The Value of the Middle Meningeal Artery in Cerebrovascular Bypass Surgery: An Anatomic Feasibility Study

BACKGROUND: Over the past decade, there has been a revival and a renewed interest for cerebrovascular bypass procedures. The superficial temporal artery (STA) has its value as a reliable donor vessel; however, a possible role for the middle meningeal artery (MMA) as a donor artery is still unclear.

OBJECTIVE: To assess the feasibility of using the MMA as a donor vessel in cerebrovascular surgery.

METHODS: We performed cadaveric dissections on 12 fresh specimens (23 sides) after bilateral silicone injection into the internal and external carotid arteries. We compared the size, diameter, and possibility to perform a bypass to the middle cerebral artery for both the MMA and the STA. Measurements were done using an electrical caliper. Additional measurements of the MMA and STA were performed on 20 random angiograms.

RESULTS: There was no statistically significant difference in diameter of the MMA at its ostium being 2.4 mm, compared to 2.7 mm for the STA ostium (t-test; \( P = .21 \)). The MMA could be mobilized over 4.1 cm, whereas the STA over 8.3 cm. Finally, the mean diameter of the donor vessel at the site of the anastomosis was 1.6 mm versus 1.9 mm for MMA and STA, respectively (\( P = .0026 \)). We were able to perform an MMA and middle cerebral artery anastomosis on 17 sides.

CONCLUSION: These results suggest that the MMA is a potentially valuable donor vessel to be used in selected cases. The availability of a suitable MMA branch should be assessed preoperatively on the angiogram.

KEYWORDS: Middle meningeal artery, Bypass, Anastomosis, Caliber

Abbreviations: EC-IC, extra-cranial to intracranial; MCA, middle cerebral artery; MMA, middle meningeal artery; STA, superficial temporal artery

Operative Neurosurgery 0:1–8, 2017
DOI: 10.1093/ons/opx200

AFTER the disappointing results of several trials (The EC/IC Bypass Study Group, COSS), there are still indications for an extra- to intracranial (EC-IC) bypass.1-3 Improved imaging techniques allow us to reveal impaired cerebral hemodynamics in ischemia. This has led to an increased interest of again employing EC-IC bypass surgery for flow augmentation besides its role in flow replacement and EC-IC bypass surgery in the treatment of complex aneurysms.4 For this purpose, the most often used donor vessel is the superficial temporal artery (STA). In rare occasions, however, the STA is not available or is considered to be too small to provide substantial flow.

Starting from the end of the 19th century, the middle meningeal artery (MMA) has been the object of many anatomic studies describing the morphometrics of the vessel based on the grooves it carves at the skull base and the inner wall of the temporal and parietal bone.5 Various methods have been described to pinpoint the position of the MMA before craniotomy.6 However, quantitative data on the caliber of the MMA remain scarce, while this remains essential in considering its potential role as a donor artery in EC-IC bypass surgery.

METHODS

We prepared 12 fresh cadaveric heads for dissection by bilaterally injecting a mixture of 2% formaldehyde,
alcohol, and red silicone in the external and internal carotid arteries. All work was done with the approval of the research ethics committee of the KU Leuven. The heads were placed on a plastic cylinder to allow for the right positioning and manipulation. All dissections were performed using microinstruments and an NC-4 Zeiss floating microscope (Carl Zeiss Ltd, Oberkochen, Germany). Measurements were performed on the outer diameter of the vessels using an electrical caliper. For the anastomosis, we used 10.0 BV100-4 Ethilon sutures, by Ethicon (Johnson and Johnson Ltd, New Brunswick, New Jersey). First, a large question mark skin incision was made on the lateral frontoparietotemporal surface. This allowed us to dissect the STA and its branches entirely, all the way down to the zygomatic arch. Next, the STA was traced down to its ostium on the external carotid artery (ECA). This marks the starting point of dissecting the ECA in search of the origin of the MMA. Consequently, we cut the ramus of the mandible and remove the condyle of the temporomandibular joint. In this way, the internal maxillary artery was exposed. The MMA was then easily recognized as the first main branch of the internal maxillary artery coursing towards the skull base in an almost perpendicular fashion. After confirming correct identification of the MMA, the artery was cut at its highest point on entering the spinous foramen. Dissecting the entire ECA was mandatory to enable measurements of the ostia of both the MMA and STA.

We then proceeded with the first step of the MMA and middle cerebral artery (MCA) anastomosis by opening the skull using a pneumatized drill and craniotome to maximally expose the MMA (Figure 1A). The base of the bone flap was gently transected using various sizes of Kerrison rongeurs to avoid inflicting damage to the MMA, which might run in an intraosseous canal at that point. After elevating the bone flap, we preceded with a stepwise gentle piecemeal subtemporal craniectomy while intermittently elevating the dura and MMA from the skull with microdissectors (Figure 1B). This was continued until the spinous foramen was found. The second step was to dissect the largest and longest MMA branch between the 2 dural layers in a retrograde direction to reach the main branch of the artery. Next, a dural flap was made to

![FIGURE 1. Stepwise technique in performing an MMA-MCA anastomosis. A, Frontoparietotemporal craniotomy to expose the MMA branches. B, Expanding to a temporal craniectomy for further exposure of the main MMA trunk. C, Interdural dissection and transdural tunneling of the MMA to reach the M4 MCA branches. D, Detailed photograph of the microanastomosis; note the use of the fish-mouth technique.](image-url)
expose the Sylvian fissure and the M4 branches of the MCA (Figure 1C). A small durotomy was made in the region of the sphenoidal ridge. This allowed tunneling of the MMA intradural to reach the MCA branches (step 3). The fourth and final step was to perform a classical end-to-side anastomosis of the MMA to a suitable M3 or M4 MCA branch (Figures 1D and 2).

Additionally, we assessed the calibers of the MMA and STA on 20 random angiograms of patients who had undergone selective ECA and ICA angiography. The point of measuring the vessel’s diameter was systematically determined proximally at the ostia and distally at the intersection with the horizontal level 6 cm above the external auditory canal (Figures 3A-3D). Measurements were performed by the first author and evaluated by an experienced interventional neuroradiologist.

RESULTS

In one of the specimens, the anatomy on the left side was distorted by head injury, leaving 23 sides appropriate for this study. In all cadaveric specimens, the STA could be mobilized for anastomosis to the M3 or M4 MCA branches. An MMA-MCA anastomosis was possible on 17 sides (73%). In the remaining 6 sides, the MMA was damaged during the approach because of a long intraosseous course at the level of the temporal squama.

The MMA had 3 main branches in all cases: an anterior sphenoidal branch, a middle petrosquamosal branch, and a posterior parieto-occipital branch. Without exceptions, the petrosquamosal branch was the largest and thus best suitable for
The mean length measured from the origin of the MMA to the spinous foramen was 1.5 cm (extracranial part). The length from the spinous foramen to the trifurcation of the artery was 3.2 cm on average. Finally, the mean length of the mobilized segment to the site of anastomosis was 4.1 cm. This means that on average the intradural dissection of the MMA reached back 1.0 cm proximal to its trifurcation. The STA was mobilized over a mean distance of 8.3 cm. There was no statistically significant difference in diameter of the MMA ostium being 2.4 mm, compared to 2.7 mm for the STA ostium (Shapiro and
Wilks show that data are normally distributed, Figure 4, unpaired 2-tailed t-test \( P = .21 \). Finally, the mean diameter of the donor vessel at the site of the anastomosis was 1.6 mm versus 1.9 mm for MMA and STA, respectively \( P = .0026 \). Moreover, the correlation coefficient between the diameters of the MMA and STA was 0.59 at the anastomosis site and 0.67 for the calibers at their ostia (Figure 5). This was in concordance with occasionally finding a surprisingly large MMA opposed to a relatively small STA on the same side.

With regard to the measurements on the random angiograms, we were consistently able to identify both the STA and MMA with its main branches. We found a proximal diameter of 2.2 vs 2.6 mm and a distal diameter of 1.6 vs 1.2 mm for the MMA and STA, respectively.

**DISCUSSION**

The MMA is the first and largest branch of the maxillary artery, which together with the STA forms the final branches of the ECA. Certain similarities exist between the MMA and the STA and one can even appreciate a rather analogous course of the vessels. Where the STA runs subcutaneously and extracranially in the temporal region, the MMA courses similarly intracranially over the dura mater. Theoretically, the MMA appears to be an interesting potential donor artery, had it not been overshadowed by the presence of the more prominent STA. Indeed, the STA is the larger artery as is also confirmed by our results. However, the MMA may still be a suitable donor in selected cases. The MMA lies between the double dural layers and rarely participates in capillary networks as is observed in several Moyamoya cases. Normally, it immediately drains in venous structures such as the dural sinuses. The MMA is believed to play an important role in thermoregulation only during fetal life. Usually, no major consequences are to be expected after sacrificing this artery for bypass surgery with the exception of Moyamoya disease, as in these cases, the MMA may have formed an important collateral network.

The first studies on the MMA date back from the end of the 19th century. Clinicians were confronted with the consequences of an epidural hematoma after injuries involving the vessel or iatrogenic damage to the artery during craniotomy. Several methods have been proposed and used in order to locate the MMA using surface landmarks prior to surgery. However, these and more recent studies do not elaborately mention the caliber of the vessel. Indeed, they have detailed the morphometrics using the grooves the artery leaves behind at the inner surface of the skull. This method, however, cannot provide useful information about the caliber of the MMA. Concerning our study, the assessment of the calibers of the STA and MMA

**FIGURE 4.** A, Box plot of vessel calibers of the MMA and the STA at the ostia. B, Box plot of vessel calibers of the MMA and the STA at the site of anastomosis.

**FIGURE 5.** Linear regression plots of MMA vs STA calibers at site of anastomosis.
is the keystone. An interesting finding in this regard was the absence of a statistically significant difference in the diameters of the ostia of the MMA and the STA. This means that the MMA theoretically has an equal capacity as a donor vessel as the STA. The total length measured from the MMA ostium to the point of anastomosis was 7.8 cm, which in turn is comparable to the 8.3 cm of mobilized segment of the STA. Over these lengths, the vessel diameters decreased by 0.1 mm/cm and 0.09 mm/cm for the MMA and STA, respectively. This can be translated in a relatively parallel decrease in caliber over the length of mobilization (34% for the MMA vs 30% for the STA). In addition, it should be noted that this study was performed in vitro after the injection of silicone with formaldehyde 2% causing on average 9% shrinkage. Therefore, the diameters measured are an underestimation of the in-Vivo setting. Like the STA, the MMA is also a muscular artery. On histology, the intima and adventitia of the STA and MMA were comparable. As expected, the STA has a thicker muscular layer (Figures 6A and 6B). However, with a muscular layer that reaches 50% of the wall thickness, the MMA is eligible to serve as a donor artery.

One of the advantages of using the MMA is undoubtedly that it lies intracranially, closer to the M3 and M4 branches of the MCA. This reduces the risk of kinking, a complication that might occur at the point where the STA enters the skull. With a reduced distance between the donor and recipient artery, the caliber at which the MMA reaches the point of anastomosis is still quite reasonable. Mobilizing the MMA between the dural layers was performed as described in the second step of the technique. Although this may seem technically demanding at first, it turns out to be quite manageable once the right plane is found. Freeing the MMA out of the tight dural layers resulted in the expansion of the vessel, as is also observed after dissecting the STA out of the subcutaneous tissue. In case of the MMA, however, there is no risk of inducing skin necrosis, which is frequently observed after STA-MCA bypass. A major determinant in making an MMA-MCA anastomosis feasible is a strategic tunneling of the mobilized segment. We found that a small durotomy at the sphenoidal ridge easily allowed transfer of the MMA intradurally over the Sylvian fissure. In this fashion, the MMA is provided with a wide angle over which it can approach a potential recipient MCA branch. A potential drawback of the use of the MMA is the risk of damaging it during the approach due to its long intrasosseous course at the level of the temporal squama as was the case in 26% of our procedures.

We found 2 reports and well-illustrated case descriptions on the use of the MMA as the donor vessel in an MMA-MCA anastomosis. The first was Nishikawa in 1979, who described a technique where the MMA was used for this purpose. Despite the successful results, this technique did not become generally employed. For more than 2 decades, no cadaveric anatomic study followed to assess the feasibility of using the MMA in cerebrovascular bypass surgery. The only paper related to this matter is that of Üstün et al, describing a bypass from the MMA to the petrous part of the internal carotid artery. Although it conveys an authentic technique, we are skeptical about its applicability in a clinical setting. Moreover, no reports using this approach in carotid occlusive disease have been made. The STA is the preferred vessel to be used as a donor vessel for a direct end-to-side anastomosis to the MCA. Interestingly, the calibers of the STA and MMA were not strongly correlated. This implies that a small STA does not necessarily imply a small MMA. The difference in vessel diameter at the anastomosis site is 0.3 mm. A potential drawback of using the MMA for EC-IC bypass is the low flow-carrying capacity of the MMA. As demonstrated by Poiseuille’s law, the flow is related to the internal radius raised to the fourth power:

\[ Q = \frac{\pi P r^4}{8\eta l} \]
Finally, it may serve as an additional donor for flow augmentation.

It may be employed as a “rescue donor” should the STA fail. On a rare occasion, it provides an elegant alternative donor in cases where the STA is unavailable because of prior surgery or injury. In a clinical setting, it may demonstrate its value in selective cases by serving as an alternative to the STA or as an additional donor to augment cerebral blood flow. Therefore, this artery may be considered as a “rescue donor.” From these initial results, we advise to evaluate the presence of an MMA with an eligible caliber on preoperative imaging studies.

CONCLUSION

The MMA proved to be a suitable donor vessel for an end-to-side anastomosis to the MCA in this anatomic feasibility study. In a clinical setting, it may demonstrate its value in selective cases by serving as an alternative to the STA or as an additional donor to augment cerebral blood flow. Therefore, this artery may be considered as a “rescue donor.” From these initial results, we advise to evaluate the presence of an MMA with an eligible caliber on preoperative imaging studies.

Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES


Acknowledgments

Our respect goes out to all the individuals that selflessly donated their bodies to the Vesalius Institute for anatomical research. We especially need to thank Mr Jo and Kristof for their technical support in realizing this paper and their loyal work at our anatomy institute. Last but not least, I need to thank professor Yasuhiro Kaku, chairman of the Department of Neurosurgery - Asahi University Murakami Children's Hospital, for his encouraging words to publish this work.

COMMENTS

The authors assessed the feasibility of using the middle meningeal artery (MMA) as a donor vessel in EC-IC bypass using cadaveric dissections. I agree that the MMA is a potentially useful donor for EC-IC bypass, although its clinical use might be very limited. This study provides some useful information on the feasibility of using the MMA as a donor for EC-IC bypass, however, there are some drawbacks associated with the clinical application. One of the major drawbacks of using the MMA for EC-IC bypass might be that the MMA is expected to have a significantly lower flow carrying capacity than the STA. A rough estimation of the flow carrying capacity of the MMA may be only 50% of that of the STA. MMA should therefore only be considered as a “rescue donor”, as the authors have described.

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In this interesting anatomoradiological study the authors explore the feasibility of middle meningeal artery (MMA) as a potential donor artery for EC-IC bypasses, comparing it to superficial temporal artery (STA) in a group of 12 cadaveric specimens (23 sides) and 20
angiographic studies. The study demonstrates that the ostium size is not significantly different between these 2 vessels and that, although a mean difference of 0.3 mm at the anastomotic site was found statistically significant, it probably has no clinical relevance considering its application for flow augmentation in the middle cerebral artery territory. The main limitations for using the MMA for this purpose are that the mobilized segment is shorter and that preservation during the craniotomy and dissection of the vessel are quite more risky and complex than working with the STA.

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