Internal Maxillary Artery-Middle Cerebral Artery Bypass: Infratemporal Approach for Subcranial-Intracranial (SC-IC) Bypass

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BACKGROUND: Internal maxillary artery (IMax)–middle cerebral artery (MCA) bypass has been recently described as an alternative to cervical extracranial-intracranial bypass. This technique uses a “keyhole” craniectomy in the temporal fossa that requires a technically challenging end-to-side anastomosis.

OBJECTIVE: To describe a lateral subtemporal craniectomy of the middle cranial fossa floor to facilitate wide exposure of the IMax to facilitate bypass.

METHODS: Orbitozygomatic osteotomy is used followed by frontotemporal craniotomy and subsequently laterotemporal fossa craniectomy, reaching its medial border at a virtual line connecting the foramen rotundum and foramen ovale. The IMax was identified by using established anatomic landmarks, neuronavigation, and micro Doppler probe (Mizuho Inc. Tokyo, Japan). Additionally, we studied the approach in a cadaveric specimen in preparation for microsurgical bypass.

RESULTS: There were 4 cases in which the technique was used. One bypass was performed for flow augmentation in a hypoperfused hemisphere. The other 3 were performed as part of treatment paradigms for giant middle cerebral artery aneurysms. Vein grafts were used in all patients. The proximal anastomosis was performed in an end-to-side fashion in 1 patient and end-to-end in 3 patients. Intraoperative graft flow measured with the Transonic flow probe ranged from 20 to 60 mL/min. Postoperative angiography demonstrated good filling of the graft with robust distal flow in all cases. All patients tolerated the procedure well.

CONCLUSION: IMax to middle cerebral artery subcranial-intracranial bypass is safe and efficacious. The laterotemporal fossa craniectomy technique resulted in reliable identification and wide exposure of the IMax, facilitating the proximal anastomosis.

KEY WORDS: Brachiocephalic vein, EC-IC bypass, Infratemporal approach, Internal maxillary artery

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The cervical carotid artery has been routinely used as a site of proximal anastomoses for radial artery or saphenous vein grafts for extracranial-intracranial (EC-IC) high-flow bypass.[1-4] Recently, internal maxillary artery (IMax)–to–middle cerebral artery (MCA) bypass had been described as an alternative to cervical EC-IC bypass to reduce graft length. This graft distance reduction may correlate with improved patency and flow.

ABBREVIATIONS: **EC-IC,** extracranial-intracranial; **IMax,** internal maxillary artery; **MCA,** middle cerebral artery; **SC-IC,** subcranial-intracranial; **STA,** superficial temporal artery

Additionally, exposure of the IMax avoids the potential morbidities of a cervical carotid artery exposure.[5-9] Exposure of the IMax was previously described using a small “keyhole” craniectomy between V2 and V3 in the temporal fossa floor.[5] This limited exposure forces a technically challenging end-to-side proximal anastomosis that is performed through a limited and narrow window. We advocate a more lateral subtemporal craniectomy of the middle cranial fossa floor rather than the keyhole craniotomy to facilitate wide exposure of the IMax. This modification results in a less demanding end-to-end proximal anastomosis for subcranial-intracranial (SC-IC) bypass.

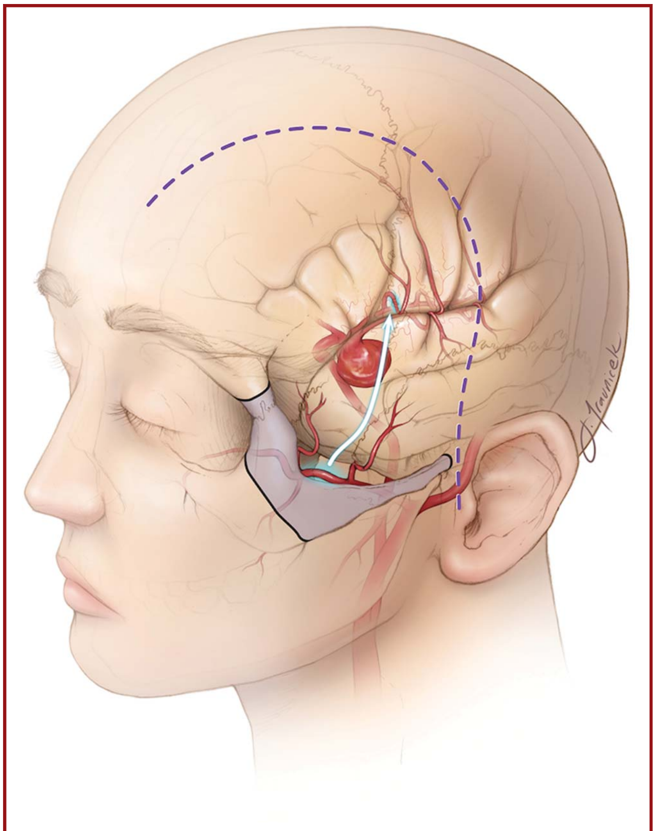

FIGURE 1. *Drawing of contemplated internal maxillary artery–middle cerebral artery bypass. Curvilinear incision, zygomatic osteotomy. The light blue arrow indicates the location of the bypass.*

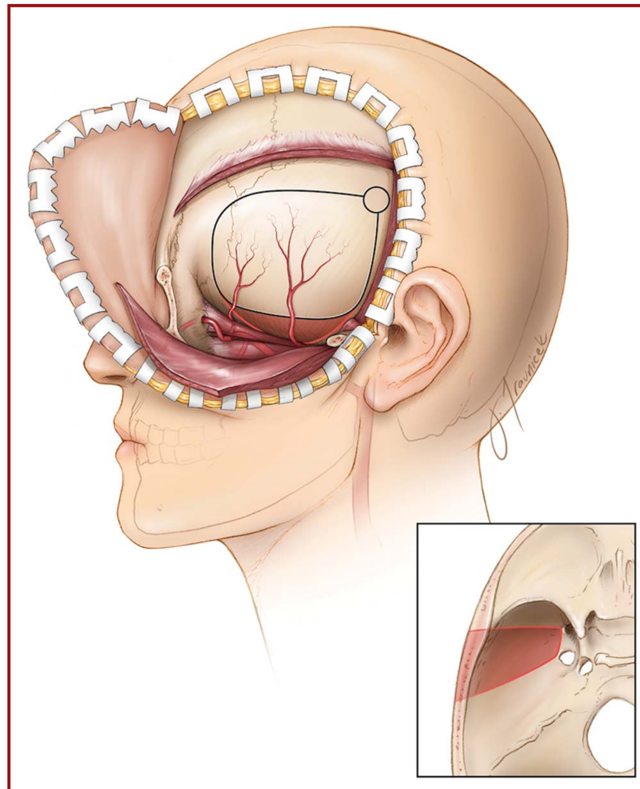

FIGURE 2. *Drawing of an elevated skin flap and temporalis, after osteotomy; the line indicates the craniotomy site. The red area indicates the contemplated craniectomy of the middle cranial fossa floor to unroof the infratemporal fossa. The inset shows the craniectomy in a superior view. The "corridor" craniectomy will reach a line 2 mm lateral to the virtual line between the foramen ovale and foramen rotundum.*

METHODS

We recently treated 4 patients with SC-IC bypass who required cerebral bypasses to effectively treat various cerebrovascular pathologies. The decision to treat the patient with a bypass and the feasibility of the SC-IC bypass was made in a multidisciplinary fashion by the neurovascular, neuroradiology, and cranial base teams.

Our multidisciplinary team performed cadaveric dissection to better assess the subcranial approach for exposure of the IMax in the infratemporal fossa. In this dissection, an orbitozygomatic osteotomy was followed by temporal craniotomy. Subsequently, a lateral rectangle craniectomy of the temporal fossa floor was created up to a point that was 2 mm lateral to a virtual line connecting the foramen rotundum and foramen ovale (Figures 1-4). The deep temporal arteries on the medial aspect of the temporalis muscle were then identified and followed to the IMax.

Intraoperative Technique

Zygomatic osteotomy (with or without orbital osteotomy) was used followed by frontotemporal craniotomy and subsequently temporal fossa craniectomy reaching its medial border designated by the same virtual line connecting the foramen rotundum and foramen ovale (Figures 4 and 5). We use computed tomography angiography–based neuronavigation and micro Doppler probe (Mizuho Inc. Tokyo, Japan). To identify the IMax artery in the pterygoid muscles (Figures 6 and 7). Anatomically, the deep temporal arteries in the medial aspect of the temporalis muscle were followed proximally to allow definitive identification of the IMax artery. The first patient's proximal anastomosis was performed in an end-to-side fashion, whereas the proximal anastomoses in the subsequent 3 patients were end to end (Figures 8-10). The end-to-end anastomoses were technically less demanding than the end to side. In the 3 end-to-end cases, reversed subcutaneous brachiocephalic veins were used rather than the radial artery. This vessel was consistently an excellent diameter "match" with the donor IMax. In our experience, the brachiocephalic vein was consistently reliably free of valves and had a paucity of branches. This graft represents our preference going forward. Intraoperative flow measurements using the Charbel microflow probe (Transonic Systems Inc., Ithaca, New York) was performed in all patients. Intraoperative angiography and indocyanine green videoangiography were obtained to evaluate bypass patency in all patients. All patients also underwent postoperative angiography to further assess the flow within the bypass and to further treat the aneurysms with endovascular techniques, as deemed necessary.

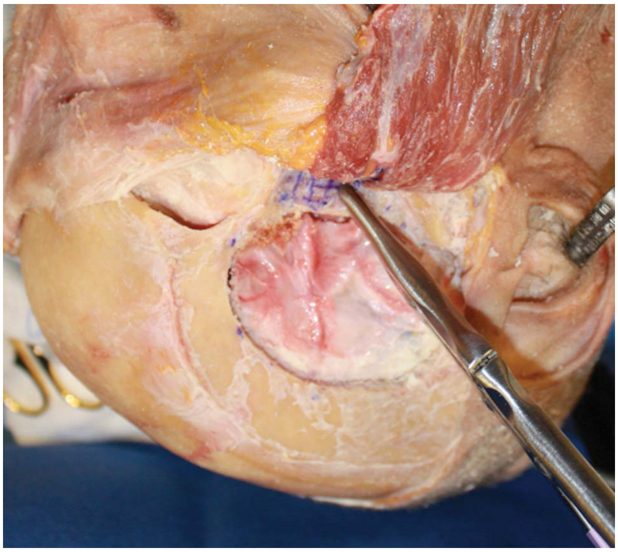

FIGURE 3. *A right-sided cadaveric dissection demonstrates an orbitozygomatic osteotomy and frontotemporal craniotomy. The rectangular craniectomy site is marked in blue.*

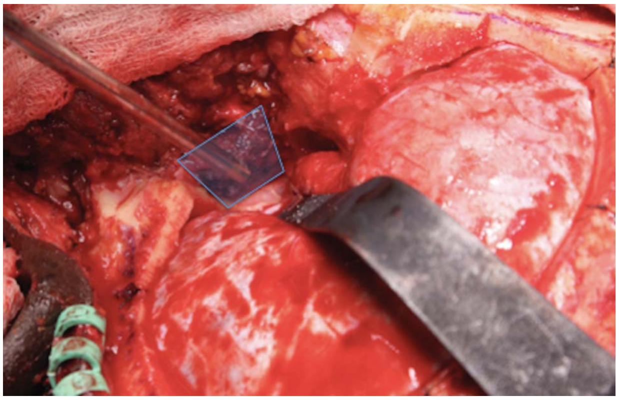

FIGURE 5. *Left side intraoperative craniectomy of the middle cranial fossa floor, similar in view to the cadaveric dissection shown in Figure 4. (The rectangular craniectomy portion is shown as transparent blue.).*

RESULTS

Patients

The SC-IC IMax technique described was used in 4 cases. One case was a flow augmentation bypass for a hypoperfused hemisphere in a patient with neurofibromatosis type 2 who underwent cervical surgery for resection of a cervical neurofibroma that resulted in occlusion of the internal carotid artery. This patient also had a very small-caliber superficial temporal artery (STA). The clinical presentation of this patient was hemiparesis due to stroke. Two patients have a diagnosis of a giant MCA aneurysm not amendable to endovascular treatment or direct microsurgical clipping (Figures 11 and 12). One of these patients had undergone a previous craniotomy in which the ipsilateral STA had been sacrificed. Both patients underwent SC-IC bypass and subsequent endovascular trapping of the aneurysms. The last patient was treated for a recurrent partially thrombosed giant MCA aneurysm. This patient experienced major recanalization of her aneurysm after endovascular coiling and presented with severe brain edema. She was recoiled and subsequently underwent SC-IC bypass and distal M1 trapping. Subsequent to SC-IC bypass, the distal M1 segment was clipped, and the patient was subsequently treated by trapping of her proximal M1 segment using coil embolization.

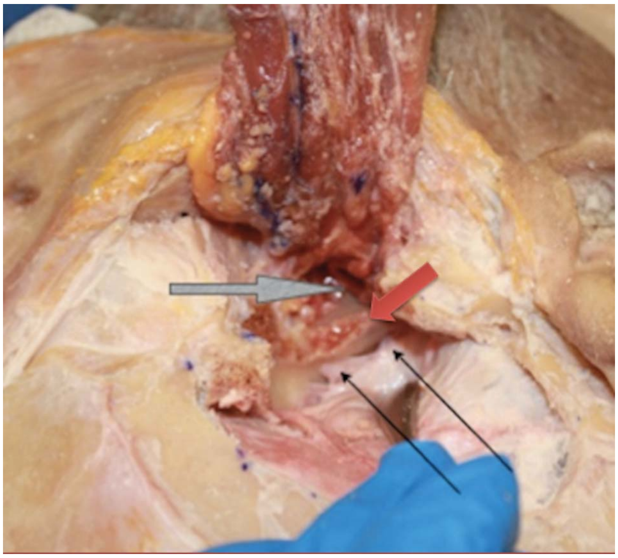

FIGURE 4. *A right-sided cadaveric dissection demonstrates the craniotomy. The craniectomy (thick red arrow) is done up to the virtual line 2 mm lateral to V2 and V3 entering foramen rotundum and foramen ovale, respectively (thin arrows). The internal maxillary artery is dissected in the infratemporal fossa (large gray arrow).*

Anastomoses

In the first patient, the IMax was identified in the infratemporal fossa by neuronavigation coupled with micro Doppler confirmation (Figure 6). In the subsequent patients, anatomic landmarks formed by the virtual line between the foramen rotundum and foramen ovale (which marks the medial border of the craniectomy), as well as the deep temporalis arteries that lead to the IMax, were identified, resulting in more rapid and atraumatic localization of the IMax. The position of the Imax was then confirmed by micro Doppler. In our last case, the identification of the IMax was more difficult due to unusual distal tortuosity.

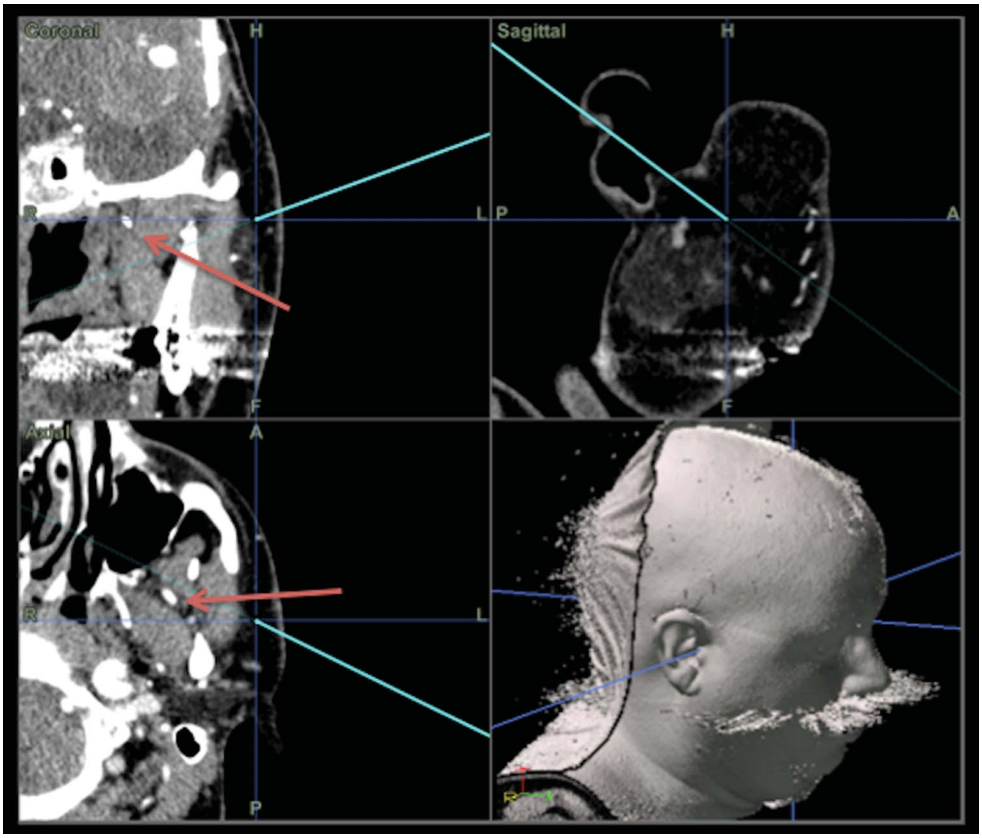

FIGURE 6. *A screen shot from the Stryker neuronavigation system (Stryker Instruments, Kalamazoo, Michigan) shows the localization of the internal maxillary artery (red arrows).*

Intraoperative flow measurements, in the graft, using the Charbel flow probe (Transonic Systems Inc), ranged from 20 to 60 mL/min. In the cases of end-to-end anastomosis (Figure 13), we did not observe any symptoms resulting from IMax sacrifice. Retrograde filling of distal IMax territory by external carotid artery collaterals was demonstrated on all postoperative angiograms.

Outcome

All patients tolerated the IMax SC-IC bypass well. Postoperative angiography demonstrated good filling of the graft with robust distal flow in all cases (Figures 14 and 15). Two aneurysm patients underwent aneurysm occlusion with concomitant MCA deconstruction using interventional techniques. This plan allows early flow demand to be placed on the transplanted graft with real-time angiographic flow assessment before aneurysm deconstruction. In addition, by eliminating surgical exposure of the aneurysm, less surgical dissection is required, limiting surgical morbidity to the construction of the bypass itself. The last case underwent distal microsurgical M1 segment sacrifice with the residual aneurysm coiled and completely occluded postoperatively. The M1 segment was clipped immediately distal to the aneurysmal fundus. Retrograde

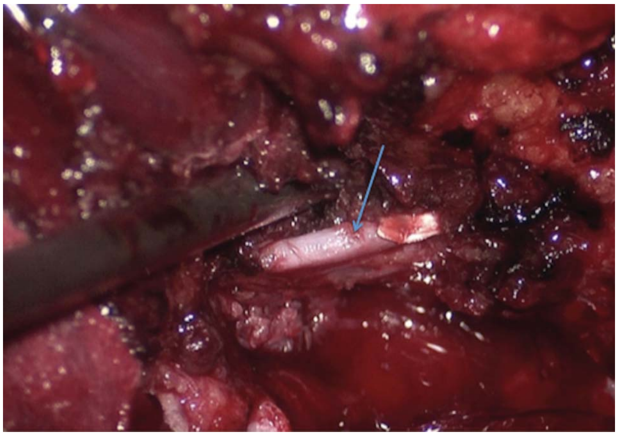

FIGURE 7. *A left-sided intraoperative image of the internal maxillary artery (blue arrow) dissected in the infratemporal fossa.*

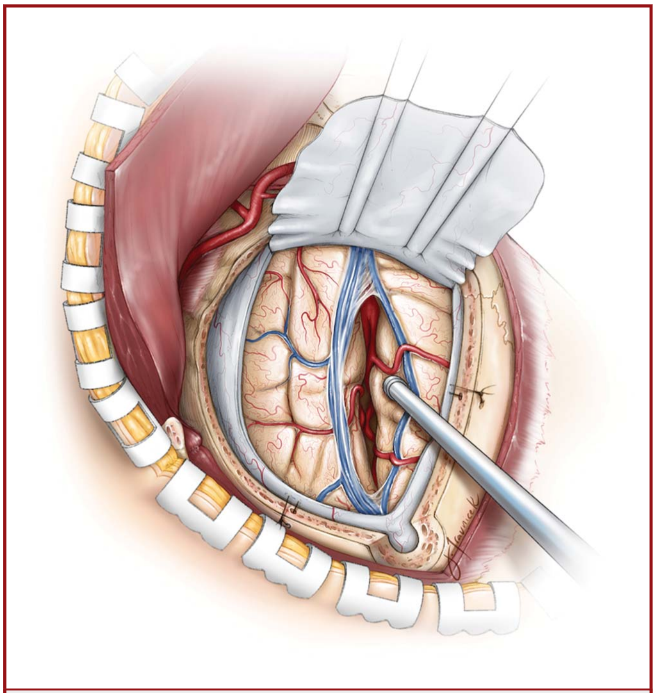

FIGURE 8. *Drawing of the donor internal maxillary artery and the recipient M3 in the opened sylvian fissure.*

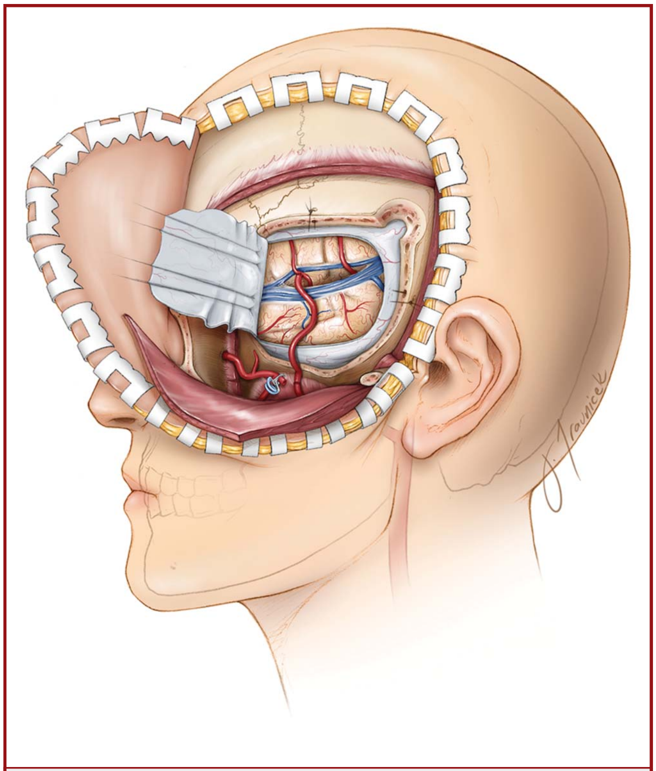

FIGURE 10. *Drawing of the final result of the subcranial-intracranial bypass.*

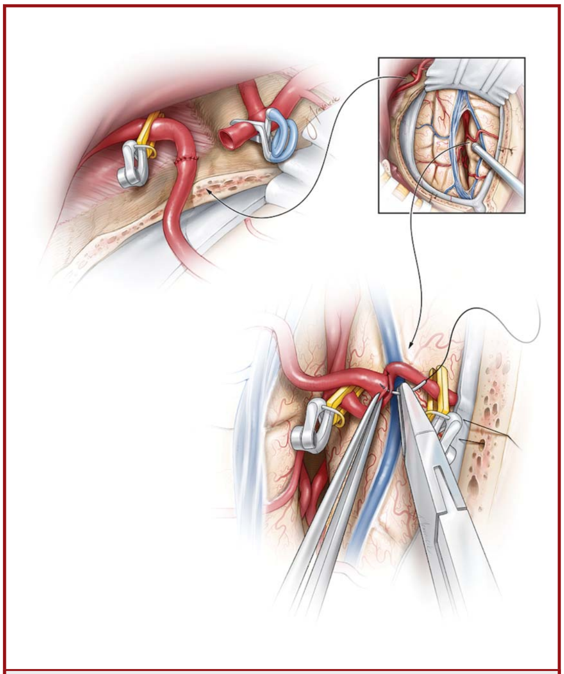

FIGURE 9. *Drawing of the proximal end-to-end anastomosis and a permanent clip on the distal internal maxillary artery and distal end-to-side anastomosis to the M3.*

filling was demonstrated from the SC-IC anastomosis into the M1 segment up to the clip, allowing flow into the lateral lenticulostriate arteries arising from this portion of the M1 segment.

One of the aneurysm patients in our series experienced postoperative swelling of the hemisphere after aneurysm embolization and underwent decompressive craniectomy. He ultimately underwent cranioplasty before discharge and recovered to his preoperative baseline.

DISCUSSION

Cerebral bypass has been used for many years for the treatment of cranial base tumors and giant aneurysms as well as for flow augmentation into hypoperfused cerebral hemispheres.[1-4,10] The 2 basic modalities of bypass are either EC-IC bypass or IC-IC (in situ) bypass.[11-13]

The most common EC-IC bypass is the STA-MCA bypass. In cases in which the target of the bypass is flow replacement, a higher flow bypass graft is often required.[14,15] In these cases, the cervical carotid artery is typically used as the donor site, using either a saphenous vein or radial artery as a graft vessel, which is then anastomosed to an appropriate recipient MCA branch.[1,2,14,16] This technique typically requires a graft in excess of 20 cm, which can be prone to kinking and subcutaneous compression. These grafts need to be safely tunneled from the neck to the cranial insertion site; alternatively, a long skin incision from the

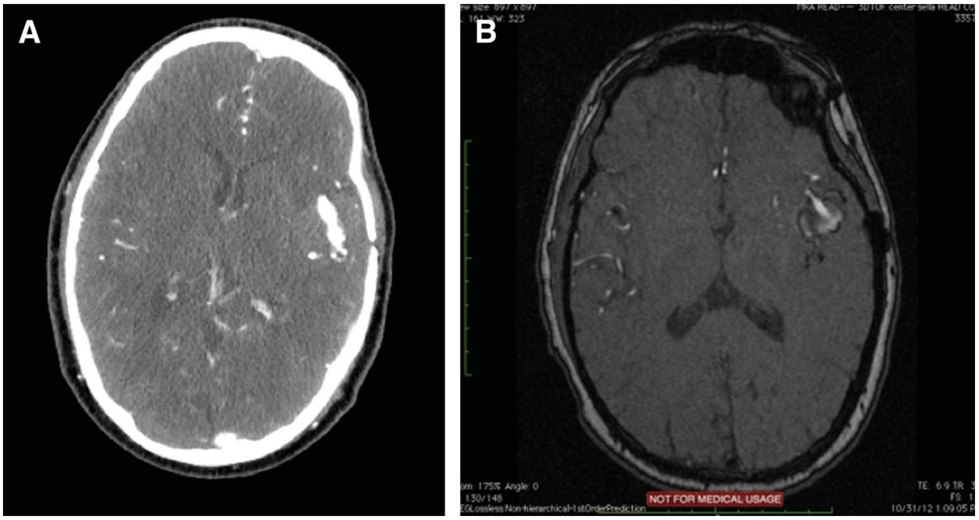

FIGURE 11. **A**, *computed tomography angiography of a patient with enlarging serpentine M2 aneurysm.* **B**, *magnetic resonance angiography demonstrates the thrombosed aneurysm and the flow into the aneurysm.*

craniotomy site down to the cervical carotid is required. Additionally, the 2 operative fields are not well visualized through a single operative microscopic view. The surgeon must move from neck to cranial exposure when performing the 2 anastomoses, and any graft complication is therefore managed with only a partial view of the totality of the graft length.

Imax-MCA (SC-IC) bypass as a high-flow EC-IC bypass option has been described in both cadaveric studies[6-9,17] and clinical microsurgical practice.[5] This bypass option is efficacious in cases that require high flow where the use of the cervical carotid as a donor is contraindicated (ie, after neck surgery or in the setting of occlusion of the common carotid artery).

The Imax-MCA bypass technique and the important modifications that we propose carry a number of distinct advantages over the conventional EC-IC bypass in which the cervical carotid artery

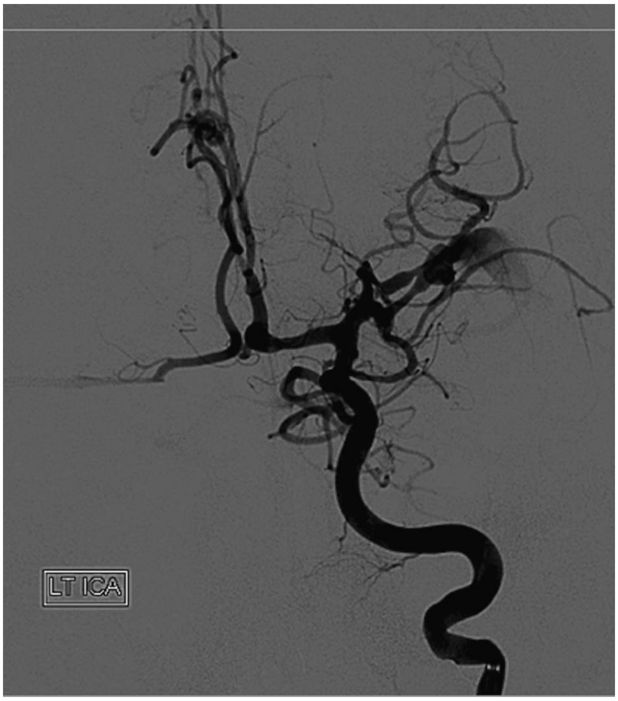

FIGURE 12. *Angiogram of the patient. A left internal carotid artery injection demonstrates a fusiform M2 aneurysm. Patient had had a previous fronto-temporal craniotomy for meningioma and had no superficial temporal artery.*

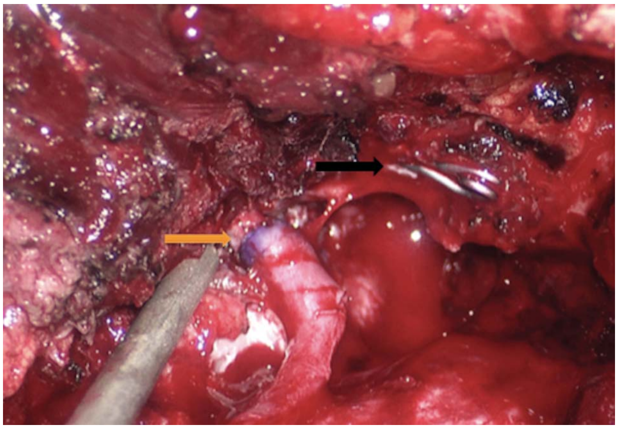

FIGURE 13. *A left-sided intraoperative image of the proximal end-to-end anastomosis of the internal maxillary artery (IMax) and the vein graft (orange arrow). The black arrow indicates the permanent clip on the distal IMax.*

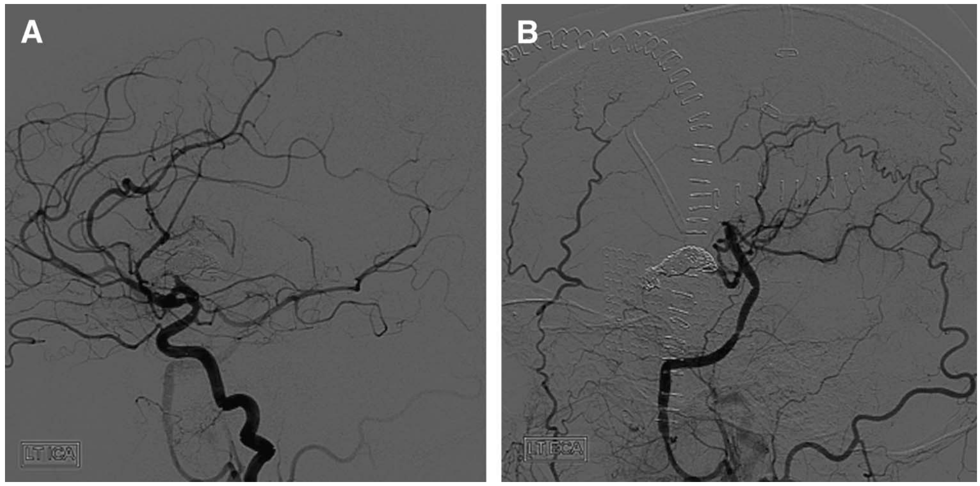

FIGURE 14. *Postoperative angiogram.* **A**, *an internal carotid artery injection demonstrates complete occlusion (no distal flow) of the aneurysm by coil mass.* **B**, *an external carotid artery injection demonstrates a patent bypass that fills the middle cerebral artery territory.*

is used as a donor. First, the SC-IC graft is significantly shorter (7-9 cm) than the typical length required when using the cervical carotid artery as a proximal anastomosis site. Although bypass length has not been described as a prognostic factor for bypass longevity, longer grafts are theoretically more prone to mechanical disruption such as kinking and compression. These grafts may have lower patency rates with lower flows. Short graft length permits the use of a brachiocephalic rather than a saphenous vein, and graft size can then be tailored more effectively to recipient size. The brachiocephalic vein has few, if any, valves, which improves overall donor quality. Additionally, potential upper extremity arterial complications that can be associated with radial artery are then avoided.[1,18,19]

An additional benefit of the SC-IC bypass technique is that the entire intracranial graft—both the proximal and distal anastomoses—is visualized within the same microsurgical field (Figures 16 and 17). This allows for immediate inspection of the graft, the proximal anastomosis site, and the distal anastomosis site simultaneously and thus improves the safety and efficiency of the operation.

Our modification of the previously described IMax bypass technique, in which the IMax was identified through a small

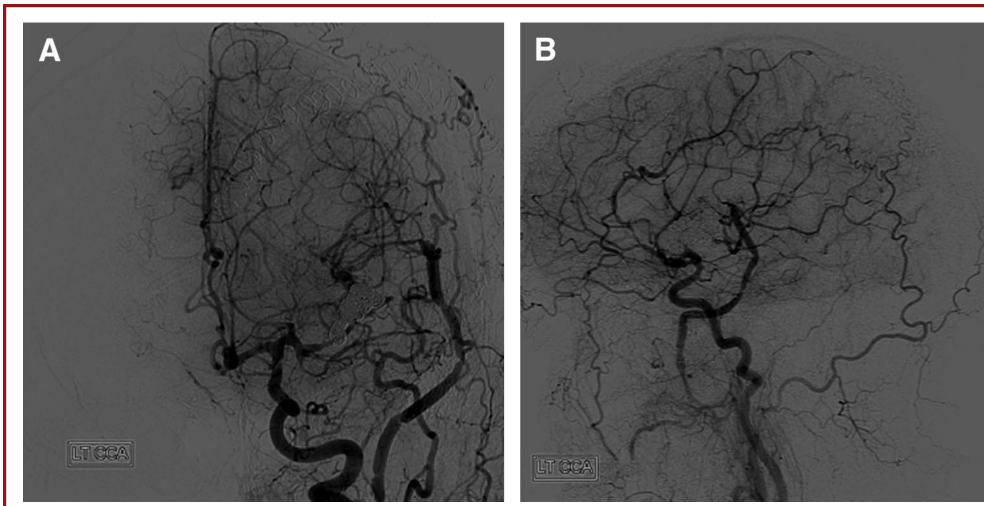

FIGURE 15. *Postoperative angiogram. Anteroposterior (***A***) and lateral (***B***) projections of a common carotid artery injection demonstrate a patent bypass and filling of the entire hemisphere.*

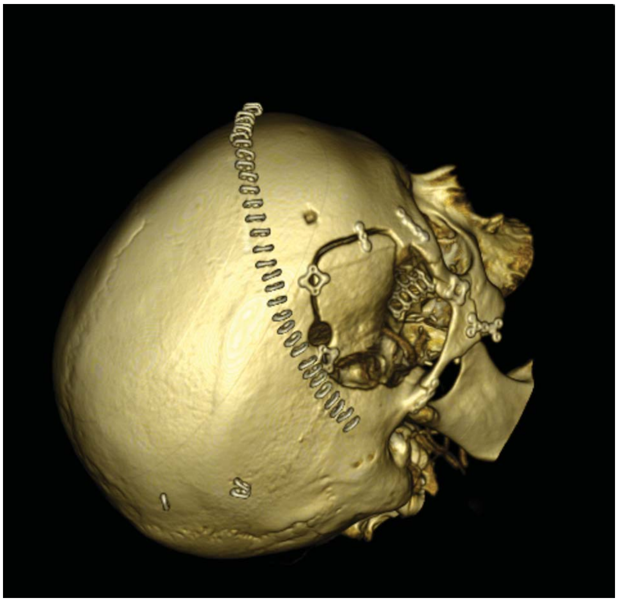

FIGURE 16. *A postoperative computed tomography 3-dimensional reconstruction of the cranium (from a second patient) that demonstrates the vein graft bypassing through the floor of the middle cranial fossa. Note the craniectomy at the base of the middle cranial fossa overlying the infratemporal fossa.*

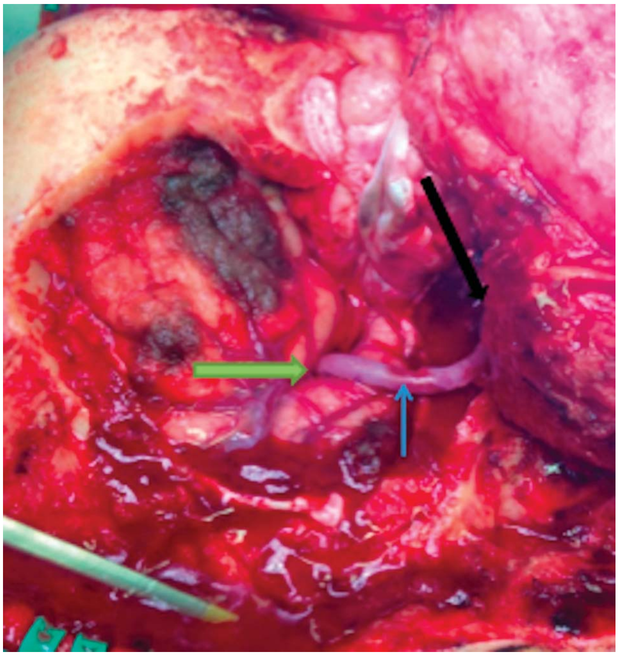

FIGURE 17. *Intraoperative image of a right-sided craniotomy. The final result demonstrates the vein graft (blue arrow) emerging from the infratemporal fossa (black arrow) into the sylvian fissure (green arrow) in the same operative field.*

middle cranial fossa floor window, represents a distinct technical improvement.[5] This original technique is highly demanding, requiring drilling in the anterior aspect of the floor of the middle cranial fossa and the subsequent end-to-side anastomosis through this small, constricted middle cranial fossa craniectomy. Precise localization and manipulation of the IMax through this small window can be tedious and time-consuming.

Our SC-IC technique modification used either a zygomatic osteotomy or orbitozygomatic osteotomy followed by a lateral rectangular craniectomy of the middle fossa. This modification allowed the IMax to be reliably anatomically identified over a considerable length of 15 to 20 mm. In cadaver dissections, we localized the IMax just anterior and parallel to the line between the foramen rotundum and foramen ovale. This experience allowed us to execute the craniectomy in situ up to this same line and then readily identify the vessel within the infratemporal fossa; this exposure then allowed for the performance of the anastomosis in an end-to-end fashion, Ultimately, we found that the completion of proximal anastomosis could be performed in a straightforward manner, with wide exposure and illumination of the IMax in the infratemporal fossa. There was no need for retractors throughout the procedure.

CONCLUSION

The Imax-MCA (SC-IC) bypass is safe and effective and has a number of advantages over the conventional EC-IC bypass using the cervical carotid. These advantages include (1) shorter graft length, (2) avoidance of a cervical carotid artery dissection and its attendant complications, (3) a microsurgical view of the entirety of the intracranial graft and both the proximal and distal anastomoses within the same field, (4) minimization of the risk of graft kinking and compression, (5) the ability to use a subcutaneous vein with easier graft sizing rather than the radial artery with its known risks, and (6) the use of a lateral temporal fossa rectangular craniectomy technique combined with a zygomatic osteotomy. This craniectomy was found to significantly improve the previously described anastomotic technique by allowing the IMax to be reliably identified, accessed, and then used as a proximal blood flow source without the need for significant drilling. We believe that this technique should be considered as a first choice for an EC-IC bypass in which the STA is either unavailable or inadequate relative to the flow required. We strongly advocate preparatory cadaveric dissection by the multidisciplinary team before microsurgical in vivo SC-IC bypass using the IMax.

Disclosure

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

REFERENCES

1. Sekhar LN, Duff JM, Kalavakonda C, Olding M. Cerebral revascularization using radial artery grafts for the treatment of complex intracranial aneurysms: techniques and outcomes for 17 patients. *Neurosurgery*. 2001;49(3):646-658.

2. Lawton MT, Hamilton MG, Morcos JJ, Spetzler RF. Revascularization and aneurysm surgery: current techniques, indications, and outcome. *Neurosurgery*. 1996;38(1):83-92.
3. O'Shaughnessy BA, Salehi SA, Mindea SA, Batjer HH. Selective cerebral revascularization as an adjunct in the treatment of giant anterior circulation aneurysms. *Neurosurg Focus.* 2003;14(3):e4.
4. Sundt TM Jr, Piepgras DG, Marsh WR, Fode NC. Saphenous vein bypass grafts for giant aneurysms and intracranial occlusive disease. *J Neurosurg.* 1986;65(4):439-450.
5. Abdulrauf SI, Sweeney JM, Mohan YS, Palejwala SK. Short segment internal maxillary artery to middle cerebral artery bypass: a novel technique for extracranial-to-intracranial bypass. *Neurosurgery*. 2011;68(3):804-808.
6. Büyükmumcu M, Ustün ME, Seker M, Karabulut AK, Uysal YY. Maxillary-to-petrous internal carotid artery bypass: an anatomical feasibility study. *Surg Radiol Anat.* 2003;25(5-6):368-371.
7. Eller JL, Sasaki-Adams D, Sweeney JM, Abdulrauf SI. Localization of the internal maxillary artery for extracranial-to-intracranial bypass through the middle cranial fossa: a cadaveric study. *J Neurol Surg B Skull Base.* 2012;73(1):48-53.
8. Karabulut AK, Ustün ME, UysalII, Salbacak A. Saphenous vein graft for bypass of the maxillary to supraclinoid internal carotid artery: an anatomical short study. *Ann Vasc Surg.* 2001;15(5):548-552.
9. Vrionis FD, Cano WG, Heilman CB. Microsurgical anatomy of the infratemporal fossa as viewed laterally and superiorly. *Neurosurgery*. 1996;39(4):777-785.
10. Amin-Hanjani S, Butler WE, Ogilvy CS, Carter BS, Barker FG II. Extracranial-intracranial bypass in the treatment of occlusive cerebrovascular disease and intracranial aneurysms in the United States between 1992 and 2001: a population-based study. *J Neurosurg.* 2005;103(5):794-804.
11. Dengler J, Kato N, Vajkoczy P. The Y-shaped double-barrel bypass in the treatment of large and giant anterior communicating artery aneurysms. *J Neurosurg.* 2013;118(2):444-450.
12. Nussbaum L, Defillo A, Zelensky A, Nussbaum ES. A short segment intracranial-intracranial jump graft bypass followed by proximal arterial occlusion for a distal MCA aneurysm. *Surg Neurol Int.* 2011;2:98.
13. Sanai N, Zador Z, Lawton MT. Bypass surgery for complex brain aneurysms: an assessment of intracranial-intracranial bypass. *Neurosurgery*. 2009;65(4):670-683.
14. Sia SF, Morgan MK. High flow extracranial-to-intracranial brain bypass surgery. *J Clin Neurosci.* 2013;20(1):1-5.
15. Amin-Hanjani S, Charbel FT. Flow-assisted surgical technique in cerebrovascular surgery. *Surg Neurol.* 2007;68(suppl 1):S4-S11.
16. Ashley WW, Amin-Hanjani S, Alaraj A, Shin JH, Charbel FT. Flow-assisted surgical cerebral revascularization. *Neurosurg Focus.* 2008;24(2):E20.
17. Ulku CH, Ustun ME, Buyukmumcu M, Cicekcibasi AE, Ziylan T. Radial artery graft for bypass of the maxillary to proximal posterior cerebral artery: an anatomical and technical study. *Acta Otolaryngol.* 2004;124(7):858-862.
18. Evans JJ, Sekhar LN, Rak R, Stimac D. Bypass grafting and revascularization in the management of posterior circulation aneurysms. *Neurosurgery*. 2004;55(5): 1036-1049.
19. Zhu YY, Hayward PA, Hadinata IE, et al. Long-term impact of radial artery harvest on forearm function and symptoms: a comparison with leg vein. *J Thorac Cardiovasc Surg.* 2013;145(2):412-419.

COMMENT

This is an interesting small technical case series with nice illustrations. For the open vascular subspecialist, it highlights an important nuance to a newer option for an extracranial-intracranial bypass, the internal maxillary–middle cerebral artery (IMax-MCA) bypass. Although the overall technique is not novel and the patient number is small, the authors demonstrate the feasibility of, and rationale for, using this modification. As originally described, the IMax-MCA bypass provides access to the donor artery through only a small opening in the middle fossa floor, which presents technical challenges. The nuance provided allows for better exposure and control of the donor artery and for end-to-end as well as end-to-side anastomosis.

Although the IMax-MCA bypass may represent a "slick" alternative to more traditional methods, indications for using it are probably very limited. When available, the superficial temporal artery (STA) is a technically easier bypass that does not require a separate graft harvest and can be used even for "high-flow" indications. I have advocated double-barrel STA-MCA bypass whenever feasible, and when both branches are used (one for the superior division and one for the inferior division), flows approaching 100 mL/min are possible in patients with robust arteries. Intracranial-intracranial bypass is also emerging as an attractive option in many cases and shares the benefits of short graft length and the lack of a cervical incision with the currently described technique.

Microvascular anastomosis, in whatever form it takes, remains an important skill for cranial neurosurgeons and should continue to be taught to our trainees. In the laboratory, synthetic kits, turkey wings, and rats are good models for early experience, and although a high level of trust is required, I have found that senior residents can safely participate in bypass surgery in the operating room.

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