

## M2/M2 Side-to-Side Rescue Anastomosis for Accidental M2 Trunk Occlusion during Middle Cerebral Artery Aneurysm Clipping: Technical Note

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**OBJECTIVE:** A technically feasible and rapid technique for revascularizing the main branches of the middle cerebral artery (MCA) is described. This technique is applied mainly when clipping of an MCA aneurysm is complicated and occlusion of the origin of an MCA main branch results.

**METHODS:** M2/M2 side-to-side anastomosis was applied in two patients in whom unplanned M2 occlusion occurred during the course of complicated MCA aneurysm clipping. The first patient underwent an emergency procedure after temporoparietal intracerebral hemorrhage. Unilateral mydriasis precluded preoperative angiographic workup, and a complex large MCA aneurysm was found as the source of hemorrhage. Shaping of the aneurysm neck by bipolar coagulation and clipping resulted in accidental occlusion of the superior trunk, and patency could not be regained despite multiple clip corrections. The second patient had an unruptured multilobulated aneurysm 8 mm in maximum diameter. Continuity of the inferior trunk was lost during clipping because of a tear at the origin. In both instances, side-to-side anastomosis was placed approximately 15 mm from the bifurcation, where the MCA main trunks ran side by side for a length of approximately 5 mm.

**RESULTS:** After intracerebral hemorrhage, the first patient recovered to a level of moderate disability within 2 months. Substantial hemiparesis and expressive dysphasia remained as sequelae of the intracerebral hemorrhage. Digital subtraction angiography 2 months after the emergency procedure confirmed patency of the side-to-side anastomosis. The second patient was neurologically intact after recovery from anesthesia. Before discharge from the hospital on postoperative Day 8, digital subtraction angiography confirmed patency of the anastomosis.

**CONCLUSION:** The MCA main branches usually run in close proximity for a short segment at the bottleneck entrance to the insular cistern. M2/M2 side-to-side anastomosis at this site is a rapid and feasible mode of revascularization of an M2 trunk accidentally occluded during complicated MCA aneurysm clipping. (Neurosurgery 49:743–748, 2001)

**Key words:** Cerebral aneurysm, Clipping, Middle cerebral artery, Revascularization, Side-to-side anastomosis

Occasionally, middle cerebral artery (MCA) aneurysms are multilobulated and have an ill-defined neck that defies clipping, even with the use of complex clip designs or multiple clips. During the course of MCA aneurysm clipping (e.g., if the origin of the branch is severed during manipulation), irreversible occlusion of an M2 trunk can occur. In the case of MCA main branch occlusion, initial consideration is given usually to a superficial temporal artery (STA)-to-MCA branch bypass. Because neither the donor nor the recipient arteries are dissected during a normal aneurysm procedure, the bypass takes a substantial amount of time and the ischemic tolerance of the dearterialized tissue is stretched. Connection of both main branches is a theoretically attractive technique; however, it is accompanied by the risk of a complete MCA territorial infarction in the case of failure. Because the arteries run parallel over a longer distance, the method of side-to-side anastomosis is an obvious technique for connecting the pericallosal arteries. Several case reports and small series have been published describing this (8, 9). Not as well known is that the MCA main branches usually join each other some distance behind the MCA main bifurcation and run parallel for a short distance. To our knowledge, the clinical application of M2/M2 side-to-side anastomosis for revascularization of an occluded MCA main branch has not been described. We encountered two instances of accidental M2 origin occlusion during clipping of complex MCA aneurysms. To prevent partial MCA territory infarction, M2/M2 side-to-side anastomosis was performed in both patients.

### CASE REPORTS

#### Patient 1

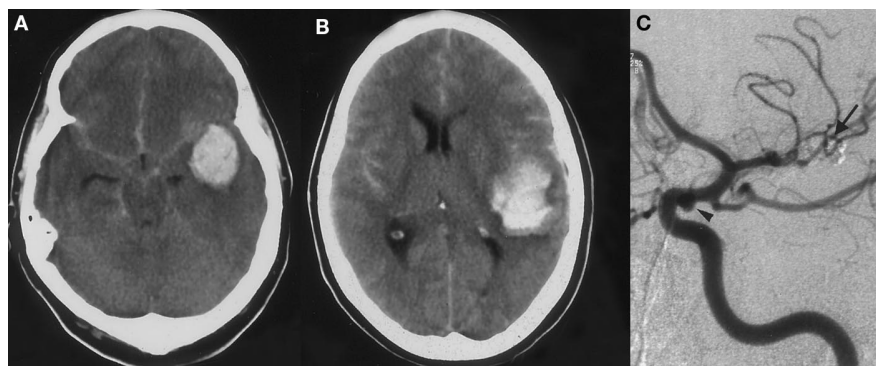
A 41-year-old woman with known arterial hypertension experienced the sudden onset of severe headaches associated with nausea. She sought the advice and treatment of her family physician, who prescribed analgesics. Six hours af-

ter the onset of symptoms, she collapsed in her bathroom. The emergency physician attending to her at her home found an unconscious patient breathing spontaneously and with normal pupillary responses. The patient's Glasgow Coma Scale score was 7. The patient regained consciousness during transport to the emergency room, and her Glasgow Coma Scale score reached 14; the systolic arterial pressure was 170 mm Hg. Computed tomographic scanning demonstrated subarachnoid hemorrhage predominantly in the left sylvian fissure and a limited temporopolar intracerebral hematoma. Because it was past midnight, it was decided to stabilize the patient's arterial pressure at the intensive care unit and to have the patient undergo angiography the following morning. At 2:00 AM, the patient suddenly lost consciousness and developed bilateral areactive mydriasis. After endotracheal intubation and the administration of 50 g of mannitol, repeat computed tomographic scanning confirmed suspected massive intracerebral rehemorrhage (Fig. 1) and the patient was taken immediately to the operating room. The patient was saturated with 1000 mg of thiopental, which was given

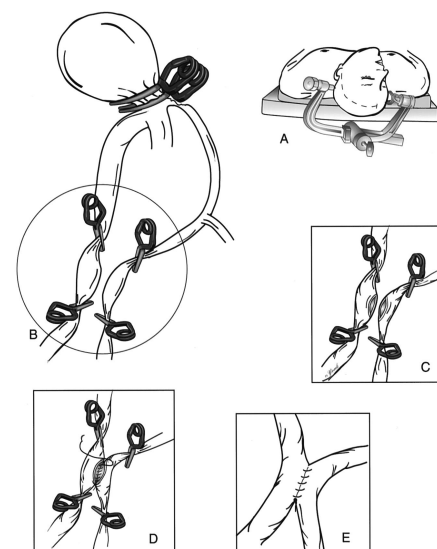
during a period of 15 minutes. When the patient arrived at the operating room, her right pupil had substantially decreased in size but left areactive mydriasis persisted.

Decompressive frontotemporal craniectomy was performed, and the hematoma was cautiously removed via the superior temporal gyrus after limited opening of the very tight dura. The source of hemorrhage was revealed to be a large, complex MCA aneurysm. One lobe of the aneurysm was buried in the temporal pole, and a second smaller lobe was situated in the sylvian fissure. After decompression and removal of the hematoma, the aneurysm began bleeding from its temporal aspect. The ruptured main portion of the aneurysm was clipped at that time with a large, straight Yaşargil titanium clip (Aesculap AG, Tuttlingen, Germany). The remainder of the aneurysm was completely dissected, and the MCA main trunk and its branches were identified. The superior main branch was integrated in the base of the secondary aneurysm lobe. A neck located at the base of the entire aneurysm was shaped via bipolar coagulation. It was then possible to isolate the entire aneurysm by using a large,

curved titanium clip. However, micro-Doppler ultrasound indicated no flow in the superior trunk. Several attempts to restore flow by adjusting the clip position were unsuccessful. It seemed that occlusion was a result of bipolar coagulation around the orifice of the superior trunk. After assessment of feasibility, it was decided to perform an M2/M2 side-to-side anastomosis (Fig. 2). The superior trunk was smaller in diameter than the inferior trunk and gave off a fronto-opercular branch immediately after its origin. The superior and inferior trunks ran in close proximity for a short segment at a distance of 15 mm from the



**FIGURE 1.** Patient 1. Preoperative computed tomographic scans (A and B) and postoperative angiogram (C). Repeat rupture of a suspected left MCA aneurysm produced a large temporoparietal intracerebral hematoma resulting in the patient having a Glasgow Coma Scale score of 3 and bilateral areactive mydriasis. The patient was taken to the operating room without angiography. After evacuation of the hematoma, a complex MCA aneurysm was identified as the origin of the bleed. Clipping of the aneurysm resulted in accidental occlusion of the superior M2 trunk. Revascularization was performed via M2/M2 side-to-side anastomosis. Postoperative angiography (C) demonstrated elimination of the MCA aneurysm and patency of the anastomosis (arrow). An unsuspected incidental internal carotid artery aneurysm (arrowhead) observed on angiography was clipped during the second procedure for replantation of the craniotomy flap, which had not been inserted during the primary emergency procedure.



**FIGURE 2.** Patient 1. Artist's view of M2/M2 side-to-side anastomosis for revascularization of the left superior M2 branch after accidental occlusion during emergency hematoma evacuation and clipping of a large aneurysm involving the origin of this artery. A, approach. B, perspective of the left MCA bifurcation after aneurysm clipping, resulting in accidental occlusion of the origin of the superior main branch. Branch occlusion was a consequence of manipulation and bipolar coagulation to shape the originally broad neck. Opposite segments of both M2 branches are already isolated between temporary clips in preparation for side-to-side anastomosis. C, placement of longitudinal arteriotomies. D, partially completed side-to-side anastomosis. E, completed anastomosis.

MCA main bifurcation. The superior trunk was mobilized to allow tension-free anastomosis. After isolation of the opposite segments of each branch between temporary aneurysm clips, strictly opposite longitudinal arteriotomies were placed and the arteries were anastomosed side-to-side with the use of running 8-0 polypropylene sutures. Patency of all arterial limbs was confirmed after recirculation via micro-Doppler ultrasound. The length of time for temporary clipping time was 18 minutes. Because of anticipated swelling, the dura was closed with a lyophilized fascia lata graft and the craniotomy flap was withheld for later replantation.

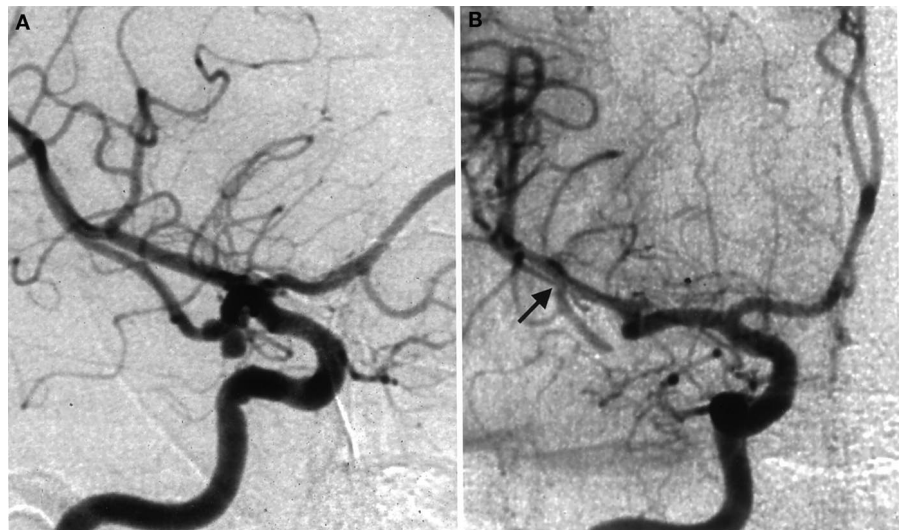
After closure of the craniotomy and transfer to the intensive care unit, the patient's pupils were equal and reactive. During the day, the patient moved the left extremities spontaneously and the right extremities moved in response to painful stimuli. Computed tomographic scanning 2 days after surgery demonstrated edema in the right hemisphere around the hematoma cavity but without significant midline shift. Transcranial Doppler ultrasound indicated moderate vasospasm in the left M1 segment during the next 2 weeks, with a maximum mean flow velocity of 145 cm/s. At 17 days after surgery, the patient was transferred to a rehabilitation unit, where she was extubated. She had a complete expressive and a partial sensory aphasia. She was able to move extremities of the left side spontaneously and the right extremities in response to pain. After 2 months, the patient was readmitted for control angiography and replantation of the bone flap. At that time, she had recovered well. She still had pronounced expressive dysphasia and paresis of the right arm but was able to walk with help and understood spoken language. Angiography confirmed adequate elimination of the MCA aneurysm and patency of the side-to-side anastomosis (Fig. 1). An unsuspected additional aneurysm 6 mm in diameter was observed on the left internal carotid artery at the origin of the posterior communicating artery. This aneurysm was eliminated during the subsequent procedure for replantation of the bone flap.

## Patient 2

A 55-year-old woman had undergone surgery for a ruptured left MCA aneurysm (World Federation of Neurological Surgeons Grade II, Fisher Grade II) 3 years before the present admission. Angiography at that time had also defined an incidental multilobulated aneurysm of the right MCA bifurcation measuring approximately 8 mm in maximum diameter. At this time, the patient decided to undergo preventive treatment of the aneurysm. Reangiography demonstrated no change in size or configuration of the aneurysm. The aneurysm projected inferolaterally and consisted of a larger lobe and a smaller lobe. The origin of the inferior trunk of the MCA bifurcation seemed to be closely associated with the smaller lobe (Fig. 3).

The aneurysm was approached via a small right sylvian craniotomy approximately 3 cm in diameter. The sylvian fissure was split, and both M2 branches were identified as well as the MCA bifurcation and the aneurysm. The aneurysm consisted of a main lobe projecting toward the temporal pole and a daughter lobe riding on the origin of the inferior trunk. The inferior trunk was smaller in diameter than the superior

trunk and gave off a small temporopolar branch 3 mm distal to the origin. Clipping of the aneurysm was attempted first by including both lobules into one straight titanium miniclip with a blade length of 6 mm. During application, the clip tore a small rent at the origin of the inferior main branch. A proper neck was then formed by bipolar coagulation, and the clip was shifted slightly higher on the neck. Unfortunately, these maneuvers resulted in irreversible occlusion of the orifice of the inferior trunk. No donor artery other than the superior main branch was available for potential revascularization. Both M2 branches ran parallel at a distance of 12 mm from the bifurcation. After assessing the technical feasibility, the decision was made to undergo a side-to-side anastomosis. Anti-ischemic protection was induced with 500 mg of thiopental initially followed by 100 mg every 3 minutes during temporary clamping. Corresponding segments 5 mm in length were isolated between temporary aneurysm clips. Strictly opposite longitudinal incisions of the arterial walls were fashioned, and the side-to-side anastomosis was sutured in an open manner with 8-0 polypropylene material. After completion of the anastomo-



**FIGURE 3.** Patient 2. **A**, preoperative angiogram demonstrating a bilobulated right MCA aneurysm. The diagnosis of this unruptured aneurysm was made in the context of a subarachnoid hemorrhage for which the patient had undergone surgery 3 years earlier because of a left MCA aneurysm. **B**, postoperative angiogram obtained 10 days after aneurysm clipping, showing accidental occlusion of the inferior trunk and demonstrating patent M2/M2 side-to-side anastomosis (arrow).

sis, the temporary clips were removed. The length of time for temporary clamping was 21 minutes. Micro-Doppler ultrasound confirmed patency of the anastomosis. The patient was neurologically intact after recovering from anesthesia 4 hours after termination of the procedure. On diffusion magnetic resonance imaging 2 days later, discrete spotty hyperintensity was demonstrated in the right temporal pole. Before the patient was discharged from the hospital, digital subtraction angiography confirmed patency of the anastomosis, although some kinking of the distal limb of the recipient branch was noted.

## DISCUSSION

### Indications for rescue revascularization

Occasionally, branch occlusion can be anticipated when clipping complex MCA aneurysms. If such an occurrence can be foreseen on the basis of preoperative angiography or after surgical exploration, several methods for preventive revascularization are possible and are described in the literature. Diaz et al. (4) described extracranial-intracranial STA-to-MCA branch bypass with or without venous interposition grafting. Spetzler and Owen (11) reported an STA-to-single MCA branch bypass in the management of a traumatic aneurysm. Bederson and Spetzler (3) published the case of a side-to-side anastomosis from the anterior temporal artery to a secondary trunk of the MCA for the treatment of a giant M1-segment aneurysm. Greene et al. (6) described the case of a giant serpentine MCA aneurysm in a 14-year-old boy who was managed in two stages, first by STA bypasses to distal MCA branches and second by proximal MCA occlusion. All of these reported procedures could be planned before MCA branch or trunk occlusion. If irreversible MCA branch occlusion occurs in an unplanned way during clipping of an aneurysm, it is less likely that the prognosis after revascularization will be good. Usually, the STA is not dissected; if available, it may not be of sufficient length for a bypass to the proximal MCA branches. The second M2 branch is the only constantly avail-

able donor artery within the area exposed for clipping of an MCA aneurysm. At first consideration, the use of the second MCA main branch as a donor artery seems unattractive because such a procedure may expose the patient to the risk of complete MCA infarction.

### Anatomic considerations

Gibo et al. (5) analyzed the microsurgical anatomy of the MCA in 50 cerebral hemispheres. They defined M1 as the sphenoid segment to the main bifurcation and M2 as the insular segments. M3 was defined as the opercular segments coursing over the frontoparietal and temporal opercula, respectively. The main trunk divided into two main branches in 78% of the specimens. A trifurcation was found in 12% and multiple branches were found in 10%. Of the MCAs with a bifurcation, the inferior trunk dominated in 40% and the superior trunk dominated in 35%; they were equal in 25%. Umansky et al. (12) analyzed the anatomy of the MCA branches in 70 unfixed hemispheres and paid special attention to the dimension of the proximal segments. The secondary trunks of the MCA were found to have a length between 12 and 15 mm and an outer diameter ranging from 1.4 to 2.3 mm. Artero et al. (1) assessed the feasibility to perform arterial reconstructive procedures within the sylvian fissure and succeeded with end-to-end, end-to-side, and side-to-side anastomoses on the MCA branches.

An important anatomic feature of the secondary trunks of the MCA is that they rejoin a short distance after the main bifurcation and run parallel for several millimeters. This constellation seems to occur because of the bottleneck of the insular cistern at the level of the limen. The two M2 segments ran in close proximity for approximately 5 mm in both patients described. In our experience with MCA aneurysms, such a pattern was found to be a general rule. Donor and recipient arteries of close proximity are necessary for side-to-side anastomosis. The classical constellation of parallel arteries is that of the pericallosal arteries, and side-to-side anasto-

mosis on these arteries has been described (8, 9).

### Methods of rescue revascularization

We used side-to-side anastomosis in both cases reported here. Alternatively, division of the occluded branch near its origin and end-to-side implantation into the donor M2 segment would be a feasible option. The reason we prefer side-to-side anastomosis is to preserve the primary branches of the recipient artery. However, side-to-side anastomosis may not be physiologically appropriate for small arteries, and there is a tendency for traction and kinking at the anastomotic site. Kinking was present in the first patient described. Ikeda et al. (7) described basic problems and technical details pertinent to microvascular side-to-side anastomosis. During experimental work on the common carotid arteries of rats, they determined that the best patency results were obtained with arteriotomies at least twice as long as the arterial diameter and in instances when the anterior wall was sutured in an interrupted manner. The tension on the suture line of a side-to-side anastomosis is larger than with other types of anastomosis, and a continuous suture harbors the danger of a pursestring effect leading to stenosis of the orifice. This danger can be minimized by close spacing of the stitches. To minimize the chance of traction and kinking, extensive mobilization of the recipient and donor artery seems imperative (2, 7, 10). If a gap remains between the two M2 branches, end-to-side anastomosis is mostly likely preferable, even if it is necessary to sacrifice the first branch of the recipient artery.

Mabuchi et al. (9) described the use of A3/A3 side-to-side anastomosis in the management of complex anterior communicating artery aneurysms. They graphically depicted both pericallosal arteries in one pair of temporary clips. Using this method, exact opposite positioning of the arteriotomies on each artery appeared difficult. In our opinion, it is important to use one pair of temporary clips for each artery (Fig. 2). This enables exact opposite placement of the arteries.

## CONCLUSION

The MCA main branches usually run in close proximity for a short segment at the bottleneck entrance to the insular cistern. M2/M2 side-to-side anastomosis at this site is a rapid and feasible mode of revascularization of an M2 main branch accidentally occluded during complicated MCA aneurysm clipping. The immediate availability of the donor artery is a distinct advantage over an extracranial-intracranial bypass. On the basis of our preliminary experience, the danger of ischemic infarction in the territory of the donor M2 branch seems to be remote. A word of caution is necessary with regard to the microvascular side-to-side anastomosis used. This anastomosis must be constructed in a completely tension-free fashion, and the arteriotomies should be twice as long as the diameter of the arteries. When there is doubt, the anterior aspect of the anastomosis should be performed with interrupted sutures to prevent a purse-string effect resulting in stenosis of the anastomosis.

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## COMMENTS

The authors describe a rescue technique of side-to-side anastomosis of two M2 branches to correct unforeseen branch occlusion occurring during middle cerebral artery (MCA) aneurysm surgery. The technique is similar to other reports for side-to-side anastomosis, especially of the anterior cerebral arteries. The concern with this strategy is the exposure of an intact arterial distribution to ischemia and, potentially, to infarction to help rescue an adjacent vascular territory that may already be irreversibly injured. In Patient 1 of this report, it is unclear whether the anastomosis improved the ultimate clinical outcome. In Patient 2, the outcome may have been improved but it is similarly unclear because the patient sustained a right temporal infarction. It is possible that the initially occluded segment had already produced an irreversible infarction that would have been clinically si-

lent, even before the side-to-side anastomosis. In any event, this type of rescue strategy is an important concept to incorporate into the aneurysm surgeon's armamentarium. Rare and unanticipated events could certainly arise where this type of approach would be the best treatment option.

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The authors report two cases that illustrate the fragility of our conceptual approach in preoperative planning in the treatment of some complex aneurysms. In the management of giant and complex lesions, unexpected findings occur in numerous cases and the loss of an arterial branch occurs with some degree of frequency. This report is timely and should serve as an alert to the generation of neurosurgeons coming out of training programs in the post-extracranial-intracranial bypass era. During the years of my training and early practice life, our institution performed approximately one microanastomosis per week. In current practice, these procedures are rarely performed for patients with ischemic disease and are almost always associated with complex aneurysmal disease or arterial injury during basal meningioma resection. It is very important for training programs and young surgeons to keep in mind that vessels will be lost from time to time during the management of these complex intracranial diseases. Surgeons must be technically proficient at performing microanastomosis in deep exposures to restore cerebral perfusion to vital territories. Innovative strategies such as that reported in this article should be kept in mind as we perform complex procedures. These concepts, however, must be bolstered by technical proficiency in the performance of these techniques. Ideally, this proficiency can be acquired and retained by repetitive practice in the microvascular laboratories.

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The authors present two cases in which clipping of a complex aneurysm of the MCA bifurcation resulted in oc-

clusion of a branch of the MCA. To salvage the affected vascular territory, the authors used M2/M2 side-to-side anastomosis approximately 1.5 cm distal to the bifurcation, where the vessels ran parallel and were in proximity to one another. The patency of the bypass was verified by intraoperative microvascular Doppler ultrasonography and postoperative angiography. The authors discuss the particular anatomic considerations pertinent to the local region and revascularization alternatives. Revascularization of the MCA for aneurysm surgery has been described. Particularly when large or complex aneurysms do not allow direct clipping, mobilization of a vascular pedicle for reperfusion of a distal territory may be necessary. Often, this vascular pedicle is derived from an extracranial source such as the superficial temporal artery or the middle meningeal artery. During the routine exposure of an MCA aneurysm, these vascular pedicles are not prepared for surgery, as was the case for Steiger et al. As a result and to minimize the duration of temporary ischemia, the authors opted to perform an in situ bypass, with the use of donor and recipient vessels that had already been exposed through their operative approach.

In situ bypass for cerebral revascularization can be used in anatomically amenable locations. Side-by-side donor and recipient vessels have been used in the distributions of the pericallosal and posteroinferior cerebellar arteries. In addition, as the authors aptly note, the anterior temporal branch of the MCA can be mobilized and used as a donor vessel to the distal MCA branches. Although we have used a variety of MCA branch anastomoses for bypass procedures, the authors document the first literature report in which an M2/M2 side-to-side anastomosis has been performed. For an in situ bypass to be feasible, several conditions must be met. The cerebral vessels in question must be close to each other so that the mobilization will not adversely affect their supplied vascular territories. Mobilization of the anterior temporal branch of the MCA will not result in a clinical neurological deficit. In the case of side-to-side anastomosis in the distributions of A2, the posteroinferior cerebellar artery, or M2, revascularization should not deprive the donor vessel or its vascular territory of cerebral blood flow. A mismatch in the blood flow or the caliber of the recipient and donor vessels must be avoided to prevent vascular steal that would deprive either the donor or the

recipient vascular territories of perfusion.

The authors used intraoperative cerebral protection during temporary clip occlusion. Mild hypothermia can also be employed for this purpose. At our facility, we routinely use intraoperative electroencephalographic monitoring to determine the effects of temporary clipping on distal cortical territories. The authors rightly state that an in situ bypass places the donor vessel and its vascular territory at risk. Instead of just one branch of the MCA being compromised, a complete stroke of the MCA becomes a risk. The authors justify their maneuver by the amount of time that would have been necessary to mobilize an extracranial donor vessel. In this instance, "time is brain." The authors used and provided a description of a novel variant of an in situ cerebral bypass. In the treatment of complex aneurysms involving the MCA, bypass pedicles are often planned and prepared from the extracranial circulation. When a branch of the MCA is inadvertently occluded, M2/M2 side-to-side anastomosis is an appealing alternative.

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