# Bypass or Not? Adjustment of Surgical Strategies According to Motor Evoked Potential Changes in Large Middle Cerebral Artery Aneurysm Surgery

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## Key words

- Aneurysm
- Motor evoked potential
- Vascular reconstruction

#### Abbreviations and Acronyms

BTO: Balloon test occlusion CT: Computed tomography DSA: Digital subtraction angiography EC-IC: Extracranial-to-intracranial MCA: Middle cerebral artery MEP: Motor evoked potential SEP: Sensory evoked potential

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#### **INTRODUCTION**

Postoperative cerebral infarction has been described as a major surgical complication after aneurysm surgery. Infarction is most often related to surgical procedures or postoperative vasospasm. Sasaki et al. (14) reviewed 1043 surgical cases of intracranial aneurysms and found that postoperative infarction occurred in 10.4%. Of these cases, 2.3% were related to vasospasm; 7.6% were related to inappropriate surgical manipulations; and 0.5% were related to angiography, embolism, and hypotension.

Because of the bifurcation location, irregular shape, large size, perforating arteries to the basal ganglia, or aneurysm type (e.g., dissecting aneurysms), direct clipping of large middle cerebral artery (MCA) aneurysms is often difficult and requires prolonged temporary occlusion of the parent artery. Giant aneurysms are often associated with intramural thrombus and sclerosis of the neck and feeding artery. According to Jaakko et al. (5), postoperative paralysis occurred in more than one-third OBJECTIVE: To report the use of neuroelectrophysiologic monitoring to alter the course in aneurysm surgery to minimize postoperative infarction and bypass-related adverse events.

METHODS: Two patients with large middle cerebral artery (MCA) aneurysms were admitted to the authors' hospital. Direct clipping seemed to be difficult, and postoperative paralysis was not rare in the authors' experience owing to prolonged temporal occlusion of the parent artery. Balloon test occlusion (BTO) was positive in one patient, who developed paralysis and aphasia 3 minutes after balloon occlusion of the feeding M1 artery. A bypass procedure seemed to be inevitable in both patients. Motor evoked potentials (MEPs) and sensory evoked potentials (SEPs) were used for monitoring during the operation.

■ RESULTS: For the patient with a positive BTO result, MEP waves did not change until 17 minutes after temporary clip placement. The aneurysm was clipped, and the occlusion time was 24 minutes. MEP waves recovered quickly after reperfusion. In the other patient, there were early changes in MEP waves after temporary clipping. After bypass construction from the temporal artery to the inferior M2 trunk, the time window of safe occlusion was prolonged to 7–8 minutes. Both the aneurysm and the bypassed branch were obliterated, and the clip reconstruction was done to preserve the flow from M1 to the superior M2 trunk. Permanent postoperative disability did not occur in either patient.

CONCLUSIONS: Intraoperative physiologic monitoring is a complementary method to preoperative BTO to evaluate the window of safe occlusion with high reliability.

of the patients. Extracranial-to-intracranial (EC-IC) bypass before clipping might decrease this number, but what are the indications for choosing revascularization surgery?

Neurophysiologic monitoring with sensory evoked potentials (SEPs) has been used for many years during cerebrovascular surgery to detect inadequate regional cerebral blood flow (15). Motor evoked potentials (MEPs) have shown superiority to SEPs in detecting functional disturbances of the pyramidal motor pathways in terms of both sensitivity and specificity (9). Combined use of MEPs and SEPs may provide a better outcome for complicated MCA aneurysm surgery. We report two cases of large MCA bifurcation aneurysms in which changes in MEPs and SEPs during the clipping process altered the course of surgical treatment. There was no permanent postoperative disability in either patient.

#### **CASE REPORTS**

#### Patient 1

An incidental intracranial mass was found on routine examination with magnetic resonance imaging in a 43-year-old man without any neurologic dysfunction. The diagnosis was later confirmed with digital subtraction angiography (DSA) as a giant left MCA bifurcation aneurysm (**Figure 1**). A balloon test occlusion (BTO) was done in the interventional radiology suite to test if the patient could tolerate occlusion dur-

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ing surgery. The balloon was placed and inflated in the left MI segment distal to the perforating arteries. Initially, the patient tolerated the procedure well, but 3 minutes later, aphasia and left-sided paralysis occurred. The balloon was deflated and removed at once, and the patient recovered to baseline in several minutes. Because of the failed occlusion test, an EC-IC bypass surgery was planned for this patient.

returned to normal in 4 minutes and 3 minutes after reperfusion.

After craniotomy, core body temperature was reduced to 32°C–34°C to decrease oxygen consumption during EC-IC bypass and clip reconstruction. During the operation, we found that the inlet and two outlets were located at the ipsilateral side of the aneu-

rysm, making it possible to do a clip reconstruction of the aneurysm without performing an EC-IC bypass. First, a temporary clip was placed on the left MI segment distal to the perforating arteries. Because of stable MEPs and SEPs, we proceeded to dissection of the neck of the aneurysm. Needle puncture and suction decompression were performed to facilitate dissection of the wall of the aneurysm from surrounding structures. However, MEP waveforms decreased by > 50% in amplitude at 17 minutes of occlusion, and they disappeared completely at 21 minutes of temporary clipping. SEP waveforms decreased by > 50% in amplitude but did not fully disappear at 20 minutes after temporary occlusion. Because of the late changes in MEP signals at 17–21 minutes and the partial but not complete loss of SEP signals, we continued the operation and placed three clips to remodel the aneurysm by clip reconstruction. After that, the temporary clip was removed. The occlusion time was 24 minutes, and reperfusion was 3 minutes after disappearance of MEP waveforms. MEPs and SEPs returned to normal in 4 minutes (MEPs) and 3 minutes (SEPs) after reperfusion.

The patient recovered uneventfully after the operation. There was no cerebral infarction on postoperative computed tomography (CT) scan. Postoperative CT angiography showed that the aneurysm had been totally obliterated.



extracranial-intracranial bypass route to the inferior M2 and then clipped the aneurysm and kept the blood flow from the M1 inlet to the superior M2 outlet (**F**, with schematic drawing at the upper right corner). Clip reconstruction was difficult, and we removed the temporary clips after MEP wave amplitudes were found reduced by > 50%; we replaced the temporary clips after the waves returned to baseline. The temporary clips were applied for 7–8 minutes each time, and MEP amplitudes returned to baseline about 5–6 minutes after clip removal. Eventually, we trapped the aneurysm, opened the wall of the aneurysm, and performed thrombectomy and endarterectomy to facilitate clip reconstruction. The temporary occlusion time was 21 minutes; MEP waveform amplitudes were reduced by > 50% at 5 minutes and disappeared at 21 minutes but recovered to their initial state 4 minutes after reperfusion. SEP waveforms were reduced by > 50% at 16 minutes, disappeared at 17 minutes (**E**, *yellow circle*, with details presented in the lower right corner), and recovered to their initial state simultaneously with MEP waveforms.

#### Patient 2

A 54-year-old woman was brought to the hospital after a car accident. No neurologic disability was found during the physical examination; however, axial CT scan revealed a lesion in the right lateral fissure. DSA showed a right MI bifurcation aneurysm (**Figure 2**).

As in the first case, mild hypothermia was used during surgery. The aneurysm was exposed via the left lateral fissure approach. The aneurysm had one inlet (left MI) and two outlets (superior and inferior M2). The MI and superior M2 were located on one side of the aneurysm, and the inferior M2 was located on the other side. We proceeded with clip reconstruction surgery by

first applying a temporary clip at the M1. MEPs decreased by nearly 50% in amplitude 4 minutes after temporary clipping. Because of these early changes and the apparent difficulty of the clip reconstruction, we decided to change the surgical course and proceeded to an EC-IC bypass first, followed by clip reconstruction. The EC-IC bypass was from the superficial temporal artery to the inferior M2 trunk, using a radial artery graft. The EC-IC bypass was accomplished uneventfully. Both the aneurysm and the bypassed branch were obliterated, and the clip reconstruction was done to preserve the flow from M1 to the superior M2 trunk. However, more difficulties were encountered. After clip placement, the blood

flow of the superior M2 trunk was found to be insufficient by intraoperative micro-Doppler. Clip repositioning was needed to achieve the reconstruction. We removed the clips after the MEP signals decreased by >50% in amplitude and replaced the clips after the waves returned. The changes in MEPs occurred 7 minutes after proximal temporary occlusion and returned to normal 6 minutes after the release of the temporary clips. This set of maneuvers was done twice. At this point during the surgery, an attempt to trap the aneurysm was made. We opened the wall of the aneurysm and performed a thrombectomy. We found that the aneurysm had severe thickening of arteriole intima, which had partially dissected

from the wall of the vessel. The lumen from M1 to the superior M2 tended to be occluded by the intima. We continued to perform the endarterectomy from M1 to the superior M2, to facilitate clip reconstruction. MEP signals decreased by > 50% in amplitude 5 minutes after trapping the aneurysm; in the following 16 minutes, no MEP monitoring was performed. Because releasing the trapping was impossible, the only remaining option was to complete the clip reconstruction as soon as possible. The SEP waveforms were reduced by 50% in amplitude at 16 minutes and disappeared completely at 17 minutes. MEPs and SEPs simultaneously recovered to baseline 4 minutes after reperfusion.

After the operation, the patient had transient contralateral paralysis, but she recovered completely I month later. Basal ganglia infarction was found on CT scan I2 hours after the operation, indicating blood flow insufficiency to perforating arteries during surgery. Postoperative CT angiography showed that the aneurysm had been totally obliterated, with fluent bypass flow from the superficial temporal artery to the inferior M2 trunk via the bridging radial artery.

## **DISCUSSION**

There are many ways to treat complex large or giant MCA aneurysms, including the multiclip method (2, 8, 13, 21), trapping with bypass (17, 20), and the combination of the two methods. Surgical maneuvers involved in the first method include dividing the neck and some part of the body of the aneurysm to avoid entrapment of any perforating arteries, aneurysm puncture and suction decompression, thrombectomy and sometimes endarterectomy, and clip reconstruction of the blood flow from the inlet to the outlet. Although some extremely effective methods of clip reconstruction have been recommended (2, 8, 13, 21), long-time temporary clip occlusion of the parent arterv and some branches is still inevitable in most cases. Because neither the "window" of safe occlusion nor the occlusion time needed to complete the clip reconstruction is predictable, the chances of ischemic stroke are unpredictable during operation.

In view of confirming the safety of the distal area of MCA, EC-IC or intracranialto-intracranial bypass provides a good alternative during the management of giant and large complex MCA aneurysms. The pros and cons of the bypass surgery are obvious: It provides a way to augment or replace the interfered blood flow, minimizing ischemic complications, but also adds surgical trauma while harvesting a bridging artery or performing the vascular anastomosis. The long time patency of the bridging artery is still a concern, and subsequent anticoagulation is prolonged in some patients.

For a lateral wall aneurysm, increased distal pressure after the bypass surgery might cause altered blood flow, resulting in thrombosis of the aneurysm. How can we know the optimal pressure and flow rate to achieve equilibrium in the aneurysm? At the bifurcation location, distal bypass flow is usually designed to one branch (8) and less commonly to both branches (20). The concern about optimal bypass pressure and flow rate still exists. To ensure a cure, direct clipping or trapping of the aneurysm is recommended after the bypass.

Bypass flow retains distal perfusion after proximal occlusion, prolonging the safe occlusion time. For an aneurysm with a branch derived from its dome or neck, such as in case 2, the upstream flow of this branch can be permanently replaced from the bridging artery. Both the aneurysm and the bypassed branch can be obliterated, and the clip reconstruction preserves the flow from MI to the other branch and the perforators. This maneuver is helpful to reduce the occlusion time of the parent artery.

If the aneurysm can be obliterated in the time window of safe occlusion, the patient can achieve a cure with less injury. Intraoperative neurophysiologic monitoring provides a reliable way to detect ischemia after temporal occlusion. In case 1, the aneurysm was able to be clipped during the operation because its inlet and both outlets were located on one side and the body of the aneurysm was located on the other side. The occlusion time was not long, and the patient tolerated the reduction of blood flow well under MEP and SEP monitoring. The bypass contingency should be routinely prepared for large or giant MCA aneurysms. Cantore et al. (3) reviewed 130 cases of giant intracranial aneurysms and concluded that surgical clipping ought to remain the "gold standard," with bypass reconstruction being the choice when direct clipping was contraindicated. When exactly is direct clipping "contraindicated," however, and bypass surgery "indicated"?

According to the available literature, BTO is recommended before the procedure. Temporal occlusion of an artery that may be sacrificed or occluded for a prolonged period is helpful to judge tolerance of these interventions. Because the patient is awake and not sedated, any symptomatic ischemic event can be assessed immediately. However, a false-negative rate of 5%-20% in BTO has been reported (7, 10, 16, 22). To predict the outcome of the occlusion test better, single photon emission computed tomography and induced hypotension are used with balloon occlusion test (11, 18). The available data from the literature are mainly focused on assessment of the permanent sacrifice of the internal carotid artery, and little is known about the result of temporal occlusion of the MCA during the operation. An anesthetic state and body temperature lowered to 32°C-34°C decrease oxygen consumption and presumably enhance the time window of safe occlusion. In addition to BTO, an intraoperative means of monitoring blood flow sufficiency is indispensable.

Generally, we divide the means of intraoperative monitoring of blood flow sufficiency into two categories: blood flow monitoring and functional brain monitoring. Blood flow monitoring includes intraoperative DSA, fluorography, microvascular Doppler ultrasound, and flow quantification with Charbel micro-flowprobe (1). However, decreased blood flow always occurs after temporary occlusion and can be partially compensated for by augmented collateral flow by increasing the mean arterial pressure by 20%-30% above its baseline. Increasing the mean arterial pressure may increase oxygen available for neuronal tissues. Monitoring of brain tissue oxygenation during aneurysm surgery has been reported (6) but has not been routinely used in clinical practice because of its inaccuracy, invasiveness, and limited area of monitoring on the superficial cortex.

Intraoperative monitoring of MEPs has been found to be safe and reliable for detecting intraoperative blood flow insufficiency in aneurysm surgery (4, 9, 19). In predicting early postoperative infarction, the sensitivity and specificity of any MEP change during operation are estimated to be 90.9%–100% and 84.3%–87.8%. Permanent loss of MEPs is associated with a positive predictive value of 20%-36.4% and negative predictive value of 87.1%-100%. Horiuchi et al. (4) evaluated the usefulness of MEP monitoring to detect blood flow insufficiency in the cortical branches of the MCA and lenticulostriate arteries during MCA aneurysm surgery in 53 patients. Transient MEP changes occurred in nine patients, and three patients had transient motor paresis. MEP waveforms disappeared and did not recover in one patient, and this patient developed severe paralysis. No other patient had a motor deficiency after operation.

In the first case we described, we had predicted that EC-IC bypass would be necessary for the patient because preoperative BTO was positive. Neurophysiologic monitoring in this patient did not change until 17 minutes after temporary clip placement, and the MEP waveforms recovered quickly after reperfusion. The other important reason we attempted direct clipping of the aneurysm was that we had found that the inlet and two outlets were located on the ipsilateral side of the aneurysm, and there was no obvious sclerosis of the aneurysm wall or the parent artery, making it feasible to clip the aneurysm directly.

The patient in the second case had infarction of basal ganglia on the ipsilateral side with temporary contralateral paralysis. Infarction in the internal capsule is more common than infarction in the cortex for paralyzed patients after aneurysm surgery (14). The perforators to the internal capsule might be from C4, anterior choroidal artery, A1, left subclavian artery, posterior cerebral artery, or their combinations (12). On average, there are 10 left subclavian arteries per hemisphere, and 80% of them arise from the prebifurcation part of the MI segment (12). If the medial group of the left subclavian artery is well developed and the temporal clip can be placed distally or if the blood supply of the internal capsule is mainly from other perforators, the time window of safe occlusion can be longer, just as case 1. However, blood supply from the lateral group of left subclavian arteries is indispensable in certain cases, and these patients must be quickly recognized after placement of the temporal clip. Neurophysiologic monitoring is a reliable way to recognize these patients. Trapping time is essential to be attributed to the ischemic insult of the basal ganglia. In case 2, although we tried our best to reduce the trapping time and we released the trapping clips several times according to the MEP and SEP changes, postoperative infarction of the basal ganglia still occurred.

The vulnerability of the basal ganglia to ischemic insult should always be fully recognized, and clinicians should do all they can to minimize that possibility. Monitoring using MEPs and SEPs is a reliable way to determine the danger. In case 2, MEP waves disappeared after we opened the aneurysmal wall to perform a thrombectomy. All we could do at that time was to accelerate the procedure to shorten the trapping time; all brain protection methods we could apply had been used in the patient. The postoperative state of transient motor disability corresponded to the transient MEP changes during the operation. The value of MEP and SEP monitoring in this patient was to realize the danger of ischemia of the motor pathway and to remind the operator to release the trapping clips if possible or accelerate the surgical procedure if the release of the clips had become impossible. Although we describe only two cases here, the MEP changes we observed occur frequently, and much information can be derived from them to adjust the therapeutic strategy.

# CONCLUSION

To bypass or not is still a question that poses a significant clinical dilemma because it is difficult to identify preoperatively patients who may need the bypass operation. The clinician can decide on a surgical plan of bypass first versus clip reconstruction directly only after testing for how long the patient can tolerate occlusion. Preoperative BTO and intraoperative physiologic monitoring are complementary methods to evaluate the window of safe occlusion. If longer continuous occlusion time is needed than the time tolerated during the BTO, owing to the morphology of the aneurysm, a construction of bypass flow to the distal branches is recommended before obliteration of the aneurysm. To our knowledge, this is the first study to use MEP changes as an intraoperative bypass indication. A controlled study design is required to confirm the true efficacy of MEP monitoring in large or giant MCA aneurysm surgery.

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