Monitoring of muscle motor evoked potentials during cerebral aneurysm surgery: intraoperative changes and postoperative outcome

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Object. The authors in this study evaluated muscle motor evoked potentials (MMEPs) elicited by transcranial electrical stimulation (TES) and direct cortical stimulation as a means of monitoring during cerebral aneurysm surgery. The analysis focused on the value and frequencies of any intraoperative changes and their correlation to the postoperative motor status.

Methods. One hundred nineteen patients undergoing surgery for 148 cerebral aneurysms were included in the study. Muscle motor evoked potentials were elicited by a train of five constant-current anodal stimuli with an individual pulse duration of 0.5 msec and a stimulation rate of 2 Hz. Stimulation intensity was up to 240 mA for TES and up to 33 mA for direct cortical stimulation. The MMEPs were continuously recorded from the abductor pollicis brevis and tibialis anterior muscles bilaterally and from the biceps brachii and extensor digitorum communis muscles contralateral to the surgical side. The motor status was evaluated immediately after surgery and 7 days later.

In 97% of the patients MMEPs were recordable for continuous neurophysiological monitoring of the vascular territory of interest throughout the surgery. In 14 patients significant intraoperative MMEP changes occurred, resulting in a transient motor deficit in one patient and a permanent motor deficit in six. The permanent loss of MMEPs in three patients was followed by a permanent severe motor deficit in one patient and severe clinical deterioration in the other two.

Conclusions. Data in this study demonstrated that MMEPs are a useful means of intraoperative neurophysiological monitoring of motor pathway integrity and predicting postoperative motor status. The intraoperative loss of MMEPs reliably predicts both severe and permanent postoperative motor deficits.

Key Words • cerebral aneurysm • direct cortical stimulation • intraoperative monitoring • motor evoked potential • motor outcome • transcranial electrical stimulation

Postoperative motor deficits following neurosurgical procedures result in significant morbidity and mortality rates as well as increased medical costs associated with an extended length of stay and rehabilitation. The multipulse electrical stimulation technique for intraoperatively eliciting MMEPs introduced in the early 1990s opens the possibilities for both the prevention and documentation of motor deficits and represents a significant advantage, given that postoperative motor deficits can occur without changes in SSEPs. Therefore, MMEPs have become the modality of choice for intraoperative monitoring of the motor pathways.

Abbreviations used in this paper: ACA = anterior cerebral artery; ACoA = anterior communicating artery; BA = basilar artery; CT = computed tomography; ICA = internal carotid artery; MCA = middle cerebral artery; MMEP = muscle motor evoked potential; MRC = Medical Research Council; PCA = posterior cerebral artery; PCoA = posterior communicating artery; PICA = posterior inferior cerebellar artery; SAH = subarachnoid hemorrhage; SSEP = somatosensory evoked potential; TES = transcranial electrical stimulation.
as the technology becomes more popular and as the expertise increases. Nevertheless, the use of MMEPs in supratentorial vascular procedures remains uncommon.12–14,17,20 The purpose of the present study was to correlate the changes in MMEP parameters (elicited by TES and direct cortical stimulation) with the postoperative motor status and neuro-radiological imaging findings in a large group of patients undergoing aneurysm surgery.

Clinical Material and Methods

Patient Population

One hundred nineteen consecutive surgeries performed under intraoperative neurophysiological monitoring were included in this study. Data from 76 patients were analyzed retrospectively and those from 43 were analyzed prospectively from the date of opening this study. The patients consisted of 89 women and 30 men, who ranged in age from 9 to 85 years (mean 51.2 ± 15.8 years, median 53 years, mean male age 41.5 ± 14.4 years, and mean female age 53.9 ± 14.7 years). Sixty-seven patients presented with incidental aneurysm findings. Fifty-two patients had suffered an SAH, and 14 of these underwent aneurysm clipping within 72 hours of the SAH. In another 14 patients surgery was performed within 4 to 14 days after SAH. For logistic reasons, only patients undergoing surgery during working hours were included in our analysis. Informed consent was obtained from all patients or their relatives before surgery. The local ethics committee approved the study protocol.

Neurophysiological Monitoring Methods

For transcranial and direct cortical stimulation as well as for recording, a modified analyzer (Sentinel 4 EP; Axon System, Inc., Hauppauge, NY) was used.

Transcranial Electrical Stimulation. For TES, corkscrew design stimulation electrodes (VIASYS NeuroCare; Nicolet Biomedical, Inc., Madison, WI) were placed subcutaneously at C2 anode and C3 cathode for left hemispheric stimulation and at C3 anode and C2 cathode for right hemispheric stimulation (according to the international 10-20 electroencephalography system), with the anode serving as the active electrode. If MMEPs could not be elicited with this combination, C1 anode and C3 cathode for left hemispheric stimulation or C2 anode and C1 cathode for right hemispheric stimulation were chosen instead. In some patients, stimulation at C2 anode and Fp1 cathode was also applied to elicit MMEPs from the lower-extremity muscles. To elicit MMEPs, short trains of five rectangular stimuli with an individual pulse width of 0.5 msec and an interstimulus interval of 4 msec were applied using a train repetition rate of 2 Hz. The maximum stimulation intensity did not exceed 240 mA. To prevent bite injuries due to contraction of masticatory muscles, a bite block (rolled gauze) was placed in the patient’s mouth. Transcranial electrical stimulation was not performed in patients with a history of frequent epileptic seizures or implanted electronic devices (for example, cardiac pacemakers).

Direct Cortical Stimulation. For direct cortical stimulation, a strip electrode with eight contacts (each 4 mm in di-
Monitoring of MMEPs in cerebral aneurysm surgery

**Results**

**Motor Evoked Potentials Obtained With TES and Direct Cortical Stimulation**

Transcranial electrical stimulation was attempted in all 119 patients. A seizure occurred while TES-induced MMEP baseline recordings were obtained in one patient, and thus further TES and direct cortical stimulation were abandoned. In all but one patient who had an ACA–ACoA aneurysm, motor responses reflecting the vascular territory of interest were recordable.

In 19 (16%) of 119 patients, based on the surgeon’s opinion, direct cortical stimulation was deemed unnecessary, and thus only TES was performed. Direct cortical stimulation was performed in 100 (84%) of 119 patients. Because of subdural venous bleeding, the strip electrode had to be removed in two patients. In one patient a seizure occurred after direct cortical stimulation; further direct cortical stimulation and TES were abandoned in this patient. The MMEPs for the vascular territory of interest were obtained in 95 (97.9%) of 97 patients in whom the grid electrode had been placed.

Therefore, in 95 (79.8%) of 119 patients MMEPs were elicited by direct cortical stimulation and TES, and in 21 (17.6%) of 119 patients MMEPs were elicited by TES alone. These values represent a total of 116 (97%) of 119 patients for whom data were included for analysis. These 116 patients were treated for 143 aneurysms that were located as follows: ICA, 40 aneurysms including those of the ophthalmic or anterior choroidal artery; MCA, 48 aneurysms; ACA or ACoA, 19 aneurysms; PCA or PCoA, 22 aneurysms; PICA, six aneurysms; superior cerebellar artery, one aneurysm; and BA, seven aneurysms.

**Intraoperative MMEP Changes**

In 14 (12%) of 116 patients, significant intraoperative MMEP changes occurred. In nine of these 14 patients, the changes occurred in MMEPs elicited by direct cortical stimulation. To exclude a technical problem with the strip electrode in these nine patients, the electrode location was inspected by the surgeon to exclude possible migration, and eliciting MMEPs was attempted with TES as well. After losing MMEPs with direct cortical stimulation, attempts to elicit MMEPs with TES were also unsuccessful. Note that on observation of an MMEP change, the stimulation intensity for TES was carefully increased while a patient’s movements and the microsurgical technique were monitored. With this procedure, electrical stimulation did not induce unacceptable movements in the patient. The MMEP changes in 14 patients occurred as follows: 1) after temporary occlusion of the aneurysm-bearing vessel (nine [64%] of 14 patients); 2) after positioning a permanent clip (four [29%] of 14 patients); 3) during a decrease in blood pressure (two [14%] of 14 patients); and 4) while a retractor position compromised blood flow in the ICA (one [7%] of 14 patients).

Significant MMEP changes took place in association with three (8%) of 40 ICA aneurysms, four (8%) of 48 MCA aneurysms, one (5%) of 19 ACA or ACoA aneurysms, two (9%) of 22 PCA or PCoA aneurysms, one (14%) of seven PICA aneurysms, and three (43%) of seven BA aneurysms. The occurrence of MMEP changes during surgery for a BA aneurysm was significantly greater compared with that for aneurysms of the anterior circulation (p = 0.02) but not the other localizations of the posterior circulation.

**Surgical Strategy and MMEP Changes**

Temporary clipping was performed more often in the group of patients with MMEP changes than in the group of patients without such changes, but this rate did not reach statistical significance (p = 0.07; Table 1). The number of repeated clippings between the two groups was the same.

Although the mean duration of a temporary clipping was longer in patients with MMEP changes (11.8 ± 11.5 minutes) compared with that in patients without changes (5 ± 5.6 minutes), there was no statistically significant difference (p = 0.07). In cases of an MMEP change, the surgeon took immediate action. In one patient, the retractor compromising the ICA was successfully repositioned. In patients in whom permanent clip placement had been followed by an MMEP change, the surgical side was carefully inspected, Doppler ultrasonography was performed, and the permanent clip was repositioned. If temporary clipping was followed by an MMEP change, clip reopening to allow reperfusion was considered, and the duration of the clipping was kept as short as possible. Despite the surgeon’s immediate action, MMEP loss was permanent in three patients: premature aneurysm rupture and consecutive ICA occlusion; permanent clipping in an arteriosclerotic MCA aneurysm most likely causing an embolic plaque loosening; and temporary vessel occlusion on the BA.

**Correlation Between Intraoperative MMEP Changes and Postoperative Motor Status**

Of the 14 patients with significant intraoperative MMEP changes (permanent in four patients and transient in 10), the postoperative motor status was normal in four (29%) of 14 patients and not assessable in three (21%) of 14 patients (Table 2). These three patients suffered further deterioration of their neurological condition. The underlying cause of the
In the present study, the intraoperative MMEP changes, whereas eight (44.4%) did not (Table 3). Of the eight patients without MMEP changes, six had mild transient motor deficits that resolved within the first postoperative week. In the two remaining patients, low blood pressure or brain edema during the postoperative course caused the permanent motor deficit. An episode of low blood pressure developed in one patient during the wake-up period while in the intensive care unit, leading to a permanent motor deficit. Progressive hemiparesis developed within the first 8 hours following surgery in the other patient. In that case, brain edema after the surgery was thought to be the origin of the hemiparesis. Therefore, in these latter two patients, it is very likely that periods of hypotension during the immediate postoperative period resulted in reduced cerebral blood flow in one patient and brain edema in the other. The MMEPs in these two patients were not considered as false negatives. In summary, seven (7%) of 102 patients without MMEP changes suffered a transient motor deficit, whereas seven (50%) of 14 patients with either permanent or transient MMEP changes suffered a transient or permanent motor deficit (p > 0.001). The MMEP method’s sensitivity for all postoperative motor deficits is 0.5 (seven of 14 patients) and its specificity is 0.96 (95 of 99 patients). The positive predictive value is 0.63 (seven of 11 patients), and the negative predictive value is 0.93 (95 of 102 patients).

**Discussion**

In 97% of 119 patients, MMEPs were recordable for continuous neurophysiological monitoring for the vascular territory of interest throughout the course of aneurysm surgery. It has been shown that the combination of TES and direct cortical stimulation allows for monitoring of the functional integrity of motor pathways bilaterally without unacceptable patient movement interfering with microsurgical maneuvers. The evaluation of the technical aspects of MMEP monitoring during vascular surgery is part of another study and is discussed only briefly here. In the present study the number of significant intraoperative adverse events was one (0.84%) of 119 with TES and three (3.2%) of 95 with direct cortical stimulation. None of these adverse events was followed by neurological sequelae. Other authors have presented a slightly lower incidence of significant adverse effects, but they did not encounter uneventful bleeding from a bridging vein. Our own experience with the intraoperative application of TES in adult and pediatric patients with neurosurgical and orthopedic procedures (> 5000 cases, unpublished data) is comparable with other groups using the same method. Eliciting MMEPs by either TES or direct cortical stimulation is considered a safe method and does not appear to put the patient at risk for severe injury or a seizure disorder.

The introduction of total intravenous anesthesia has permitted reliable intraoperative recording of MMEPs. We induced anesthesia with propofol and fentanyl (or as an alternative, a shorter-acting opioid such as sufentanil), which have been safely used and described as favorable in eliciting MMEPs. Anesthesia for neurovascular procedures combined with neuromonitoring should not only provide the best conditions for evoking motor and a postoperative motor deficit and three without an assessable motor status), we noted that 10 (55.6%) had intraoperative MMEP changes, whereas eight (44.4%) did not (Table 3). Of the eight patients without MMEP changes, six had mild transient motor deficits that resolved within the first postoperative week. In the two remaining patients, low blood pressure or brain edema during the postoperative course caused the permanent motor deficit. An episode of low blood pressure developed in one patient during the wake-up period while in the intensive care unit, leading to a permanent motor deficit. Progressive hemiparesis developed within the first 8 hours following surgery in the other patient. In that case, brain edema after the surgery was thought to be the origin of the hemiparesis. Therefore, in these latter two patients, it is very likely that periods of hypotension during the immediate postoperative period resulted in reduced cerebral blood flow in one patient and brain edema in the other. The MMEPs in these two patients were not considered as false negatives. In summary, seven (7%) of 102 patients without MMEP changes suffered a transient motor deficit, whereas seven (50%) of 14 patients with either permanent or transient MMEP changes suffered a transient or permanent motor deficit (p > 0.001). The MMEP method’s sensitivity for all postoperative motor deficits is 0.5 (seven of 14 patients) and its specificity is 0.96 (95 of 99 patients). The positive predictive value is 0.63 (seven of 11 patients), and the negative predictive value is 0.93 (95 of 102 patients).

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somatosensory potentials but also should be cerebrally protective. Propofol has been safely used in cerebral aneurysm repair and was included in protocols for cerebral protection during phases of reduced focal cerebral perfusion.9,15

Surgical Strategy and MMEP Changes

Assessing a method’s effect on surgical management is the most difficult part of an analysis. When an MMEP alteration occurred, immediate surgical action was taken because of the growing evidence that MMEP loss usually results in a severe, permanent motor deficit. Changes in intraoperative MMEPs thus influence surgical strategy and intraoperative decision making.13,18 Unfortunately, there are situations in which immediate action cannot be taken (for example, temporary vessel occlusion in an aneurysm rupture) or no measurable effect of MMEP recovery can be noted despite manipulation. During the course of this study, the relevance of MMEP loss to postoperative outcomes was clear. The surgeons and operative team developed a methodology for responding to lost or diminished MMEPs depending on the issues at hand. During temporary clipping, blood pressure can be raised in an attempt to improve MMEPs; if MMEPs decrease after final aneurysm clipping, a fastidious inspection of the aneurysm rest was considered in an attempt to determine its cause, that is, perforating or parent vessel occlusion. Often, the clip was simply removed to allow MMEPs to recover, and the clip was reapplied after MMEP recovery. The response of the operative team to these events clearly evolved over the course of the study and likely affected outcome. Still, temporary clipping was performed more often and was more prolonged in the group with MMEP changes. A longer temporary clipping was possible without MMEP changes, and because MMEPs correlate with the clinical outcome in this scenario, patients

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Aneurysm Location</th>
<th>Preop Motor Function</th>
<th>MMEP Changes†</th>
<th>Duration of MMEP Changes (mins)</th>
<th>MMEP Changes Correlated w/ Postop Motor Function</th>
<th>Postop CT Scan Showing Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64, F</td>
<td>rt MCA</td>
<td>normal</td>
<td>loss</td>
<td>2</td>
<td>PC during TC</td>
<td>normal</td>
<td>normal</td>
</tr>
<tr>
<td>2</td>
<td>62, F</td>
<td>rt PCoA</td>
<td>normal</td>
<td>loss</td>
<td>3</td>
<td>TC</td>
<td>normal</td>
<td>normal</td>
</tr>
<tr>
<td>3</td>
<td>59, F</td>
<td>lt ACoA</td>
<td>normal</td>
<td>loss</td>
<td>4</td>
<td>PC, BP decrease</td>
<td>normal</td>
<td>normal</td>
</tr>
<tr>
<td>4</td>
<td>68, F</td>
<td>basilar tip</td>
<td>normal</td>
<td>loss</td>
<td>5</td>
<td>retractor on ICA</td>
<td>normal</td>
<td>normal</td>
</tr>
<tr>
<td>5</td>
<td>66, F</td>
<td>lt ICA</td>
<td>normal</td>
<td>loss, MT increase</td>
<td>12</td>
<td>TC</td>
<td>rt hemiparesis</td>
<td>normal</td>
</tr>
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<td>6</td>
<td>57, F</td>
<td>rt PICA</td>
<td>normal</td>
<td>MT increase</td>
<td>permanent</td>
<td>PC</td>
<td>lt hemiparesis</td>
<td>lt hemiparesis</td>
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<tr>
<td>7</td>
<td>42, F</td>
<td>rt ICA</td>
<td>normal</td>
<td>loss</td>
<td>8</td>
<td>TC</td>
<td>rt hemiplegia</td>
<td>lt hemiparesis</td>
</tr>
<tr>
<td>8</td>
<td>71, F</td>
<td>lt PCoA</td>
<td>normal</td>
<td>loss</td>
<td>10</td>
<td>PC during TC rupture, PC position, BP decrease</td>
<td>rt hemiparesis</td>
<td>rt hemiparesis</td>
</tr>
<tr>
<td>9</td>
<td>69, F</td>
<td>lt MCA</td>
<td>rt arm weakness</td>
<td>loss</td>
<td>35</td>
<td>TC</td>
<td>lt hemiparesis</td>
<td>lt hemiplegia</td>
</tr>
<tr>
<td>10</td>
<td>64, F</td>
<td>rt MCA, rt MCA</td>
<td>normal</td>
<td>loss</td>
<td>permanent</td>
<td>PC during TC</td>
<td>lt hemiplegia</td>
<td>lt hemiplegia</td>
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<td>11</td>
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<td>loss</td>
<td>permanent</td>
<td>TC BA</td>
<td>rt hemiparesis</td>
<td>comatose</td>
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<tr>
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<td>54, M</td>
<td>basilar tip</td>
<td>normal</td>
<td>loss</td>
<td>6</td>
<td>TC BA</td>
<td>not assessable</td>
<td>deceased</td>
</tr>
<tr>
<td>13</td>
<td>55, F</td>
<td>lt ICA</td>
<td>normal</td>
<td>loss, MT increase</td>
<td>7</td>
<td>TC</td>
<td>not assessable</td>
<td>deceased</td>
</tr>
<tr>
<td>14</td>
<td>56, F</td>
<td>lt MCA</td>
<td>rt arm weakness</td>
<td>loss</td>
<td>permanent</td>
<td>PC on M1 after premature aneurysm rupture</td>
<td>not assessable</td>
<td>deceased</td>
</tr>
</tbody>
</table>

* ant = anterior; BP = blood pressure; MT = motor threshold; PC = permanent clip.
† Contralateral index muscle (that is, tibialis anterior muscle for the ACA/ACoA territory; the abductor pollicis brevis muscle for all other vascular territories).
‡ Or end of stay.
§ Because the patient was doing well clinically, only an angiography study was performed, which yielded normal findings.

TABLE 2

Patients with intraoperative changes in MMEPs and postoperative motor deficits

<table>
<thead>
<tr>
<th>Postop Motor Function</th>
<th>Postop CT Scan Showing Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>Day 7‡</td>
</tr>
<tr>
<td>None</td>
<td>No</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
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</table>

TABLE 3

Reliability of intraoperative MMEP changes for indicating the occurrence of postoperative motor deficits

<table>
<thead>
<tr>
<th>MMEP Changes</th>
<th>Postop Motor Deficit</th>
</tr>
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<tbody>
<tr>
<td>Permanent</td>
<td>Transient</td>
</tr>
<tr>
<td>yes</td>
<td>6†</td>
</tr>
<tr>
<td>no</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td>6</td>
</tr>
</tbody>
</table>

* All patients in whom motor status was not assessable had a further deterioration of their clinical status.
† Including four patients with a permanent moderate motor deficit.
‡ Hemiparesis developed within 8 hours after surgery in one patient and after an episode of low blood pressure in the intensive care unit in the other patient.
are not at an increased risk for neurological dysfunction. Depending on the circumstances, longer and repeated temporary clipping might simply reflect the more complex nature of the aneurysms requiring several reconstructive surgical steps.¹

Correlation Between MMEPs and Postoperative Motor Status

In supratentorial aneurysm surgery, permanent MMEP loss is always followed by a permanent postoperative motor deficit. This high sensitivity for indicating severe dysfunction of the motor pathways makes this method of intraoperative MMEP monitoring an ideal method. Furthermore, the negative predictive value and the specificity of intraoperative MMEPs are high. These findings are in accordance with those from other studies.¹²,¹³,¹⁷,¹⁸ Because of the sensitivity and specificity of MMEPs, we believe that they are an essential component in intraoperative neurophysiological monitoring. The operative morbidity rate for a permanent severely disabling motor deficit in our study was 0.8% and for a moderately disabling motor deficit was 3.4%. In other reports with comparable aneurysm locations and intraoperative monitoring methods, the surgical morbidity rates were 2%¹³ and 1%.¹⁷

Thus far, predicting either permanent mild or transient motor deficits remains difficult. This fact is reflected by the rather low sensitivity and positive predictive value of the MMEPs in predicting all grades of postoperative motor deficits, especially mild mono- or hemiparesis. Suzuki and colleagues¹⁷ reported on 10 patients with reversible loss or irreversible deterioration of the MMEP response followed by a permanent motor deficit in one patient and a transient motor deficit in nine patients. Neuloh and Schramm¹³ described 11 patients with either reversible loss or irreversible deterioration of MMEPs followed by either a permanent motor deficit in two patients or a transient motor deficit in nine patients. All these data, including our own, indicate that transient MMEP loss or deterioration is followed by a range of normal motor statuses to transient or slight permanent motor deficits. Thus far, one can conclude that intraoperative monitoring of MMEPs represents a semiquantitative method that can predict severe impairment of motor cortex or motor pathways but lacks the ability to precisely predict all transient or mild permanent motor deficits. This finding illustrates the difficulty in assessing the precise number of impaired corticospinal tract fibers.

There was no difference between the accumulated time of each single MMEP loss or the duration of a one-time loss of MMEPs with regard to clinical outcome. This result must be assessed in a larger cohort of patients because it may be a random occurrence in our study group. Suzuki and colleagues¹⁷ reported on two patients with a transient MMEP loss for 8 and 10 minutes (followed by a lacunar infarct) without postoperative motor deficits, whereas four patients suffering from transient motor deficits had transient MMEP losses for 8, 10, 12, and 16 minutes (mean 11.5 minutes). In our study group, four patients with a transient MMEP loss for 3, 4, 5, and 8 minutes had either no motor deficit or a transient one. Four patients with 8, 10, 12, and 35 minutes had a transient or permanent motor deficit. These data may indicate, depending on the individual vascular supply and collateralization, that the disappearance of MMEPs for more than 10 minutes is likely to be followed by a postoperative motor deficit.

Sensitivity of Intraoperative MMEPs

The sensitivity (0.5) and positive predictive value (0.63) in the present study are rather low. Because the surgical team determined that the deterioration of MMEPs indicates imminent injury to the corticospinal tract, such deterioration of MMEPs prompted a surgical reaction and prevented postoperative neurological sequela. Consequently, the favorable rate of low postoperative morbidity implies less sensitivity. We agree with Neuloh and Schramm,¹⁴ that it is impossible to perform a controlled randomized and double-blinded study to reveal the true sensitivity of MMEP monitoring if positive evidence of MMEP monitoring has been provided in uncontrolled studies.

Early Postoperative Imaging Studies and MMEPs

An early postoperative head CT scan provides additional information about the clinical course after significant intraoperative MMEP changes. In all four patients in whom immediate postoperative CT scans had shown signs of hypointensity within a vessel territory, such results were the early indicators of a large territorial infarct and correlated with permanent motor deficits or fatal outcome.

Postoperative Motor Deficit Despite Unchanged MMEPs: False-Negative Results

Two patients demonstrated a postoperative motor deficit despite preserved MMEPs intraoperatively. In both instances, it was determined that events in the early postoperative course—an episode of hypotension and the development of cerebral edema—were the cause of the new neurological deficit. These two cases cannot be considered as having false-negative results or a delayed perfusion deficit that led to a neurological deficit after intraoperative monitoring was stopped.

Conclusions

In this study we evaluated MMEPs during aneurysm surgery and demonstrated that MMEPs are a safe and reliable means for intraoperative neurophysiological assessment and monitoring of motor pathway integrity. The MMEPs are a valuable tool for predicting postoperative motor deficits. Data in this study demonstrate that intraoperative MMEP monitoring ought to result in an improved outcome after aneurysm surgery by giving the neurosurgeon real-time feedback about the vascular integrity of the patient. Intraoperatively preserved MMEPs always correlate with good motor outcome. A mild postoperative motor deficit, despite preserved MMEPs, will recover within the 1st postoperative week. Transient MMEP loss might be followed by a motor deficit, which in its nature is mild or transient. The permanent loss of MMEPs is always followed by severe motor deficit corresponding to significant lesions within the motor cortex and motor pathways on imaging studies. Results in this study provide evidence that intraoperative MMEP monitoring is a useful tool for the neurosurgeon for indicating potentially dangerous events and allows for safer aneurysm surgery for the patient.
Monitoring of MMEPs in cerebral aneurysm surgery

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