

# Monitoring of Somatosensory Evoked Potentials during Surgery for Middle Cerebral Artery Aneurysms

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Somatosensory evoked potentials (SEPs) were monitored during 53 procedures for aneurysms of the middle cerebral artery (MCA). "Significant" changes were reported to the surgeon, who took corrective action when possible. Changes in the SEPs were categorized as follows: *Type I*, no change; *Type II*, significant change with complete return to baseline; *Type III*, significant change with incomplete return to baseline; *Type IV*, complete loss with no return; and *Type V*, no response at baseline. Only 1 of 37 patients with a Type I SEP had a new neurological deficit, and this was a patient who could not be examined for several days after surgery because he was in a pentobarbital coma. All 4 patients with Type III and IV changes had new postoperative neurological deficits. Perhaps of greater importance, 4 of 5 patients with Type II changes had no new deficit. These patients all had changes in SEPs that were completely reversible by clip adjustment (2), prompt removal of temporary clips (1), and inducing hypertension after aneurysm trapping (1). These cases may, therefore, represent instances in which SEP monitoring allowed the clinicians to prevent a neurological deficit. The MCA supplies the area of the somatosensory cortex that controls the hand. Median nerve SEPs are, therefore, a theoretically ideal monitor during surgery for MCA aneurysms. This study suggests that the results of MCA aneurysm surgery may be accurately predicted and improved with SEP monitoring. (*Neurosurgery* 29:83-88, 1991)

**Key words:** Aneurysm, Evoked potentials, Intraoperative monitoring

## INTRODUCTION

Somatosensory evoked potentials were first described by Dawson (10) in 1947. The subsequent development of portable averaging computers led to the application of evoked potentials (EPs) in the evaluation of a wide variety of neurological disorders. Later, it became apparent that SEPs might have even greater utility as a monitor of patients under general anesthesia. Multiple publications have appeared specifically addressing their application to the monitoring of aneurysm surgery.

Unfortunately, SEP monitoring can only reasonably be expected to detect compromise of the somatosensory pathway. Many complications associated with aneurysm surgery (for example, coma after clipping of a basilar aneurysm) cannot, consequently, be reliably predicted with this technique. The superior branch of the middle cerebral artery (MCA) supplies the area of the somatosensory cortex that controls the hand. Median nerve SEPs would seem, therefore, to be a theoretically ideal monitor for MCA aneurysm surgery. To test this hypothesis, we undertook a retrospective review to assess the utility of SEP monitoring during MCA aneurysm surgery.

## METHODS

SEPs were monitored during 53 operations for MCA aneurysms performed at the University of Florida between September 1983 and March 1990. A total of 277 aneurysm procedures, including all locations, were monitored during this period. Only procedures performed during "elective" working hours were monitored. Procedures done at night or on weekends were not monitored. Five cases could not be analyzed because the anesthetic technique used totally obliterated the cortical EPs. The remaining 48 procedures were performed on 46 patients. The patients' average age was 47 years (range, 14-76 years). There were 29 women and 17 men. The locations of the aneurysms were as follows: left MCA, 16; right MCA, 25; bilateral MCA, 7. Fourteen patients also had aneurysms at other locations. The sizes of the aneurysms were as follows: 10 measured <5 mm; 25 were from 5

to 10 mm; 12 were from 10 to 25 mm; 3 were >25 mm; and the size of 3 was uncertain. The preoperative clinical grades, determined according to the Hunt and Hess classification (16), were as follows: Grade 0, 17 patients; Grade 1 or 1A, 15 patients; Grade 2, 6 patients; Grade 3, 5 patients; uncertain, 5 patients.

Induction of anesthesia was accomplished with thiopental, narcotics, and muscle relaxants. A balanced anesthetic consisting of a halogenated agent, narcotic infusion, oxygen with or without nitrous oxide, and a muscle relaxant was administered for maintenance of anesthesia. Induced hypotension was used in 16 cases. High doses of barbiturates were given to 6 patients. Pterional craniotomy was routinely used. Three patients were treated with trapping and extracranial-intracranial bypass. The remainder underwent direct aneurysm clipping.

Because of reluctance to subject patients with unclipped aneurysms to the stress of SEP recordings, preoperative studies were not performed. Immediately after the induction of general anesthesia, stimulating and recording electrodes were placed. Electrocardiogram pads were placed over the median nerves as stimulating electrodes, over Erb's point bilaterally, and over CII. Electroencephalographic electrodes were placed over F<sub>z</sub>, C<sub>z</sub>, C<sub>c</sub>, and C<sub>i</sub> (or as close as possible, depending on the surgical field). The median nerves were separately or sequentially stimulated using between 4.1 and 6.1 Hz, with 200 microsecond, constant current pulses of amplitude sufficient to produce a clear potential at the Erb's point electrode. A ground electrode was applied to the stimulated arm. Recording montages always included F<sub>z</sub>-Erb's point, F<sub>z</sub>-CII, C<sub>z</sub>-C<sub>c</sub>, and C<sub>z</sub>-C<sub>i</sub>. Electrode impedances were less than 2000 Ω. Filters were set at 10 Hz and 1000 Hz. The sweep time was 50 milliseconds, with 512 bytes/channel horizontal resolution, and 8-bit vertical resolution. Typically, 1000 repetitions were performed to produce each SEP.

SEPs were continuously recorded from the induction of anesthesia to skin closure. If only one extremity was stimulated, a change in cortical amplitude of more than 50% as compared with induction was considered "significant." If a "control" extremity was also used, a 50% decrease in amplitude compared with the control was considered "significant." The records were reviewed and graded as follows: *Type I*, no

significant intraoperative change: *Type II*, significant change with complete return to baseline; *Type III*, significant change with incomplete return to baseline; *Type IV*, complete loss of SEP with no return; *Type V*, no identifiable cortical responses at baseline, with a normal response from a control extremity, ruling out anesthetic effect. These SEP types were then correlated with the neurological examination at three points in time: before the operation, at the first postoperative examination, and at the discharge examination.

## RESULTS

In 32 patients, the findings of the preoperative neurological examination were either normal or there was a fixed cranial nerve deficit (8). Of these, 29 were found to be normal immediately after surgery; 26 had Type I intraoperative SEPs and 3 had Type II SEPs. Two other patients, both of whom had Type I intraoperative SEPs, awakened with new cranial nerve deficits, and one patient awakened with dense hemiparesis. His SEPs had been unremarkable during aneurysm clipping, but had suffered Type III changes during the same procedure when a parietal arteriovenous malformation was partially resected. The two remaining patients were treated intraoperatively with high doses of barbiturates. One patient experienced SEP changes (Type II) during surgery that reversed with hypertension. Postoperatively, she experienced several episodes of hemiparesis and aphasia, which also reversed with hypertension. The second patient who received barbiturates awakened with hemiparesis and aphasia. Examination suggested disappearance of flow through his saphenous vein bypass; this was subsequently confirmed by an angiogram on the second postoperative day, coincident with his first possible postoperative neurological examination.

Sixteen patients had preoperative motor and/or sensory deficits. Thirteen of them were unchanged postoperatively: 11 had Type I SEPs and 2 had Type V SEPs. Three patients had increased motor/sensory deficits postoperatively. Of these, two had Type IV SEP changes, and the other had no change during aneurysm clipping, but Type II changes during concurrent resection of an arteriovenous malformation (this patient had a very mildly increased deficit). Three patients suffered delayed ischemic neurological deficits that were felt secondary to vasospasm. All of these patients had Type I SEPs.

The correlation of SEP changes with new immediate postoperative deficits is presented in Table 1. Specific case examples are given below.

TABLE 1  
Correlation of Postoperative Neurological Examination and Type of Somatosensory Evoked Potentials

Type of Somatosensory Evoked Potential <sup>a</sup>	Postoperative Neurological Examination	
	Normal/Unchanged	Increased Deficit
I	36	1 <sup>b</sup>
II	4	1 <sup>c</sup>
III	0	2
IV	0	2
V <sup>d</sup>	2	0

<sup>a</sup> Type I, no change; Type II, significant change with complete return to baseline; Type III, significant change with incomplete return to baseline; Type IV, complete loss with no return; Type V, no response at baseline.

<sup>b</sup> Deficit probably occurred long after cessation of SEP monitoring (see Discussion section).

<sup>c</sup> Mild increase in preoperative deficit.

<sup>d</sup> These cases are "unmonitorable" because of the absence of a baseline SEP.

### Case 1: Type V somatosensory evoked potentials

A 40-year-old woman was seen 3 weeks after she suffered a severe subarachnoid hemorrhage from a right MCA aneurysm. Her neurological examination was remarkable for dense left hemiparesis and left central facial paresis. All sensory modalities were decreased over the left half of the body. Her SEPs at the induction of anesthesia showed normal Erb's point and cervical responses bilaterally, absent right cortical responses, and normal left cortical responses (Fig. 1). Her SEPs remained unchanged throughout surgery. The patient was subsequently discharged in unchanged neurological condition.

### Case 2: Type IV somatosensory evoked potentials

This 68-year-old woman had a Grade III subarachnoid hemorrhage secondary to a left MCA aneurysm. She underwent craniotomy. During bone plate removal, her left cortical SEPs disappeared (Fig. 2). When the dura was opened, it was obvious that an intraoperative rupture of the aneurysm had occurred. A large intracerebral hematoma was partially evacuated and the aneurysm clipped. Postoperative neurological examination revealed right hemiparesis and obtundation. A second craniotomy with further removal of the hematoma did not result in improvement. She subsequently died of a pulmonary embolus.

### Case 3: Type III somatosensory evoked potentials

This 44-year-old woman had a Grade III subarachnoid hemorrhage secondary to a left MCA aneurysm. The aneurysm ruptured during dissection. Temporary clips were used to control the hemorrhage, complete the dissection, and accomplish the clipping. The left cortical SEP decreased substantially during this period and did not return to baseline (Fig. 3). The patient awakened with severe right hemiparesis and dysphasia. A postoperative computed tomographic scan suggested a hemorrhagic infarction of the left MCA.

### Case 4: Type II somatosensory evoked potentials

This 62-year-old woman had bilateral Grade 0 MCA aneurysms for which she underwent left craniotomy. After placement of an aneurysm clip, the left cortical SEP abruptly disappeared (Fig. 4). The clip was readjusted and the SEP returned to normal. The patient was normal postoperatively and was subsequently discharged without complication. Her right MCA aneurysm was later clipped without difficulty.

### Case 5: Type I somatosensory evoked potentials

This 39-year-old man had a Grade 0 right MCA aneurysm and underwent craniotomy. After the induction of anesthesia, no SEPs (Erb's point, cervical, or cortical) could be obtained from the right

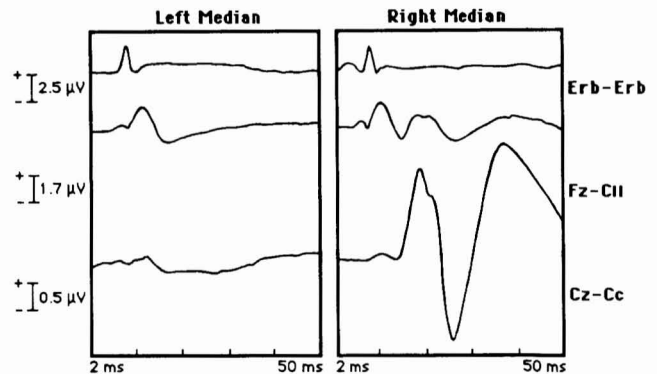


FIG. 1. The SEP from stimulation of the right median nerve shows a normal Erb's point, cervical, and cortical response. The SEP from stimulation of the left median nerve shows a normal Erb's point and cervical response. This verifies signal entry into the central nervous system. No cortical response is seen in this patient, who had a severe left sensory and motor deficit.

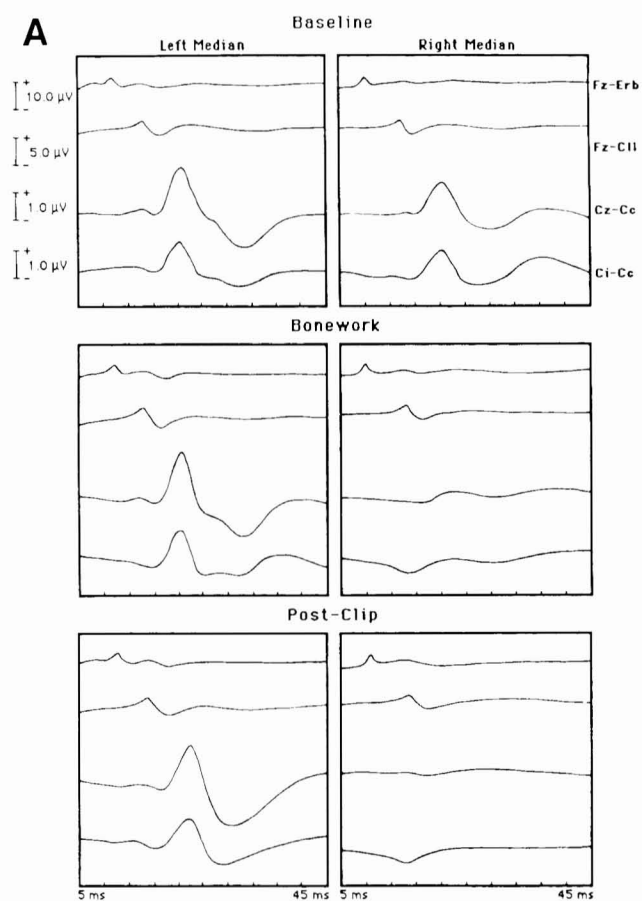


FIG. 2. *A*, sequentially recorded SEPs from stimulation of the left and right median nerve are displayed. The SEPs from the left median nerve (control) remained normal throughout surgery. The Erb's point and cervical potentials from stimulation of the right median nerve also remained intact. During craniotomy, however, the cortical potentials disappeared. They did not return (Type IV SEP). *B*, a subsequent computed tomographic scan revealed a massive intracerebral hematoma severely compressing the sensorimotor pathways in the left hemisphere.

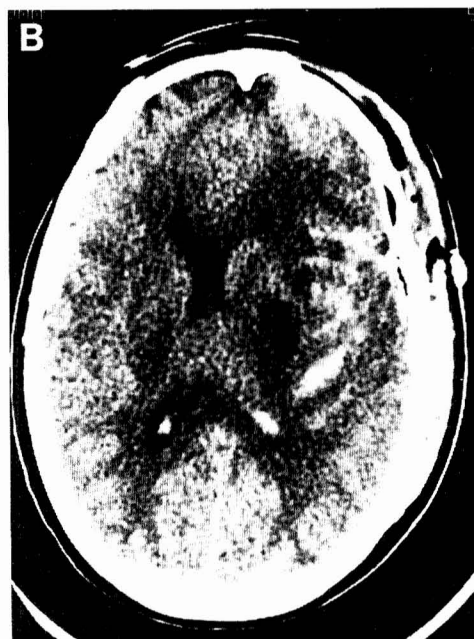
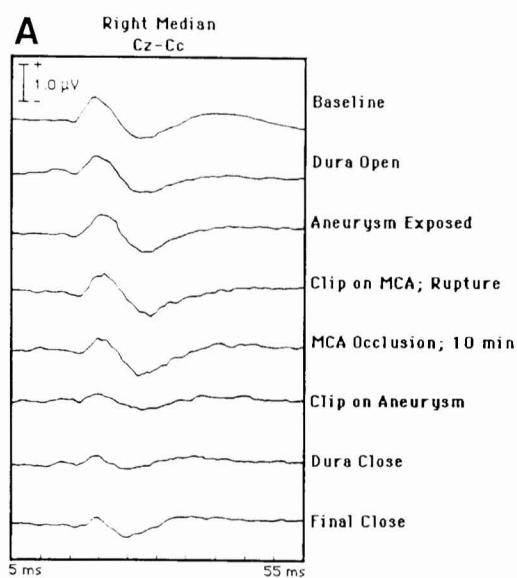


FIG. 3. *A*, the cortical potential from stimulation of the right median nerve significantly (>50%) decreased after aneurysm clipping. The Erb's point and cervical responses remained unchanged (not shown). At the time of closure, the potential had returned, but incompletely. The patient was found to have severe right hemiparesis and dysphasia. *B*, a subsequent computed tomographic scan showed a partially hemorrhagic, mass-producing lesion in the MCA distribution, most consistent with hemorrhagic infarction. A postoperative angiogram was not performed.

median nerve (Fig. 5). Since all components of the SEP were absent, it was clear that the signal was not getting into the central nervous system. Investigation of the stimulus site revealed that the automatic blood pressure cuff had malfunctioned in the inflated position, leading to ischemia of that arm. The cuff was deflated, leading to prompt appearance of the SEP. The patient was normal postoperatively.

DISCUSSION

Improvements in microsurgical techniques have greatly reduced the morbidity and mortality of aneurysm surgery. Im-

FIG. 4. Cortical SEPs from stimulation of the left median nerve (control) remained normal throughout this case. Immediately after clipping, the cortical potential from stimulation of the right median nerve disappeared. The surgeon was alerted, and the clip adjusted. The SEP promptly returned (Type II SEP) and the patient awakened without deficit.

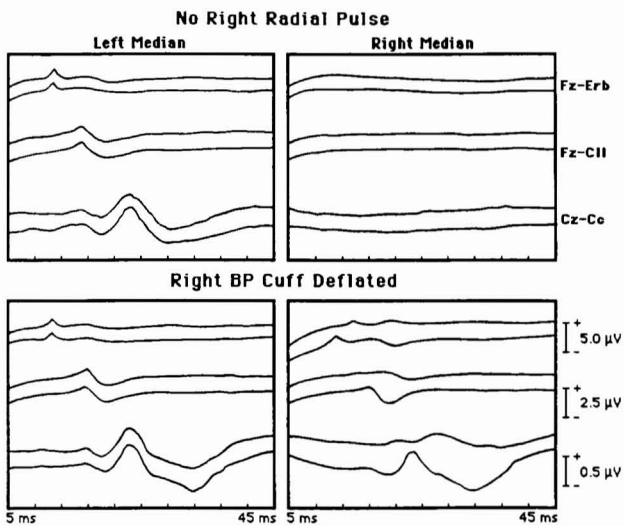
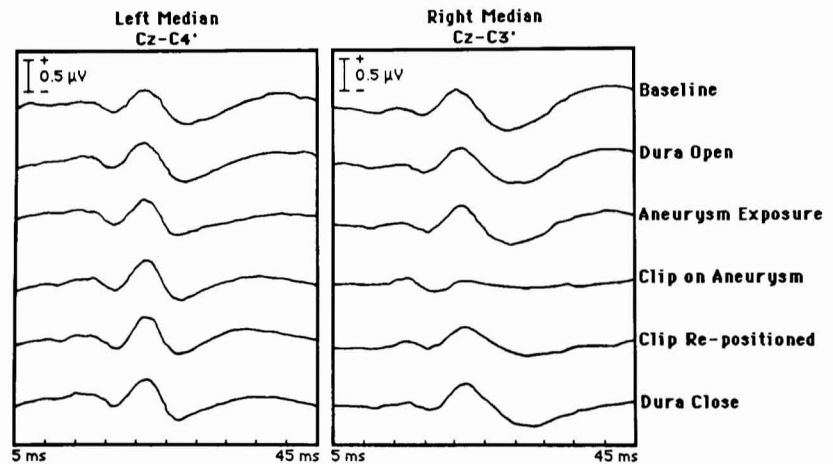


FIG. 5. Erb's point, cervical, and cortical responses were easily obtained from stimulation of the left median nerve. No responses could be obtained from stimulation of the right median nerve, however. The absence of an Erb's point response suggested that the signal was not entering the nervous system. Inspection of the stimulation site revealed a malfunctioning blood pressure cuff causing right arm ischemia. With deflation of the cuff, the SEP normalized. In this case, a potential ischemic arm injury was averted through SEP monitoring. Even a Type I SEP can, therefore, be of benefit!

mediate postoperative deficit secondary to inadvertent occlusion of a major vessel or small perforating artery remains, however, a feared complication. This is also true when long periods of temporary clipping or hypotension must be utilized (34). An intraoperative monitoring technique that would provide an accurate warning of cerebral ischemia would, theoretically, reduce the incidence of these problems.

A large body of experimental data exists to support the use of SEPs as a monitoring tool in patients with cerebral ischemia. In a series of experiments, Symon and colleagues (15, 18, 30) have demonstrated that median nerve EPs are affected at cerebral blood flows of 15 ml/100 g/min after acute occlusion of the middle cerebral artery in the baboon. SEP changes also correlate with blood flow changes after experimental head trauma and global ischemia (9, 13, 20). Others have reported similar findings in different animal models (23, 28). Branston and colleagues (3, 4, 5) also showed that irreversible changes in cellular metabolism, including failure of the sodium-potassium pump, occur at a lower threshold (approximately 10

ml/100 g/min). Mitochondrial electron transport is affected at approximately the same level (34). The concept of an ischemic "penumbra" wherein blood flow is below that required for synaptic activity, but above that needed for basic cellular metabolism, was popularized by Astrup and colleagues (1, 2). The fact that changes in SEPs occur at higher levels of blood flow than are necessary for cellular survival is crucial to their use as a monitoring tool.

In the past decade, a number of investigators have reported their experience with EP monitoring during aneurysm surgery. Symon's group first suggested their utility in a report of 33 monitored cases in 1984 (27, 32, 33). In subsequent reports, they have suggested that factors predicting postoperative neurological deficit include speed of disappearance and reappearance of the  $N_{20}$  (24, 31). If the SEP persisted for 3 to 4 minutes after arterial occlusion and/or recovered within 20 minutes of unclamping, permanent deficit was rarely seen. Carter et al. (7), Hyman et al. (17), McPherson et al. (22), Nakasu (23), and Grundy (14) also reported early experiences with SEP monitoring in small numbers of aneurysm patients.

Buchthal and colleagues (6) reported their successful experience with SEP monitoring during temporary clipping for aneurysm surgery in 25 patients (including 15 with MCA aneurysms). In another study, they used SEP monitoring during temporary clipping for 5 large MCA aneurysms (25). In no case was occlusion continued for more than 3 minutes in the presence of a severely disturbed SEP. No patients had postoperative deficits. Ducati et al. (11) used SEP monitoring during 50 aneurysm procedures (including 12 involving the MCA). They found that a central conduction time (CCT) greater than 9 milliseconds correlated with postoperative deficits. Kidooka et al. (19) used SEP monitoring during 31 aneurysm procedures (10 involving the MCA). They found that prolongation of the CCT by 1.2 milliseconds or disappearance of the  $N_{20}$  peak predicted postoperative deficit in 8 of 13 patients (62%).

Friedman et al. (12) reported, in 1987, on 50 aneurysm patients in whom EPs were monitored. Postoperative deficits were accurately predicted in patients with prolongation of the CCT, decrease in cortical amplitude, or disappearance of the EP wave form. Basilar aneurysms were not accurately monitored by either SEPs or brain stem auditory evoked potentials. Similar difficulties with monitoring during procedures for basilar aneurysms were reported by Little et al. (21). Schramm et al. (29) reported on their experience with EP monitoring in 134 aneurysms of various types (40 involving the MCA). Significant SEP changes were found in 12 cases of temporary clipping, in 2 cases of accidental occlusion, and in one case each

of retraction of the cerebellum, retraction of the MCA, and intentional permanent vessel occlusion. Response to these changes included reapplication of aneurysm clips, repositioning of retractors, or removal of temporary clips. Conversely, stable SEP signals during 13 procedures allowed the surgeon to proceed with the surgical course. In another report, this group described trapping and excision of an MCA segment (8). Preservation of the SEP accurately predicted the absence of postoperative neurological deficit. They suggested that EP monitoring was helpful in procedures for aneurysms where the pathway monitored was at risk.

We believe that this concept—that the pathway monitored must be at risk—is indeed crucial to the success of EP monitoring of any surgical procedure. For example, Momma et al. (24) reported that temporary occlusion of the A1 segments in five patients led to no change in the median nerve CCT. This is almost certainly because the anterior cerebral complex does not supply any portion of the brain serving the median nerve somatosensory pathway. Other investigators (14, 29) have suggested that posterior tibial nerve SEPs would be more appropriate for aneurysms of the anterior cerebral complex because the anterior cerebral artery does supply the areas of the somatosensory cortex controlling the foot and leg. Likewise, basilar aneurysms may not be effectively monitored with SEPs or brain stem auditory evoked potentials because basilar perforator occlusion, although devastating to consciousness, may not embarrass either the somatosensory or auditory pathways.

Median nerve SEPs may be an ideal monitor during surgery for MCA aneurysms because the MCA supplies the area of the somatosensory cortex that controls the hand. This series represents an effort to analyze the accuracy and utility of EP monitoring in a large number of these aneurysms. In all but two patients, the neurological outcome was correctly predicted by the monitor. The first of these patients could not be examined for 2 days because he was in a pentobarbital coma. At the time his hemiparesis was recognized, his saphenous vein graft was also found to be occluded. It is entirely possible, therefore, that this deficit occurred long after cessation of SEP monitoring. The second patient suffered a very mild increase in a preexisting motor deficit. No new language deficits were observed immediately after surgery in this series. We do not believe that such deficits (as they are not somatosensory) are likely to be predicted by SEP monitoring.

Most importantly, five patients had significant changes in their SEPs that were reversible during surgery (Type II). One patient, as mentioned above, awakened with a mildly increased motor deficit. In two patients, the aneurysm clip was repositioned more distally on the aneurysm neck—presumably relieving the compromise of the parent artery—causing the prompt return of the SEP. In one case of intraoperative aneurysm rupture, temporary clips were placed. Three minutes later, the SEP disappeared. The aneurysm was promptly clipped, with removal and temporary clips and return of the SEPs 6 minutes later. The final patient underwent trapping of a fusiform aneurysm, with superficial temporal artery to middle cerebral artery bypass grafting. It was found during surgery that the SEP deteriorated below a mean arterial pressure of 90 mm Hg. Postoperatively, the patient had several episodes of transient aphasia and hemiparesis, which resolved totally with induced hypertension. Eventually she was weaned from all drugs and discharged in normal condition.

In this series, SEP monitoring proved extremely accurate as a predictor of postoperative neurological function. In addition, at least some of the Type II patients likely benefited from intraoperative adjustments that would not have been possible without the warning provided by SEP monitoring. We view

SEP monitoring as a valuable adjunct to successful MCA aneurysm surgery.

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