputation requires viable heel pad. When Syme amputation is anticipated, Chopart amputation can be useful as a preliminary procedure.

**Technical Principles**

When compared with the Lisfranc amputation, the frontal plane varus deformity is rare because the amputation is performed proximal to the transverse arch, and tendon insertions of tibialis posterior and tibialis anterior are eliminated, but the foot shortens even further (29). The Achilles tendon is a lone tendon that is attached to the foot, causing sagittal plane deformity. An open or percutaneous transaction of the Achilles tendon is recommended. Ideally, transferring the tibialis anterior tendon medially, the extensor tendons laterally, and Achilles tendon lengthening should be performed (26,29).
Once again, a thickened plantar flap is used from the arch, but it is not as durable as the skin from the plantar forefoot. Early, many surgeons believed that after Chopart amputation patients are more prone to developing plantar lateral deformity, callus formation, or ulceration on the distal anterior aspect of the stump.

**Operative Technique**

Achilles tendon lengthening or a complete tenotomy may be performed first. Next, the incision is made proximal to the navicular tuberosity and extends dorsally between the fifth metatarsal base and lateral malleolus. Then the medial and lateral incisions extend distally along the first and fifth metatarsal mid-shafts and carried plantarly. Initially, we recommend creating a larger and longer plantar flap which can then be revised to fit the shape of the foot. It is vital to remember to handle the flap in an atraumatic manner.

Next, the tibialis anterior tendon is identified and dissected from the insertion site on the dorsal surface of the base of the first metatarsal and medial cuneiform. To access the Chopart’s joint, use a key elevator to elevate the dorsal soft tissues from the midtarsal joint. Once the joint is identified, using a blade, the foot is sharply disarticulated at the midtarsal level. All tendons except for the tibialis anterior tendon are pulled distally and transected as proximally as possible. The tendons are allowed to retract. If there is a bony prominence on the anterior process of the calcaneus and dorsal talar head, then it can be resected appropriately. Complete cartilage removal from the talus and calcaneus can lead to better flap adherence (26).

The tibialis anterior tendon is transferred into the neck of the talus through a hole drilled in the neck of the talus. The tendon is then sutured upon itself and the extensor tendons are carefully sutured to the fascia and soft tissue of the sole of the foot. The incision site is closed using nonabsorbable sutures. A drain is inserted at the surgeon’s discretion. Care is taken not to put too much pressure when wrapping the wound to cause iatrogenic tissue ischemia. When placing the foot in a well-padded posterior splint, the talus is slightly placed in a dorsiflexed position in relation to the tibia, and the calcaneal tuberosity is parallel to the long axis of the tibia (Figs. 28.10 and 28.11).

**POSTOPERATIVE CARE**

The postoperative course of Lisfranc and Chopart amputation is similar to TMA. Depending on the underlying cause for the amputation, the wound should be checked daily and immobilization in a splint should be continued until the wound is healed. Sutures are removed only when the wound is healed. Weight-bearing is not permitted until the soft tissues or transferred tendons have healed and stabilized.

The goal of these amputations is to provide independent weight-bearing limbs. In a Lisfranc amputation, once the wound has healed completely, the patient may benefit from a Plastazote forefoot filler with a rocker-bottom shoe, with the rocker positioned more proximally. These inserts may benefit the patient in ambulation to decrease plantar surface pressure. Commonly, patients with Chopart amputation need a custom-fitted ankle foot orthosis (AFO) with a filler to hold a shoe adequately.

**COMPLICATIONS**

Complications of the Lisfranc and Chopart amputations are similar to those in TMA, which include residual equinus/equinovarus deformity leading to ulceration of the stump, necrosis of incision line, delayed healing, proximal amputation, and recurrent ulceration. Chopart amputation tends to be more mechanically unstable and may predispose to anterior subluxation of the ankle in diabetic neuropathic patients.
CALCANECTOMY

The calcaneus is part of the hindfoot that plays a vital role in weight-bearing and gait. When an infection or osteomyelitis occurs in the calcaneus, it poses a unique problem. The calcaneus receives most of its blood supply from nutrient branches of the posterior tibialis and peroneal arteries (30). The calcaneus can be vulnerable to conditions affecting the microvasculature, such as DM and PVD. Eradication of infection is important to reduce associated morbidities and further complications of proximal amputation, contralateral lower extremity amputation, and amputee ambulation energy costs.

A calcanectomy involves either portion of calcaneus, known as a partial or subtotal calcanectomy, and a total calcanectomy.

Figure 28.11 A patient with a limb-threatening infection and necrotizing infection (A–C), followed by an open Chopart amputation (D).
The first such procedure was performed by Gaenslen in 1931 (31). He treated 11 patients with hematogenous osteomyelitis of calcaneus using a midline posterior incision approach, splitting the bone longitudinally into medial and lateral halves, debridging infected cancellous bone, and maintaining the integrity of the cortex by hollowing out the calcaneus. He reported that 91% healed primarily and one healed with secondary intention. The scars on the heel were found to be painless and well-adapted to weight-bearing, and all the patients were able to walk independently.

Despite an overall satisfaction with the surgical approach, numerous investigators found this technique to bring disappointing long-term results. In 1974, Martini et al. reported results of 20 cases of partial or total calcanectomy with excision of local infected soft tissues based on preoperative radiographs and in some cases tomograms for the treatment of chronic osteomyelitis (32). After experiencing wound complications from using a horseshoe-shaped incision, the authors modified their technique to a posterior longitudinal incision near the midline that would incorporate any nearby sinus tracts. The authors reported eradication of infection in 19 cases and postoperative complications of abscesses, a papilloma of the surgical scar, and an eventual proximal amputation of the foot. In their study, 17 patients resumed an effective or even nearly normal ambulation, with or without an orthotic shoe insert. The authors concluded that partial or total calcanectomy provided good results with return to function and eradication of infection.

In 1981, Crandall and Wagner reported the largest of these series (33). This study included 31 patients who underwent partial or total calcanectomy in over a 10-year period. Osteomyelitis of the calcaneus was documented in 20 patients, including all 18 patients with DM. The authors incorporated ulcerations in the posterior vertical incision and all wounds were closed primarily over a drain. Of the 18 diabetic patients, eight underwent partial calcanectomy and the remainder underwent total calcanectomy. During the follow-up it was noted that non-diabetic patients had 92% success rate versus only 33% in diabetic patients. However, the authors still concluded that partial or total calcanectomy will be adequate in eliminating all diseased bone while maintaining the talocalcaneal and calcaneocuboid articulations (Fig. 28.12) (32,33). If the disease process appears to involve the entire bone or the patient has previously undergone a partial calcanectomy with recurrence of infection or ulceration, then total calcanectomy is the procedure of choice (32–34). The surgeon should always be prepared to perform a total calcanectomy if one discovers more extensive involvement intraoperatively. As a result, during the preoperative discussion, the patient should be made aware of this possibility. Also total calcanectomy was found to be less stable and resulted in less of a functional foot than partial calcanectomy, which do not interfere with any articulations or joint capsules.

Operative Technique

Place the patient in the prone position and start the incision approximately 2 to 4 cm proximal to the insertion of Achilles tendon, depending on the size of any overlying ulcer. The incision extends distally to the level of the calcaneocuboid joint. The incision can extend medially or laterally to allow incorporation of ulcers or sinus tracts. The dissection is carried deep down to bone to create full-thickness soft tissue flaps for preservation of blood supply to the skin. Medially and laterally, vital neurovascular bundle and tendons should be identified and protected.

Upon examining the Achilles tendon, if the tendon is grossly infected or involved in the heel ulcer, the tendon should be debrided and released. The Achilles tendon is preserved if the tendon is intact and not involved in the disease process. If the Achilles tendon is left intact, it will aid in ambulatory function once there is complete postoperative healing (32,34). Because the Achilles tendon is continuous with the plantar fascia through
Figure 28.12 A patient with a calcaneal osteomyelitis and extensive soft tissue loss (A), followed by a débridement, partial calcanectomy and negative pressure wound therapy (B), returned to the operating room for application of as STSG, bolster dressing (C–F), and off-loading external fixation device (G). This device also helps the lower extremity to be in slight equinus and helps heal the wound without any tension or ground pressure. Final clinical outcome of the partial calcanectomy (H). (continued)
the periosteum of the calcaneus, the tendon may be divided longitudinally, allowing its attachments to the soft tissues of the plantar aspect of the foot to be maintained via medial and lateral flaps. After the osseous resection, the tendon and its distal extent are repaired with sutures or sutured to the plantar fascia (37).

A sharp dissection is performed to separate the soft tissue and periosteum from the calcaneus beginning at the posterior tuberosity of the calcaneus. In partial excision of the calcaneus, go 1 cm posterior to the posterior aspect of the subtalar joint to begin the osteotomy using an oscillating saw. The osteotomy is made dorsal proximal to distal plantar bone, ending slightly proximal to the calcaneocuboid joint. The subtalar and calcaneocuboid joints and joint capsules are not violated using this technique. Any ligamentous attachments to the bone are released and the remaining fragment of the calcaneus must be inspected for signs of infection. The cortical edges of the remaining bone are contoured and smoothed. The functional prognosis does not depend on the size of the resection but on the cure of the infection (32). For total calcanectomy, the subtalar and calcaneocuboid joints are opened so that the ligaments surrounding these joints are resected. The calcaneus is then removed in its entirety and sent for culture and tissue pathology. Care must be taken to remove all pieces of the bone, as any remaining fragments may allow the infection to recur or spread. The articular cartilages of the inferior surface of the talus and posterior aspect of the cuboid are then excised with a
tough and durable skin from the heel flap covering the weight-bearing surface. When performing Syme amputation, meticulous attention to detail is essential to ensure a satisfactory outcome.

The Syme amputation has high failure rate and many patients complain of the bulbous stump. Over the years, various modifications to the original technique have been published to improve the outcome and cosmetic appearance in patients with PVD and diabetic infections.

PIROGOFF (1854)

This procedure maintains leg length by rotating the calcaneus in hopes of preventing pain because of preservation of calcaneus and fat pad for weight-bearing. It preserves both malleoli to allow improved prosthesis fit (40).

ELMSLIE’S (1924)

This procedure introduced supramalleolar resection to reduce bulbosity of the stump, but this often jeopardized the posterior tibialis artery and compromised prosthetic suspension (39).

BOYD (1939)

This procedure was modified to fuse the calcaneus to tibia in the ankle mortise. It provides a better weight-bearing stump with no need for an artificial limb (41).

SARMIENTO (1972)

This procedure was modified to improve the bulk of the stump for better cosmetic appearance and prosthetic fit by reducing the mediolateral diameter of the stump with osteotomy of the tibial and fibular malleoli (42).

WAGNER (1977)

This is a two-stage amputation. The first stage includes ankle disarticulation, leaving the cartilage of the distal aspects of the tibia and the fibula to act as a barrier to infection. Six to eight weeks later, with successful healing of the ankle disarticulation comes the second stage, in which the medial and lateral malleoli are removed and made flush with the ankle joint. This allows preserving the weight-bearing cartilage of the distal part of the tibia (43).

Indications

The main indications are traumatic foot injuries, PVD, and diabetic infections of the forefoot with viable heel pad. It is indicated for patients for whom partial foot amputation is no longer an option. The Syme amputation has been used in various congenital deformities and deficiencies of the lower limb, including proximal focal femoral deficiency, fibular hemimelia, and congenital pseudoarthrosis of the tibia. A palpable posterior tibial artery is essential for healing to occur after a Syme amputation (39).

The Syme amputation should not be performed in the presence of ulceration involving the heel pad, or when the viability of heel pad is questionable. Although an insensate stump is generally considered a contraindication, several authors have
reported good results with neuropathic stumps without any postoperative complications (39,44).

**Technical Principles**

Syme and Harris (38,45) recommended the following important principles to adhere to when performing a Syme amputation. The posterior flap must be preserved, because it provides a blood supply to the heel flap by the posterior tibial artery. Special attention should be paid not to ligate the vessel proximally when the malleolar osteotomy or medial ligament releases are performed. To provide resilience and hydraulic resistance from weight-bearing forces, the heel flap should be dissected subperiosteally from the calcaneus to include the septae running from the skin to the periosteum of the calcaneus enclosing adipose tissue compartments. Subperiosteal dissection prevents injury from occurring on the calcaneal branches of the posterior tibial artery. The heel pad should be secured to the distal surface of the tibia. Overzealous trimming of the edges of the flap to remove “dog ears” should be avoided, as it may compromise the integrity of heel flap. It is important to divide the tibia at the level of the dome of the ankle, parallel to the floor. This provides an optimal weight-bearing surface with prevention of migration of the heel pad over the cut surface of the tibia. The commonly observed problem of heel-pad migration has been alleviated either by securing the Achilles tendon to drill-holes in the distal posterior surface of the tibia, or by suturing the anterior heel-pad flap to drill-holes in the distal anterior part of the tibia (45).

**Operative Technique**

Spittler et al. are credited first with describing a two-stage procedure in 1954 (46). In 1977, Wagner popularized two-stage procedures, with a >90% success rate (45). Currently, Syme amputation is performed as a single operation because similar results were prospectively obtained in comparison of the amputation as a single stage and two-stage procedure (8). In the presence of gross infection of the foot, patients who are not candidates for a more distal amputation and have insufficient vascularity, a two-stage Syme amputation is preferred.

**SINGLE-STAGE SYME AMPUTATION**

Isolate the foot from the sterile field by using a sterile towel to drape it off from the ankle joint. Using a modified fish-mouth incision, begin the incision at the distal tip of the lateral malleolus and pass along the anterior aspect of the ankle joint at one finger-breath inferior to the tip of the medial malleolus. Pinzur recommends this incision rather than Wagner’s traditional approach, starting 1 to 1.5 cm anterior and distal to the tips of bilateral malleoli (8). Moving the apex of the incision anterior and posterior minimizes dog ear formation, which is usually removed at the second stage of Wagner’s operation. The incision is then extended across the sole of the foot to the lateral aspect, ending at the lateral starting point.

As the foot is plantarflexed, an anterior incision is made down to the bone. The tendons, nerves, and deep fascia crossing the ankle joint are severed. The anterior tibialis artery is ligated and anterior capsule of the ankle joint is severed. The blade is inserted into the joint space between the medial malleolus and talus and the deltoid ligament is identified and released, although care is taken to avoid injury to the posterior tibialis artery because this artery provides blood to the heel flap. The calcaneofibular ligament on the lateral aspect of the joint is sectioned in the same manner, which allows disarticulation of the ankle joint. A bone hook is placed on the posterior surface of the talus and the posterior capsule of the ankle joint is cut, which brings the superior surface of the calcaneus into view. The Achilles tendon is now identified and full release of the tendon is performed.

Now begin the subperiosteal dissection of calcaneus, which continues posteriorly along the calcaneus. The skin in this area is densely adherent to the calcaneus and care must be taken to avoid buttonholing. Using several sharp knives, the soft tissues are separated from the medial and lateral surfaces of the calcaneus. The posterior tibialis artery and other medial tendons and nerves are identified at the distal end of the heel pad, ligated, and released. Continue the dissection along the inferior surface of the calcaneus to the end of the plantar flap. The entire foot is then removed from the field, with the exception of the heel pad.

Once the entire foot has been removed, the decision is made to either retain or resect the articular cartilage of the distal tibia. Removing the articular cartilage from the distal tibia will allow for better adherence of the plantar fat pad to inferior surface of the tibia, but cause increased limb-shortening (7). In cases of severe infection in which spread to the tibia is of concern, the cartilage at the distal end of the tibia may be left to serve as a physical barrier to bacteria (43). Resection osteotomy of tibia is performed with a power saw. This osteotomy is performed so that the inferior tibial surface is parallel to the ground when the patient is standing. The medial and lateral malleoli are exposed, and both malleoli are resected at approximately 5 to 6 cm above the joint or at the metaphyseal flares of the malleoli. The osteotomy is performed using an osteotome or a power saw to create a narrow distal stump, which facilitates an optimal fit of the prosthesis. The sharp edges of the bone are rounded off. Only minimal débridement of the soft tissues in the heel pad flap is performed and the wound is irrigated.

A variety of techniques are available to prevent heel pad migration over the cut surface of the tibia. These include taping the heel pad with adhesive tape, using Kirschner wires to transfix the heel pad to the bone, or drilling holes in the anterior edge of tibia and fibula and suturing the plantar fascia to the bone (8,38–40,42). Pinzur (8) recommends drilling two to three oblique holes in the anterior distal aspect of the tibia, and the heel pad is secured to the tibia through the drill holes with nonabsorbable sutures. A suction drain is recommended and brought out through a separate stab incision in the distal third of the leg. The skin of the heel pad is then sutured to the skin of the anterior flap using nonabsorbable sutures.

**TWO-STAGE SYME AMPUTATION**

During the first stage, the incision is placed as described by Wagner 1 to 1.5 cm anterior and distal to the bilateral malleoli. The first stage consists of disarticulation at the ankle joint without resecting the malleoli or the articular surface of the tibia. Small stab incisions may be made on the sides of the heel pad to accommodate the malleoli. A drain may be placed, the skin edges are loosely reapproximated, and a soft compressive dressing is loosely applied.

The second stage or definitive amputation is performed after 6 to 8 weeks. Elliptical incisions are made over each malleolus so
as to excise any redundancy or dog ears. The bilateral malleoli are dissected subperiosteally and resected flush with the articular surface of the tibia. The distal tibial articular surface is not disturbed other than resection of the medial and lateral flares of tibial metaphysis to decrease the bulk of the stump. The plantar heel pad is secured in the same manner as described in the single-stage section. The skin is closed with nonabsorbable sutures.

**Postoperative Care**

A well-padded rigid dressing is applied in the operating room to control edema and enhance the adherence of the heel flap to the undersurface of the tibia. Weight-bearing is delayed until the wound has completely healed, up to 6 weeks. Once the sutures are removed and as the postoperative swelling decreases, the patient may be placed in a walking total contact cast, or an elastic stump shrinker may be implemented. If the patient is placed in a total contact cast, serial cast changes should be performed. Once the stump has stabilized, an ambulatory cast should be constructed by an expert prosthetist.

**Complications**

Complications include early difficulty with postoperative wound healing, stump infection, intractable stump pain, excessive stump length, migration of fat pad, ulceration of the distal stump, difficulty in fitting with a prosthesis, or prosthetic failure (7).

**CONCLUSION**

This chapter describes the pertinent points and techniques of performing amputations about the foot and ankle in patients with DM. A multidisciplinary team approach with vast knowledge of the treatment of the diabetic foot is paramount to the patient’s successful outcome.

**REFERENCES**

INTRODUCTION

The World Health Organization (WHO) defines rehabilitation as follows:

Rehabilitation of people with disabilities is a process aimed at enabling them to reach and maintain their optimal physical, sensory, intellectual, psychological and social functional levels. Rehabilitation provides disabled people with the tools they need to attain independence and self-determination.

Relating to patients with diabetes mellitus and related complications, rehabilitation comprehends a broad range of preventive and therapeutic measures (Table 29.1).

Optimization of glycemic control serves for improvement of wound healing, decreasing symptoms of peripheral neuropathy and lowering the rate of predominantly microvascular complications (i.e., diabetic retinopathy and nephropathy) (1,2). Regular physician visits are necessary to make sure a blood glucose level is within the normal range. The clinical exam consists of examination of the skin integrity, skeletal deformities, vascular pathology and, last but not least, signs of peripheral neuropathy and in particular “loss of protective sensation” (LOPS). Diabetic foot care is an essential part of the preventive measures. Removal of any hyperkeratotic or preulcerative lesions might be necessary to reduce any local pressure that will lead into a deep infection. To avoid ulcers, the patient has to be educated on how to properly examine the feet and must also wear the appropriate shoe gear (Table 29.2) (3).

On the other hand, not every patient with diabetes mellitus has to wear orthopaedic shoes with custom-made inserts for even pressure distribution. In the presence of LOPS or considerable peripheral atherosclerotic disease, the term diabetic foot syndrome is justified, and the diagnosis should not be made from the detection of an ulcer. Foot deformities can lead to areas of high (plantar) pressure, thereby increasing the risk of ulceration. Structural deformities such as a clubfoot with elevated pressure under the lateral ball, and functional deformities such as a hallux rigidus with elevated pressure under the great toe have to be taken into consideration when calculating the risk of ulcer formation (4).

With a history of a healed ulcer, the risk of developing a new ulcer is further increased (5). Mechanical factors contributing to an increase risk of new ulcer formation include partial foot amputations and Charcot feet. The latter with a potential accumulation of risk factors like peripheral neuropathy, deformity, joint stiffness, sharp bony prominences, and thin soft tissue should be regarded as one of the highest risks of ulcer formation in the patient with diabetes mellitus (6). However, the diagnosis of the Charcot foot comprehends a variety of conditions. A Charcot foot that is in the reconstructive phase (Eichenholz stage III) (Table 29.3) (7) and primarily affected the Lisfranc joint (Sanders type II) (Table 29.4) (8) with no deformity during the Charcot process, can be fitted with an off-the-shelf shoe with a stiffened outer sole plus custom-molded or pre-molded insole. An acute Charcot foot (Eichenholz stage I or II), on the contrary, with concomitant instability or high-grade deformity needs further immobilization in a cast or an orthosis unless reconstructive surgery is indicated (9). Partial foot amputations reduce foot contact area, whether performed as a transversal, longitudinal (ray, wedge) or internal pedal amputation. The smaller the support surface, the higher the plantar foot pressure, which is one of the most important factors causing ulcers, when it exceeds a critical threshold. (The value of this threshold is still under debate.) A common problem of partial foot amputations is tendon imbalance, leading to additional deformities. Although an adequate operative technique can guard against tendon imbalance in many cases, the remaining cases pose a serious problem to the podologist secondary to the deformity progression and very high pressure over bony prominences (10).

RISK STRATIFICATION OR INDIVIDUAL CARE?

Many countries have developed risk stratification systems for the diabetic foot syndrome. The International Working Group
**TABLE 29.1**

**Rehabilitation Measures in Patients with Diabetes Mellitus and Related Complications**

<table>
<thead>
<tr>
<th>Category</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycemic control</td>
<td>Walking aids</td>
</tr>
<tr>
<td>Patient education</td>
<td>Preventive shoes</td>
</tr>
<tr>
<td>Foot care, callus removal</td>
<td>Custom made orthopaedic shoes</td>
</tr>
<tr>
<td>Regular physician visits</td>
<td>Prostheses and orthoses</td>
</tr>
</tbody>
</table>

**TABLE 29.2**

**Recommendations for Foot Care in Patients with Diabetes Mellitus**

- Check their shoes and socks on a regular basis.
- Check for foreign objects in shoes before putting them on.
- Check for rough areas inside shoes.
- Wear proper fitting shoes and socks that have no seams or darning.
- Look at feet daily and check for cuts, scratches, or blisters.
- Use a mirror or have another person check the feet in case of impaired vision.
- Cut nails straight across and have calluses cut by a healthcare provider.
- Wash and dry feet daily (and gently between each toe).
- Use a moisturizer for dry skin (but not between the toes) and do not soak feet.
- Do not use chemical agents or plasters to remove calluses or strong antiseptics on feet.
- Avoid walking barefoot indoors or outdoors and wearing shoes without socks.

**TABLE 29.3**

**Modified Staging System of Diabetic Neuroarthropathy (7)**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage I</td>
<td>Deformity, no osseous changes on conventional radiographs. Bone bruise on MRI</td>
</tr>
<tr>
<td>Stage II</td>
<td>Soft-tissue inflammation and edema, joint fragmentation, osseous dislocation</td>
</tr>
<tr>
<td>Stage III</td>
<td>Reduction of edema, bone callus proliferation, and fracture consolidation</td>
</tr>
</tbody>
</table>

**TABLE 29.4**

**Sanders Classification of Diabetic Neuropathic Osteoarthropathy (8)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Metatarsophalangeal joints, toes</td>
</tr>
<tr>
<td>Type 2</td>
<td>Lisfranc joint</td>
</tr>
<tr>
<td>Type 3</td>
<td>Chopart joint</td>
</tr>
<tr>
<td>Type 4</td>
<td>Ankle joint</td>
</tr>
<tr>
<td>Type 5</td>
<td>Subtalar joint, calcaneus</td>
</tr>
</tbody>
</table>

**TABLE 29.5**

**IWGDF Diabetic Foot Risk Categorization**

<table>
<thead>
<tr>
<th>Category</th>
<th>Risk Profile</th>
<th>Check-up Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No sensory neuropathy</td>
<td>Once a year</td>
</tr>
<tr>
<td>2</td>
<td>Sensory neuropathy, signs of peripheral arterial disease and/or foot deformities</td>
<td>Once every 6 months</td>
</tr>
<tr>
<td>3</td>
<td>Previous ulcer</td>
<td>Once every 3 months</td>
</tr>
</tbody>
</table>

**TABLE 29.6**

**UTHSC Diabetic Foot Risk Categorization**

<table>
<thead>
<tr>
<th>Category</th>
<th>Possible Treatment (with shoes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Possible shoe accommodations</td>
</tr>
<tr>
<td>1</td>
<td>Possible therapeutic footwear</td>
</tr>
<tr>
<td>2</td>
<td>Podiatric/orthotist consultation for possible molded/extra depth shoe accommodation</td>
</tr>
<tr>
<td>3</td>
<td>Podiatric/orthotist consultation for molded/extra depth shoe accommodation</td>
</tr>
<tr>
<td>4</td>
<td>Neuropathic wound</td>
</tr>
<tr>
<td>4A</td>
<td>Acute Charcot’s joint</td>
</tr>
<tr>
<td>5</td>
<td>The infected diabetic foot</td>
</tr>
<tr>
<td>6</td>
<td>The ischemic limb</td>
</tr>
</tbody>
</table>
on the Diabetic Foot (IWGDF) proposes a risk categorization system with four levels (Table 29.5). This rather basic classification has proved its applicability to function as a tool to prevent foot complications related to diabetes mellitus (11).

On the other hand, no detailed information is given about protective or therapeutic footwear. The more comprehensive classification by the University of Texas Health Science Center in San Antonio, Texas (Table 29.6) includes additional pathology like infection and Charcot disease, but it also cannot be used as a guide for prescription form for orthopaedic shoes like all the other classification systems.

The prescribing physician must have detailed knowledge about the different types of shoes and orthoses and their components. Although conditions like peripheral neuropathy or history of an ulcer can be treated with shoes in a rather uniform manner, pathologies like partial foot amputations and Charcot foot disease require individual considerations concerning therapeutic footwear (Table 29.7).

## COMPONENTS OF ORTHOPAEDIC FOOTWEAR

While the footwear recommendations in Table 29.7 relate to off-the-shelf shoes designed for diabetic patients, custom-made shoes offer numerous adaptations to foot deformities and pathologies. The different components of orthopaedic footwear can be assigned to two functions; the first function is to modulate plantar pressure and ground reaction forces, and the second function is to provide stability or adapt to a structural deformity. However, some of the components could fulfill both functions.

### INLAYs OR PLANTAR ORTHOSES

Inlays belong to the first group. Total contact casting, multiple density removable inlays that are directly molded to the patient’s foot or a model made after a footprint, a foam impression, or a cast can reduce plantar pressure peaks. Evenly soft insoles without any supporting elements have an inferior effect on pressure relief. Areas of the sole of the foot that are covered with robust skin and tissue with sufficient load-bearing capacity need to be exposed to higher pressure to relieve vulnerable areas. Excavations filled with compressible material serve for additional relief under bony prominences. The softness and viscoelastic properties of the inlay material are under debate. Too soft and thin materials bear the risk of a bottoming-out effect, which reduces the material’s ability to distribute force (12). Soft and flexible inlays and shoes may increase shear forces because of increased adhesion during forward movement of the foot within the shoe. The material should resist permanent deformation from repeated shear and compression after long-term use (13). Thus, semirigid materials are recommended to fulfill both criteria, pressure reduction, and durability.

However, material stiffness may have unexpected effects on the diabetic foot. Gefen developed a finite element (FE) model of the plantar tissue under the second ray of the foot, suggesting a positive feedback mechanism of diffusion of ulcers in the diabetic foot, where the lesion is spreading from deep muscles to the skin surface by an evolving mechanical stress wave. With a soft insole material, FE simulations for an uninjured diabetic foot suggested compression within the plantar musculature that was about 1.25-fold greater than compression with a stiffer insole. Also, the soft insole produced shear stresses on muscle tissue that were about 1.5 greater in comparison with the stiffer insole (14). As long as deep internal tissue stresses cannot be measured routinely, quality management of protective insoles can only rely on plantar pressure measurements.

Apart from the discussion on viscoelastic material properties, the shape of the inlay should not be underestimated, because molded orthoses are more effective than nonmolded orthoses in reducing plantar pressure (15). The feasibility of regular disinfection of the inlays must be guaranteed without altering surface qualities and moisture should not lead to cracks and hardening of the inlay, as happens with drying leather. Basic recommendations for therapeutic shoe inserts for patients with diabetes mellitus have been summarized by Medicare (Table 29.8).

## ROCKER-BOTTOM SOLES

Stiffened rocker-bottoms are also effective in reducing plantar pressure in the area of the ball. When relief of metatarsal heads is intended, the pivot point of the rocker-bottom profile needs to be proximal of the metatarsal heads (16). One mechanism for pressure reduction is the acceleration of the center of pressure (progression of the gait line), so that the rather high forces during toe-off bear down the area of the metatarsal heads for a shorter period of time. The other mechanism is restriction of hyperextension in the metatarsophalangeal joints, which otherwise exposes the metatarsal heads to high pressure. Peak pressure relief in the area of the ball is as effective as by means of inlays, but in contrast, its efficacy decreases with lower walking speed (17). However, patients with diabetic neuropathy should not be encouraged to walk faster, as peak pressure is expected to increase with higher walking speed and stride length (18).

The effects of these different pressure-relieving methods are additive, so that an inlay should always be combined with a stiffened rocker-bottom for optimum pressure relief. Under the metatarsal heads, where the majority of plantar ulcers occur,
the combination of both methods is twice as efficacious as each single measure alone and can amount to some 50% peak pressure reduction in comparison with shoes with flat cork inlays and without rocker-bottom soles (Fig. 29.1A,B) (17).

A stiffened rocker-bottom (Fig. 29.2) also contributes to stabilization of the foot structure, protecting the tarsal and metatarsophalangeal joints from bending and torque forces. Besides pressure reduction in a particular area of the foot, a stiffened outsole serves for deformity correction and immobilization of the foot in the shoe. Please note that molded inlays should always be combined with stiffened rocker-bottoms for pressure relief under the metatarsal heads.

**CUSHIONED HEEL**

Besides alleviation of impact force during heel strike, a cushioned heel acts like a posterior rocker and thereby displaces the center of pressure anteriorly. In case of thin or fragile skin under the calcaneal tuber, a cushioned heel can redirect impact force toward more robust tissue under the anterior calcaneus. In case of a mild dropfoot, the cushioned heel diminishes dropping of the foot at heel contact. An exaggerated anterior rocker and cushioned heel (posterior rocker) narrows the contact area substantially, thereby interfering with postural stability. Please note that optimum pressure distribution has to be weighted against stance and gait stability.

**SHOE HEIGHT AND REINFORCED LEG**

Stability in terms of resistance against deforming forces and adaptation to an already existing foot deformity, the second

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**TABLE 29.8**

**Medicare Criteria for Custom-Fabricated Shoe Inserts for Diabetics**

1. The therapeutic shoe insert for diabetics is a total contact, custom-fabricated, multiple-density removable inlay that is molded to a model of the individual’s foot so that it conforms to the plantar surface and makes total contact with the foot, including the arch.
2. The insert must retain its shape during use for the life of the insert.
3. A custom-fabricated device is made from materials that do not have predefined trim lines for heel cup height, arch height, and length or toe shape.
4. The base layer of the device must be of sufficient thickness and durometer to maintain its shape during use (e.g., at least 3/16 in. of Shore A 35 material or higher).
5. The base layer is allowed to be thinner in the custom-fabricated device because appropriate arch fill or other additional material will be layered up individually to maintain shape and achieve total contact.
6. The central portion of the base layer of the heel may be thinner (but at least 1/16 in.) to allow for greater pressure reduction.
7. The specified thickness of the lateral portions of the base layer must extend from the heel through the distal metatarsals and may be absent at the toes.
8. The top layer of the device may be of a lower durometer and must also be heat moldable.
9. The materials used should be suitable with regard to the individual’s condition.

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**Figure 29.1**

A. Combination of custom-made full-contact inlays and stiffened outsole with pivot point proximal of the metatarsal heads. B. Medium pressure relief (10 healthy volunteers walking at self-selected speed in low shoes of the same manufacturer) at different foot areas relative to shoes without rocker-bottom soles and with flat cork inlay (17).

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**Figure 29.2**

Stiffened rocker-bottom with pivot point proximal of the metatarsal heads. The cushioned heel is marked on the shoe.
function of shoe components, can only be achieved by means of a high shoe. Shoe height may vary from Bottini (ankle-high) shoes to high shoes with a leg extending above the ankle joint. The proper degree of flexibility of the leg depends on outsole flexibility. As diabetic feet after partial amputation or surgical reconstruction are ideally protected by a stiffened outsole, a high leg should also be stiff to prevent wrinkling of the shoe and friction between the foot and the shoe (19).

Shoe height and reinforcing elements of the leg are chosen according to which movement of the foot needs to be restricted. If the ankle joint is stable and offers a reasonable range of motion, restriction of (exaggerated) pronation and supination may be sufficient by means of medial and lateral reinforcing elements (Fig. 29.3A,B) within the leg and the shoe height is about 6.5 in. This type of shoe is lighter than a high (8.5 in.) and completely stiff shoe and facilitates roll-off and stepping on the gas which is an important aspect with respect to the common walking disability of many diabetic patients with foot problems. Additionally, the reinforcing elements can be fabricated as an integral part of the inlay (Fig. 29.4A,B). If the ankle joint demonstrates considerable instability or deformity in the sagittal plane, a high shoe is inevitable and the leg has to be reinforced at the medial, lateral, and dorsal aspect of the shoe.

**TONGUE AND CLOSURE**

The three-point principle is applied if maximal fixation of the foot in the shoe is mandatory. In addition to leg and outsole, the tongue is also stiffened (19). If all three components of the shoe are stiff and the patient has a stiff foot, donning and doffing a shoe can be quite a challenge despite a wide opening. The effectiveness of a stiffened tongue with regard to immobilization of...
As in most cases the process has left a deformity that requires a custom-made shoe. An active osteoarthropathic process needs treatment with rigid fixation in an orthosis or a total contact cast, and Charcot feet after operative reconstructions also have to be protected from excessive loading or from bending and torque forces by means of orthotic postoperative management.

**BASIC PRINCIPLES**

After reconstructive foot and ankle surgery, weight-bearing of the limb has to be restricted so that bony fusion can be achieved and the osteoarthropathic process can coalesce or will not be provoked, depending on the Eichenholz stage at the time of operation. Internal osteosynthesis may require postoperative non–weight-bearing for some weeks, followed by partial or full weight-bearing for several months. External fixation surgery also needs orthotic aftertreatment for even a longer period of time, but a difference has to be made between midfoot and rearfoot surgery. Reconstructions in the area of the midfoot have to be protected against external forces, whereas axial loading may be necessary to improve bony or fibrous fusion in the area of the rearfoot and or ankle (4). Prefabricated walkers or custom-made orthoses with different designs are available to fulfill distinct demands for aftertreatment.

**TOTAL CONTACT CAST**

The total contact cast (TCC) is made of plaster of Paris or fiberglass by the physician or a cast technician, so that it is cheap to fabricate and immediately available. The foot and lower leg have to be wrapped in cotton wool or a comparable padding, and bony prominences are separately protected from high pressure by local pads. Frequent replacements of the cast may be necessary because of regression of swelling, which lead to increasing patient costs and are very time consuming. Although the TCC has been the gold standard for the treatment of neuropathic plantar ulcers (20), it cannot be recommended unre- serveedly for the treatment of Charcot feet, and in particular after reconstructive surgery, when weight-bearing is intended. Mechanical stability and restriction of movements of the foot and ankle joints are better controlled by a custom-made orthosis. Therefore, walking in a TCC may have a higher risk of inadequate immobilization of the osteosynthesis or the joint to be fused after removal of the external fixation.

**PREFabricated DIABETIC WALKER**

Similar to the TCC, a prefabricated diabetic walker (DW) is also available immediately if it can be stored. Mechanical stability decreases with use, depending on the model. In principle, the DW is an off-the-shelf TCC, so some authors even lock it with cable fixers to prevent its removal by the patient, thereby trying to enforce compliance. Irremovable devices have proved to be as safe and effective as a TCC for the treatment of neuropathic ulcers (21). However, with regard to neuropathic osteoarthropathy, the DW has little scope for modifications, its shape is designed to enclose a foot with some swelling, but not with considerable deformity. As Charcot feet mostly retain at

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**Figure 29.5** Loaded foot with check shoe. Areas of insufficient clearance are marked.
least some degree of deformity after surgery, the DW is not the orthosis of choice after reconstructive foot and ankle surgery in diabetic patients with polyneuropathy. Recent developments could ensure a more precise embedding of the foot in a prefabricated DW by using chambers filled with Styrofoam granules for fixation of the foot and lower leg (Fig. 29.6A). After evacuating the chambers the cushioning material becomes stiff and maintains its shape until air is filled in again. The same method is used for adjustments after edema regression or tissue atrophy. Even if a Charcot foot with a marked deformity is not a suitable subject to be treated with such a DW, the assumed more rigid fixation of the foot in comparison with a DW with air chambers (Fig. 29.6B,C) could offer an advantage in the orthotic treatment of the initial stage of the disease, when a skeletal deformity is not yet present, or after reconstructive surgery, if the foot is well-aligned after the operation.

CHARCOT RERAINT ORTHOTIC WALKER

The Charcot restraint orthotic walker (CROW) fits more precisely than a TCC or a DW, as it is made over a positive model. The device is durable and allows for good control of edema. Load transmission on the lower leg depends on the way of fastening the device. High pressure on soft tissues thereby enforces their atrophy, which can lead to worse fit of the orthosis and undesirable motions in the area of the osteosynthesis or the joint to be fused. Provided that the CROW is applied correctly and examined regularly, it is a useful tool for mobilization of the patient but immobilization of the Charcot joint(s) (Fig. 29.7) (22,23).

FRAME ORTHOSIS

The frame orthosis (FO) as it is built in the author’s department follows the neurotraumatic theory and focuses attention on joint immobilization. Based on this, the FO is a consistent derivative of the CROW. The neurotraumatic theory asserts that the loss of neurogenic joint control with repetitive stress leads to the initiation of an inflammatory response that results in destruction of cartilage and bone. A recent hypothesis proposes that an initial insult, even a minimal one, would suffice to trigger an inflammatory cascade through increased expression of proinflammatory cytokines. Hence, it appears to be logical that orthoses for the treatment of Charcot feet have to be targeted at protection from joint movements by means of restricting bending and torque forces instead of vertical unweighting as it is exerted in the treatment of neuropathic plantar ulcers.

The nonarticulated frame structure and the lack of weight-bearing at the tibial head characterize this type of ankle foot orthosis (FO) (Fig. 29.8). Full axial load is used to facilitate bony fusion after external fixation surgery, particularly with neuroarthropathic processes at the rearfoot and/or ankle. Depending on the surgeon’s demands, the FO can of course
be constructed with an additional infracondylar or infrapatellar support. The rigid three-dimensional fixation of the foot serves for the reduction of shearing forces. An important feature is a pretibial shell form-locking with the triangular shape of the tibia to eliminate lower leg rotary motion, because this is forwarded via the subtalar joint to the midtarsal joints. The orthotic frame with rear entrance and a solid heel holder wedges the lower leg from tibial head to heel so that the fastener around the calf is no longer the factor determining suspension in this orthosis. Additionally, the foot is fixed through a tongue from synthetic leather. A relatively thin pad appears to be more suitable to control motion of the foot, because stability is more important than soft padding. Vulnerable bony prominences have to be protected against high pressure (24). Please note that axial load within an orthosis is used to promote bone fusion after external fixation surgery at the hindfoot.

MANUFACTURING OF THE FRAME ORTHOSIS

For cast taking, the foot must be brought into the corrected position. Particularly if the ankle joint is still flexible, exact adjustment of the foot is the vital step in the production of the author’s orthotic device, because the vector of plantar forces is determined by this. Before suction molding of the interim orthosis that is made of polyethylene terephthalate glycol (PETG), a relatively thin soft pad made of 6-mm nonperforated ethylenvinylacetate (EVA) is wrapped around the foot and ankle of the model. As a clear, transparent material, PETG allows identification of pressure marks and modification of the orthosis using a hot air gun. Finally, the interim orthosis is reinforced with carbon fibers. The final orthosis is made from epoxy casting resin and is fitted after edema regression. The rocker-bottom is formed from polyurethane and individually ground during dynamic gait analysis. In addition to an anterior and posterior rocker bar, the plateau of the sole is important for safe standing and stance phase stability. The comfortable rear and front cutouts make the orthosis lightweight, with concomitant stability.

REHABILITATION AFTER EXTERNAL FIXATION SURGERY

After removal of the external fixation, the subsequent plaster cast and antiedematous treatment for 2 to 3 days is followed by fitting of an interim orthosis. Because most of the patients with polyneuropathy are not able to reduce weight-loading of the foot in a controlled manner with the help of crutches, full weight-bearing is allowed immediately, but time is limited to 15 to 30 minutes at the beginning. Unless problems such as ulcers, pain, or swelling develop, the duration of weight-bearing is continuously increasing. The axial compression leads to compaction of the osseous structures of the hindfoot (Fig. 29.9A,B). This can require a correction of the interim orthosis. After an extended period of full weight-bearing, it is occasionally detectable.
on radiographs that the distance between the bone fragments has declined.

The final resin-casted orthosis is fabricated after 3 to 5 months, as soon as constant volume conditions of the soft tissue can be resumed. Orthotic treatment is continued after external fixation surgery for 9 to 12 months, because the risk of recurrent foot malpositions is higher after a short postoperative orthotic care. If a considerable deformity of the foot does not exist, custom-made orthopaedic shoes can be fitted. A smooth transition from orthoses to shoes should be preferred. A fixing shoe with rolling sole (high shoe with stiffened leg) is initially worn for not more than 15 to 30 minutes per day. Unless skin lesions or a new episode of arthropathy occur, ambulation time in shoes may increase. In summary, orthotic treatment after fixation surgery of Charcot feet is an integral part of the treatment concept, and therefore requires close teamwork between the surgeon and orthopaedic technicians.

REHABILITATION AFTER RECONSTRUCTIVE SURGERY WITH OSTEOSYNTHESIS

After osteosynthetic stabilization of non-osteoarthropathic fractures in patients with peripheral polyneuropathy (PNP), the non-weight-bearing time has to be twofold in comparison to patients without PNP. The reason for the prolonged immobilization is not just an impaired fracture healing that almost does not exist in diabetic neuropathy. It is the risk of an acute osteoarthropathic process to be provoked by the operation or the preceding trauma (25,26). If weight-bearing starts too early, the following inflammatory process (Eichenholz stage I) with joint fragmentation and osseous dislocation destabilizes the osteosynthesis. Continual walking in the absence of pain leads to movements of the hardware against the foot structure. Broken hardware and destructed bone is one of the worst-case scenarios for the reconstructive surgeon (Fig. 29.10A,B). The same problems, of course, may occur after reconstructive surgery of pre-existing Charcot feet with screws, plates, or intramedullary nails.

Prevention of an incipient Charcot process is achieved by non-weight-bearing, casting, and bracing. After some weeks of non-weight-bearing in a cast, mobilization in an orthosis or a TCC starts with partial weight-bearing. On average, full loading of the foot is allowed 2 or 3 months after the operation. Protection of the foot with bracing or casting is necessary for 6 to 12 months, before custom-made shoes can be fitted. Exemplary postoperative procedures after osteosynthetic stabilization of Charcot feet are shown in Table 29.9. Please note that orthotic aftertreatment following reconstructive surgery of a neuropathic limb has to be prolonged in comparison with patients without polyneuropathy.

Despite differences in postoperative orthotic treatments, it is obvious that the considerable time of non-weight-bearing is important to avoid the mentioned problems. In contrast to external fixation surgery, axial loading of the rearfoot to facilitate bone fusion is not indicated. Bracing or casting is rather targeted at rigid fixation of the foot. The required postoperative duration of casting and immobilization also depends on the site of the lesion. In general, the rearfoot has to bear more stress than the midfoot, which can be protected more easily from bending forces by a device with a rigid lever extending to the tibial tuberosity. Walking with a well-fitted orthosis is not harmful, but can even improve the rate of healing (27).

An important point to mention is that the surgeon should be able to follow and examine operated Charcot patients on a regular basis over a longer period of time. In contrast to standardized procedures, such as after total hip or knee replacement, each patient needs a rather individual rehabilitation with fine-tuning depending on clinical and radiographic examinations every 6 weeks within the first half year and at least every 3 months thereafter.
Figure 29.10  A,B. Examples of broken osteosynthesis material because of improper aftertreatment.

<table>
<thead>
<tr>
<th>Author</th>
<th>Postsurgical Treatment 1</th>
<th>Postsurgical Treatment 2</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armstrong DG Phys Ther 1998</td>
<td>Patients with arthrodeses or bilateral Charcot’s arthropathy were casted for approximately 6 months. It took approximately 11 months to return to permanent footwear.</td>
<td>The lower limb was immobilized until skin temperature and edema normalized. The patient was then progressed to a removable cast walker, followed by permanent footwear.</td>
<td></td>
</tr>
<tr>
<td>Johnson EJ JBJS-A, 1998</td>
<td>The postoperative regimen included 3 months of non-weight-bearing in a total contact cast followed by 1 to 2 months in a weight-bearing total contact cast.</td>
<td>The patient was managed with a bivalved ankle-foot orthosis with a rocker sole until the use of footwear and a definitive brace was possible. Bracing was continued for 12 to 18 months postoperatively.</td>
<td></td>
</tr>
<tr>
<td>Schon LC CORR, 1998</td>
<td>Postoperative non–weight-bearing was maintained at least 6 weeks with subsequent bracing for 6 months.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinacore DR J Diabet Compl, 1998</td>
<td></td>
<td>Healing times to promote bony stability after surgical fixation or arthrodesis generally exceeded 3 months.</td>
<td></td>
</tr>
<tr>
<td>Simon SR JBJS-A, 2000</td>
<td>Postoperative treatment consisted of immobilization of the limb in a non–weight-bearing cast for a minimum of 6 weeks. If radiographs then showed further bone incorporation without adverse effects, the patient wore a weight-bearing cast boot for an additional month.</td>
<td>When there was no evidence of increased warmth or swelling in the lower extremity, the boot was discarded.</td>
<td>Eichenholz stage I; 14 patients; only midfoot Charcot</td>
</tr>
<tr>
<td>Marks RM CORR, 2001</td>
<td></td>
<td>All patients who had a reconstructive procedure required orthotics or braces after surgery. Radiographs must be obtained on a regular basis to ensure adequate healing without an incipient Charcot process.</td>
<td></td>
</tr>
<tr>
<td>Jones KB JBJS-B, 2005</td>
<td>Neuropathy correlated with the need for continued bracing at 6 months.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SHOES FOR THE RECONSTRUCTED DIABETIC PATIENT

Custom-made shoes are fitted following orthotic treatment. A high shoe (about 8.5 in.) with a reinforced leg in combination with a stiffened rocker-bottom sole is prescribed. A medially or laterally flared heel or sole is necessary in case of displacement of the foot in the sagittal plane. If the foot is well aligned in the sagittal and frontal plane, the following shoe after wear out of the first pair can be constructed with a shorter leg (about 6.5 in.), but still a mediolateral stabilization of the rearfoot is recommended. When only the midfoot is involved (Sanders type II and III), this type of shoe is an alternative to the mentioned high shoe (arthrodesis boot). A rigid rocker-bottom sole with cushioned heel serves for protection of the foot structures. The patient with a diabetic foot syndrome is in need of at least two pair of shoes, unless she or he is not able to walk outside the house. The shoes worn during the day have to dry out overnight to avoid hygienic problems. It should be kept in mind that the foot also has to be protected by means of custom-made shoes in the house, where many patients spend most of their time during the day. Hence, orthopaedic house shoes may be even more important than outdoor shoes. Low shoes without any stabilization of the ankle cannot be recommended, even though a very compliant patient with a minimally deformed foot might be able to wear them without notable complications.

AMPUTATIONS

Amputations eventually shorten the foot and lead to a substantial loss of weight-bearing areas on the diabetic neuropathic patient. To overcome the consequent problems with postural instability and increase of load on the remaining tissue, ray resections or inner pedal amputations are at the surgeon’s discretion. These kinds of operative procedures only make sense if the fitting of orthopaedic shoes or prostheses can be guaranteed. Vice versa, adequate shoes can only be provided under the precondition that the foot stump allows for weight-bearing and does not show larger axial deviations.

The device, no matter if built as a foot orthosis in a standard shoe, a custom made shoe, or a prosthesis covering the complete lower leg, has to compensate for the loss of weight-bearing area. Load transmission to the ground while walking requires a reliable connection of the residual foot with the prosthesis without any so-called “stump-pseudoarthrosis.” Axial deviations are difficult to compensate with prosthetic modifications; therefore, operative corrections should be considered.

A snug fit of the stump with the prosthesis can only be achieved by a total surface contact of the residual foot. For amputations at the Lisfranc joint or more distal it is desirable to avoid a support proximal to the ankle joint. Chopart stumps need to be stabilized by fixing the ankle joint with the aim of preventing excessive pressure at the stump end. A high prosthetic socket is particularly advisable, if there are additional factors interfering with postural stability. Some of those negative factors include contralateral amputations, postural sway because of peripheral polyneuropathy, weak knee extensor muscles, or axial deviations of the stump.

AMPUTATIONS AND RECOMMENDED SHOES OR PROSTHESES

TOE AMPUTATIONS

Toe fillers are contraindicated in the presence of arterial vascular disease. Adjacent toes tend to close the gap caused by the amputated one between them. There is no vital necessity to prevent this natural mechanism. Cosmetic replacement of several toes does not result in any improvement of stance or gait. Loss of the great toe leads to overloading of the adjacent rays with the risk of plantar ulcers or metatarsal fatigue fractures. In this case, the shoe should have a stiffened rocker sole. The optimal position of the rocker axis is slightly proximal of the metatarsal heads. Additionally, the inlay has an internal metatarsal support. Please note that toe fillers in the dysvascular patient increase the risk of ulceration.

RAY AMPUTATIONS

Unlike metatarsal resections, ray amputations may result in a considerable reduction of the weight-bearing plantar surface, depending on the extent of the forefoot segments removed. Medial or lateral border ray amputations may affect mediolateral instability with additional pressure problems. Amputations of the fifth ray with disarticulation at the metatarsophalangeal joint are crucial because of the risk of detaching the short peroneal tendon, sometimes leading to a progressive supination deformity. Custom made multilayer multidensity insoles are appropriate for even pressure distribution under the remainder of the foot. In case of first ray amputation the molded insole needs to support the medial border of the foot. A boot type shoe is recommended to provide mediolateral stability, which can be further improved by a reinforced heel counter. Central ray resections are usually less problematic and the foot is easy to fit in shoes with minor modifications and a molded insole.

TRANSMETATARSAL AND LISFRANC AMPUTATIONS

Amputations at the transmetatarsal (TMA) and Lisfranc level allow for wearing a shoe, whether off-the-shelf or custom-made, whereas a custom-fitted or custom-molded foot orthosis may be used as a replacement or substitute for missing parts of the foot. The end of the stump has to be in close contact with the foot orthosis to avoid friction forces. Additionally, the stump end is protected by a rigid cap that extends to the plantar surface. The hardness of the forefoot filler greatly influences gait. A soft material causes rolloff, but reduces stance stability (the functional weight-bearing area is smaller). Kinking at toe-off increases the risk of pressure ulcers at the stump end. On the contrary, a hard material or a long stiff sole exerts a knee stabilizing moment during gait. The rigid lever reduces the risk of pressure ulcers at the distal end of the stump. Sliding out of the heel has to be prevented by an exact anatomic fit of the shoe. Transmetatarsal and Lisfranc amputations proceed through the apex of the foot arch, so that the stump end shows a pretended supination. Pronation movement in the subtalar joint only enables partial correction, so that a foot orthosis with a medial wedge and a lateral shell-like rim is necessary.
Chapter 29  Rehabilitation and Therapeutic Footwear for the Reconstructed and Amputee Patient

A heel clamp prosthesis is a partial foot prosthesis whose suspension is provided by a posterior “clamp.” The sole is reinforced by carbon fibers and acrylic resin, and a nylon belt strengthens the heel clamp (28). Donning and doffing the prosthesis is more difficult in comparison with a foot orthosis with forefoot filler. Pressure on the (non-weight-bearing) soft tissue is generally higher, in particular in the area of the heel clamp, so that this type of prosthesis may be harmful for an amputee, who lost parts of the foot because of neuropathy or vascular disease. Hidden in a sock the heel clamp (Bellman) prosthesis is rather modest in appearance (Fig. 29.11A–C).

A silicone forefoot prosthesis offers possibly the best cosmetic restoration. Its flexibility offers adaptation to different heel heights to some degree. Just like the heel clamp prosthesis, the design of the silicon prosthesis is geared to wear it in a standard shoe. The fixation of the prosthesis onto the stump is ensured by surface adhesion and full contact fit. Prior to the fabrication of the definitive prosthesis, a trial prosthesis serves for testing by the patient and taking notes of necessary adjustments. The durable silicone of the definitive prosthesis makes further modifications impossible, so that an inconstant stump volume or pressure ulcers are a contraindication for this type of device. Further points of criticism are the rather high weight of the silicone material and the high price, so that this type of prosthesis is not covered by most of health insurances. Although the silicone prosthesis may offer high functionality in a traumatic amputee, the device deserves the same skepticism as the heel clamp prosthesis when a diabetic amputee with sensory neuropathy or peripheral vascular disease is involved.

REARFOOT AMPUTATIONS

The shock-absorbing capacity of the heel pad together with a full-thickness sole skin provide an end-bearing rearfoot stump despite its markedly reduced support surface. In the absence of deformities, plantar bony prominences, or skin grafts, no support at the tibial head is necessary. Any proximal support would rather impair venous and lymphatic circulation (edema) and implicate a potential risk of skin lesions. The pear-shaped rearfoot stumps bear a challenge for an appealing prosthetic cosmesis.

As a rule, prostheses for rearfoot stumps in diabetic amputees have a high shaft extending to the tibial tuberosity, thereby fixing the ankle joint. Embedding with dorsiflexion and pronation helps to counter the disposition of the stump to develop equinus or supination deformity because of tendon imbalance. As an exception, stumps following the amputation lines of Bona-Jaeger and Chopart may facilitate the fitting of footwear as described for the more distal amputations under the precondition that the stump has no deformity in any plane. The prosthetist may also abandon the high shaft if the patient has very limited walking

Figure 29.11  A. Lisfranc stump.  B. Bellman prosthesis.  C. Prosthesis with shoe.
capacity. Balance disorders as a result of polyneuropathy or contralateral amputation should also be excluded in this case.

The high shaft prosthesis for Bona-Jaeger and Chopart stumps has a socket design similar to the mentioned frame orthosis with a pretibial shell, heel holder, and rear entrance. The rigid lever arm eliminates peak forces during heel-strike and toe-off. The construction is lightweight and makes the use of a standard shoe possible, unless the stump is too bulky. If the stump has a rather cylindrical shape or if the ankle joint is no longer present (Pirogoff and Syme stump), the prosthetic shaft consists of an inner soft socket and a container made of casting resin or carbon fibers (Fig. 29.12).

A low level prosthetic foot serves for leg length compensation after a Pirogoff (1–1 1/2 in.) or Syme (2–3 in.) amputation. Modern carbon feet act like a spring (“energy storing”) and help to decrease energy consumption while walking. Sagittal alignment requires 1 to 2 in. lateral displacement of the prosthesis foot (Table 29.10).

### TABLE 29.10

<table>
<thead>
<tr>
<th>When to Prescribe a High Shaft/Socket in Case of Partial Foot Amputation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-grade mobility or labor</td>
</tr>
<tr>
<td>Deformity of the stump</td>
</tr>
<tr>
<td>Mesh-graft in weight-bearing areas</td>
</tr>
<tr>
<td>Balance disorder (polyneuropathy, impaired vision)</td>
</tr>
<tr>
<td>Contralateral amputation</td>
</tr>
<tr>
<td>Pirogoff and Syme amputation</td>
</tr>
</tbody>
</table>

**Figure 29.12**  Cut through Syme prosthesis with inner soft socket.

**INNER AMPUTATION**

Resections of a single metatarsal bone are well-established procedures in the treatment of osteomyelitis. This procedure can be extended to all five metatarsal bones as an alternative to a forefoot amputation. Inner Lisfranc or even Chopart amputations are also possible, as well as en bloc resections of all tarsal bones without any osteosynthesis. With shrinkage of the soft tissue, the foot shortens and stabilizes. In contrast to a “classical” amputation, the supporting area of the foot is larger, the tendons do not retract, and the patient does not sense that he or she is amputated. As an exception, wearing standard shoes with custom-made molded insoles plus stiffened rocker-bottom sole is possible in case of an inner transmetatarsal amputation. As a rule, inner amputations at the transmetatarsal or Lisfranc level require custom made high shoes with a heel counter extended above the ankle joint and the strengthened leg of the shoe at a minimal length of 6 in. (Fig. 29.13A,B). The shoe also has a stiffened rocker-bottom sole and a cushioned heel. The same type of footwear is prescribed for en bloc resections of all tarsal bones. Internal Chopart amputations result in a foot, which is very short but plantigrade. In a rather obese patient, additional footwear modifications such as a higher leg (8.5 in.) or an extended and stiffened tongue may be necessary to share load during toe-off.

**Figure 29.13**  A,B. Radiographs of both feet of a patient within high orthopaedic shoes with stiffened rocker-bottom. **A.** Inner transmetatarsal amputation on the left. **B.** Inner Lisfranc amputation on the right.
CALCANEECTOMY
Ulcers and infections of the bone are indications for resections of the calcaneus. Depending on the extent of tissue damage, partial resection or total calcaneectomy is performed. In case of a partial resection, the function of the foot depends on the preservation of the Achilles tendon attachment. If the tendon is fully intact, a foot orthosis serves for compensation of heel defect with loss of foot height and length. If the skin has been thinned out and lost its viscoelastic capacity, the orthosis needs to be soft in the area of the heel. The heel section of the shoe has to be adapted to the altered outer shape and the shoe should have a boot form to prevent slip of the heel during toe-off.

Detachment of the Achilles tendon weakens plantarflexion and supination substantially, so that additional modifications of the shoe are necessary. In a normal foot the pull of the Achilles tendon effects a varus position of the calcaneus during heel lift. By this mechanism the midtarsal joints are locked so that the foot can work as a rigid and effective lever during toe-off. The shoe has to compensate for the disturbed foot biomechanics. A reinforced and extended heel counter is recommended as well as a flared heel allowing for a wider base to control the distribution of body weight to the foot and its gravitational center. The lever function of the foot is re-established with the help of a stiffened outsole.

After total calcaneectomy, custom-made orthopaedic shoes are prescribed routinely. Weight-bearing in the area of the rearfoot is problematic, so that the material of the foot orthosis needs to be extra soft under the talus. As a consequence, the transmission of ground reaction force happens anteriorly to the axis of the ankle joint. The lacking counter pull of the Achilles tendon results in dorsiflexion, adding unwanted load to the area of the rearfoot. Hence, the supporting area of the inlay has to be extended posteriorly. If exaggerated ankle dorsiflexion cannot be controlled by this measure, the shoe must have a long and reinforced leg, if required in combination with a cushioned and strengthened shoe tongue.

TRANSTIBIAL AMPUTATION
Depending on the amputation level, the weight-bearing capacity differs significantly. Long stumps (distal half of the tibia) have a forceful lever arm but limited weight-bearing capacity because of the small diameter of the long bones at the resection level in combination with poor muscle coverage. In the presence of peripheral vascular disease a more proximal amputation level (proximal third of the tibia) is recommended. The cutting plane lies within the transition zone between tubular and cancellous bone. With further shortening of the stump, weight-bearing capacity increases, but contact surface and lever arm decrease. Transtibial amputations in diabetic patients most often result in a medium-length or short stump.

Basically, two different prosthetic designs are available: (a) A prosthesis with joints and a thigh lacer offers maximum medio-lateral or anteroposterior stability in case of knee joint instability and provides prevention of genu recurvatum. If partial unloading of the residual limb is necessary because of skin problems, the thigh corset provides some degree of shared weight-bearing. The tight-fitting corset may lead to thigh muscle atrophy and distal edema. Joints and corset add considerable weight to the prosthesis. Even joint centers located at the best result in movements between leg and prosthesis. Knee flexion >90 degrees is hardly possible. Further disadvantages are the unappealing cosmesis, the longer fabrication time, and the higher price in comparison with a short prosthesis. (b) A full contact short prosthesis has become the standard device for transtibial amputees recently. The design of the laminated or molded plastic socket is patellar tendon-bearing or has a Kondylen Bettung Munster. A model of the patient’s stump is used to achieve a total-contact fit. Most often the outer hard socket is supplemented with an inner soft socket to add comfort and protection from excessive impact or shear forces. Patients with peripheral vascular disease or neuropathy, bony prominences, and scarred skin benefit from a soft socket.

Suspension during the swing phase of gait is provided by different technical measures. The socket either has a supracondylar suspension or a supracondylar suprapatellar suspension with extended medial, lateral, and anterior walls for additional knee stability. Further suspension aids are suprapatellar cuffs or belts, removable medial brims or wedges, and suspension sleeves. A different suspension technique is implemented by the silicone suction socket or Icelandic roll-on suction socket (ICEROSS). This type of short prosthesis uses a prefabricated or custom-made silicone liner. The inherent suction capabilities of the silicone against the skin and a distal shuttle lock mechanism provide improved suspension. Shear forces because of socket pistoning are reduced by the liner. Originally, the liner was used strictly to provide suspension, whereas further developments have yielded other materials such as polyurethane or liner with increased wall thickness to add comfort and cushion.

REHABILITATION AFTER AMPUTATION
The goal of the postsurgical phase is mobilization of the patient in a controlled manner under physiotherapeutic guidance to prevent joint contractures and reduce stump edema (29). Control of edema is very important for the healing process and makes earlier prosthetic fitting possible (30). Stump dressings should be performed only by trained and skilled physiotherapists, nurses and/or physicians. In particular, partial foot stumps in a dysvascular patient with thin and vulnerable skin are prone to pressure necrosis. Padding with cotton wool keeps the foot stump warm and protects bony prominences against pressure sores. Elastic bandages or stockinettes should enclose the complete lower leg for optimum edema control. In case of a transtibial amputation the distal half of the thigh has to be included as well. If the dressing is not retained properly, circular strangulation may affect the opposite of what was intended. Silicone liners can also be used for volume control and for shaping of a below-knee amputation stump (31). They offer equal compression independent of personnel and are simple to disinfect. With decrease of volume another silicone liner with a smaller diameter has to be applied for continued shaping of the residual limb.

Immediate postoperative prostheses (IPOP) can help to reduce pain and swelling after amputation and support mobilization of the amputee. The IPOP is applied after the surgical wound has stabilized, usually in the second or third postsurgical week. Excessive weight-bearing soon after the operation has to be avoided to prevent damage to the wound site. Further benefits of the IPOP are improvement of balance and safety during transfers and protection of the wound site from trauma. The IPOP should be used under supervision of an experienced rehabilitation team.
Although hospitals for acute cases typically focus on treatment of impairment, the social and economic consequences of impairment are better managed by a well-coordinated multidisciplinary team in a rehabilitation center (32). Before transferring the diabetic amputee to a respective center, a decision has to be made about whether or not the patient is a suitable candidate for prosthetic fitting. Of course, rehabilitation is equally indispensable for those patients who do not want a functional prosthesis or who are technically impossible to fit. In such a case, a basic prosthesis can aid transfer between wheelchair and bed or a cosmetic device can augment the patient’s self-respect. The diabetic patient with multiple comorbidities, in particular coronary arterial disease, may be medically unsuitable for prosthetic fitting, similar to older or more disabled patients. The selection of patients to whom a functional prosthesis may not be supplied is not pleasant, but is a demanding task for the physician concerned with this problem.

**CONCLUSION**

This chapter reviews in detail the postoperative treatment of the reconstructed and amputee patient with diabetes mellitus. It is important to mention that post-treatment therapy is paramount to the overall patient success rate.

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