The Incidence of Unacceptable Movement with Motor Evoked Potentials During Craniotomy for Aneurysm Clipping

Laura B. Hemmer[1,2], Carine Zeeni[1,7], John F. Bebawy[1,2], Bernard R. Bendok[2,3], Mathew A. Cotton[5], Neil B. Shah[6], Dhanesh K. Gupta[1,2], Antoun Koht[1,2,4]

Key words
- Intracranial aneurysm
- Intraoperative monitoring
- Motor evoked potentials

Abbreviations and Acronyms
MEP: Motor evoked potential
PPV: Positive predictive value
SEP: Somatosensory evoked potential

From the Departments of [1]Anesthesiology, [2]Neurological Surgery, [3]Radiology, and [4]Neurology, Northwestern University, Feinberg School of Medicine, Chicago, Illinois, USA; [5]Neurological Testing Center, Northwestern Memorial Hospital, Chicago, Illinois, USA; [6]Chicago College of Osteopathic Medicine, Midwestern University, Downers Grove, Illinois, USA; and [7]American University of Beirut, Riad El Solh, Beirut, Lebanon

To whom correspondence should be addressed: Dhanesh K. Gupta, M.D. [E-mail: dhanesh-gupta@northwestern.edu]

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OBJECTIVE: **To review the experience at a single institution with motor evoked potential (MEP) monitoring during intracranial aneurysm surgery to determine the incidence of unacceptable movement.**

METHODS: **Neurophysiology event logs and anesthetic records from 220 craniotomies for aneurysm clipping were reviewed for unacceptable patient movement or reason for cessation of MEPs. Muscle relaxants were not given after intubation. Transcranial MEPs were recorded from bilateral abductor hallucis and abductor pollicis muscles. MEP stimulus intensity was increased up to 500 V until evoked potential responses were detectable.**

RESULTS: **Out of 220 patients, 7 (3.2%) exhibited unacceptable movement with MEP stimulation—2 had nociception-induced movement and 5 had excessive field movement. In all but one case, MEP monitoring could be resumed, yielding a 99.5% monitoring rate.**

CONCLUSIONS: **With the anesthetic and monitoring regimen, the authors were able to record MEPs of the upper and lower extremities in all patients and found only 3.2% demonstrated unacceptable movement. With a suitable anesthetic technique, MEP monitoring in the upper and lower extremities appears to be feasible in most patients and should not be withheld because of concern for movement during neurovascular surgery.**

INTRODUCTION

Despite advances in neuroendovascular techniques, craniotomy for clip ligation of aneurysms remains a fundamental method for definitive treatment. Reported morbidity rates for clipping of unruptured aneurysms range from 4%–11% (1). Morbidity is often due to inadvertent ischemic injury from brain retraction, compromise of small perforating arteries during dissection, temporary arterial occlusion, or permanent clips impinging on the parent vessel or perforating arteries (20, 24).

Neurophysiologic monitoring during surgery can help prevent permanent neurologic injury by alerting the surgeon and anesthesiologist to the need for modifying the surgical strategy and/or patient management (30). Transcranial motor evoked potential (MEP) monitoring that is added to standard somatosensory evoked potential (SEP) and electroencephalogram monitoring may increase the sensitivity of electrophysiologic monitoring during aneurysm surgery and improve outcome (5, 29). Because MEPs and SEPs provide complementary information about the patient's nervous system, one of these modalities alone might be less likely to reflect the patient's true postoperative neurologic status (30). In up to 25% of cases in which a new postoperative deficit (mostly paresis) manifests, there were unaltered intraoperative SEP recordings; this is likely because the motor pathways derive some blood supply from arteries that are anatomically distinct from arteries supplying sensory cortical pathways (20). In addition, likely owing to differences in the amount of collateral circulation to the vulnerable area, MEP monitoring can give relatively early warning of potential ischemic injury (8, 9).

Transcranial MEPs have become a critical modality for intraoperative monitoring of motor pathway integrity in spine surgery, and the technical aspects and safety of MEP monitoring have previously been demonstrated (14, 21, 27). Combining MEPs with SEPs has been recommended in intracranial aneurysm surgery, and MEPs have been found to be superior to SEPs in many situations during cerebral aneurysm surgery (4, 23). It has even been suggested that with MEP monitoring the incidence of motor deficits after aneurysm clipping could be reduced to at least the level obtained with aneurysm coiling procedures (31). However, MEPs in intracranial neurovascular surgery have often not been employed because of concern for unacceptable movement in a nonparalyzed patient anesthetized with a limited amount, or in the absence, of inhaled volatile anesthetic (26, 29). A survey sent to all members of the American Society of Neurophysiological Monitoring and the American Clinical Neurophysiology Society revealed that only two centers used MEPs during craniotomies for intracranial lesions (from

57 responding centers) (12). Even in spine surgery where transcranial MEPs are much more commonplace (although a survey published in 2007 showed transcranial MEPs were available in only 41% of spine surgical facilities), concern about transcranial MEP–induced movement remains, particularly with surgeons inexperienced with transcranial MEPs (15, 25). We reviewed our experience with transcranial MEPs during intracranial aneurysm surgery to determine the incidence of unacceptable movement in the absence of neuromuscular blockade while monitoring upper and lower extremity transcranial MEPs.

METHODS

After institutional review board approval, electronic neurophysiology event logs and anesthetic records from 220 craniotomies for aneurysm clipping between August 2006 and May 2009 were retrospectively reviewed for unacceptable patient movement or reason for cessation of MEP monitoring (Table 1). The neurophysiology event logs, based on our standard practice, document any change in stimulation, explain the reason for the change, and document any inability to acquire MEPs once baseline signals are obtained.

Perioperative management was consistent with routine anesthetic management for cerebral aneurysms at our institution, and it followed a modification of a protocol previously described for intracranial surgery (3). Patients were premedicated as needed with midazolam, 0–0.05 mg/kg, and standard American Society of Anesthesiologists monitors were applied. An intraarterial catheter was placed for invasive arterial pressure monitoring either before induction or after tracheal intubation, at the discretion of the anesthesiologist. Anesthesia was induced with propofol, 1–2 mg/kg, or etomidate, 0.1–0.2 mg/kg, and remifentanil infusion at 0.1–1 μg/kg/minute, or a single bolus of 0.3–1 μg/kg, or fentanyl, 1–7 μg/kg. Tracheal intubation was facilitated by a single intravenous bolus of intermediate-acting nondepolarizing muscle relaxant (rocuronium, 0.6–1.2 mg/kg, or cisatracurium, 0.15–0.2 mg/kg) or, when indicated, succinylcholine, 0.3–1.1 mg/kg. No additional neuromuscular junction–blocking agent was administered after tracheal intubation because of planned transcranial MEP monitoring. The trachea was ventilated with an air/oxygen mixture (fraction of inspired oxygen, 0.5–1), and ventilation was adjusted to achieve an arterial carbon dioxide pressure of 28–32 mm Hg. Anesthesia was usually maintained with ≥0.1 μg/kg/minute of remifentanil, ≤0.5 minimum alveolar concentration of volatile anesthetic (usually desflurane), and 0–150 μg/kg/minute of propofol.

Table 1. Aneurysm Location and Size

	Number (Percentage)
Aneurysm Location	
Middle cerebral artery	57 (25.9)
Anterior communicating artery	56 (25.5)
Posterior communicating artery	26 (11.8)
Carotid/periophthalmic artery	23 (10.5)
Internal carotid artery bifurcation	23 (10.5)
Basilar tip	17 (7.7)
Distal anterior cerebral artery	9 (4.1)
Posterior inferior cerebral artery	7 (3.2)
Vertebral artery	1 (0.5)
Posterior cerebral artery	1 (0.5)
Aneurysm Size	
<5 mm	79 (35.9)
5–10 mm	108 (49.1)
11–20 mm	24 (10.9)
>20 mm	8 (3.6)
Unreported	1 (0.5)

In cases where multiple aneurysms were clipped, the largest aneurysm is reported.

While maintaining a fixed dose of volatile anesthetic, remifentanil and propofol were titrated to maintain the mean arterial pressure within 20% of the awake, baseline value and, when used, a bispectral index (BIS; Covidien, Norwood, Massachusetts, USA) value of 30–50. If needed, a phenylephrine infusion was added to maintain the target mean arterial pressure.

Temperature was adjusted to achieve mild hypothermia or normothermia at the time of permanent aneurysm clip placement. When requested, before temporary arterial occlusion or aneurysm clipping, a burst suppression ratio of approximately 0.7–0.8 was achieved with propofol and confirmed by electroencephalogram.

Since August 2006, SEP, MEP, and electroencephalogram monitoring have been routinely performed on all patients undergoing craniotomy for clip ligation of intracranial aneurysms at Northwestern Memorial Hospital. MEP tracings were generated by multipulse transcranial electrical stimulation (Cadwell TCS-1; Cadwell Laboratories, Inc, Kennewick, Washington, USA) at sites 2 cm anterior to the C3 and C4 positions of the international 10–20 system using 3–7 square-wave, monophasic, anodal, constant-voltage electrical pulses of 50-μsec duration with an interstimulus interval of 2 msec. MEPs were recorded (16-channel Cadwell Cascade) from the contralateral upper and lower extremities simultaneously with needles placed in bilateral abductor hallucis and abductor pollicis muscles paired with reference needles in corresponding abductor digiti minimi muscles. MEPs were displayed and recorded within a 100-msec epoch after being filtered (band-pass 30–10,000 Hz) and amplified (× 10,000).

Stimulus intensity was increased by 50-V increments from 100 V to a maximum of 500 V until evoked potential responses were detectable in the lower extremities above a minimum of approximately 50 μV. MEPs were commonly recorded every 30 minutes throughout surgery and more frequently during critical surgical manipulation (e.g., at 1 minute after temporary clip placement, then every 2 minutes until 10 minutes passed, and every 5 minutes thereafter until temporary clip release). It was standard practice that once baseline signals were obtained, any change in stimulation intensity was documented and justified in the neurophysiology event log. Decreases in MEP amplitudes >50% from baseline or increases in stimulation intensity of >50 V or in train number to maintain signal amplitude were considered minimum alert thresholds.

To avoid movement of the microsurgical field during critical surgical maneuvers, brief surgical pauses (a few seconds) for monitoring of MEPs were coordinated between the neurosurgery, anesthesia, and electrophysiology teams. Specifically, most MEP acquisitions coincided with

instrument exchange and always with the knowledge of the surgeon. Often, MEP stimulation was facilitated by the anesthesiologist noting a pause in surgery and initiating communication between all teams to acquire MEPs. Video monitoring was also used to assist the electrophysiology team in timing stimulation in coordination with surgery.

To help ensure accurate collection of results, all patient records (N = 220) were reviewed by only two investigators (L.B.H. and C.Z.). Patients flagged for unacceptable movement were rechecked by a third investigator (N.B.S.), and their actual neurophysiologic data were reviewed (A.K.). Unacceptable movement was classified as either nociception-induced movement (defined as "coughing" or reflexive limb movement temporally related to MEP stimulation) or excessive field movement (defined as grossly visible head movement as determined by surgical and anesthesia teams). A random sampling of patients (25%) flagged as not exhibiting unacceptable movement was also independently verified by a third investigator (N.B.S.).

RESULTS

We were able to obtain MEPs in all 220 patients reviewed. Seven patients (3.2%) exhibited unacceptable movement with MEP stimulation. Two of the seven patients demonstrated nociception-induced movement, and the other five patients had excessive field movement that occurred with stimulation (Figure 1). For both patients with nociception-induced movement, the neurophysiology event log noted that the attending neurosurgeon complained of patient "coughing." The anesthetic record for these two patients showed an increase in the administered anesthesia just after the movement. For the patients with excessive field movement, the neurophysiology event log noted that either the surgery or the anesthesia team complained of visible movement with stimulation, and the stimulation intensity was decreased without an increase in anesthesia. In all but one case (when the surgeon requested no further MEPs), anesthesia could be increased (for nociception-induced movement), or stimulation intensity could be reduced (for excessive field movement) so that MEPs were able to be resumed, yielding a 99.5% monitoring rate.

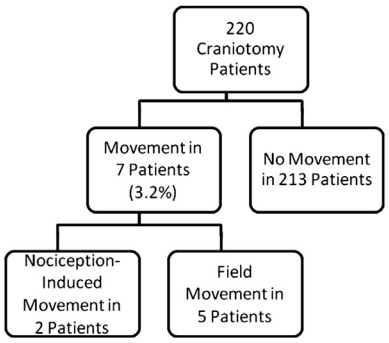

Figure 1. Incidence and type of movement resulting from transcranial motor evoked potential stimulation.

DISCUSSION

With our anesthetic and monitoring regimen, we were able to record MEPs of the upper and lower extremities in all patients and found that only 3.2% demonstrated unacceptable movement. Within our definition of unacceptable movement, we included two specific types of movement—nociception-induced and excessive field movement. Our typical expected field movement is approximately 1 mm of cranial movement (compared with 0.7 mm of localized movement with arterial pulsation), as quantified by our own video capture and measurement. Excessive field movement would be larger and result in grossly visible head movement. In this large series of patients, our data suggest that upper and lower extremity transcranial MEP monitoring is feasible and routinely obtainable in nearly all patients undergoing craniotomy for clip ligation of intracranial aneurysms.

Use of MEP monitoring in intracranial neurovascular surgery is often avoided because of concern for unacceptable movement in a nonparalyzed patient (26, 29). It was previously reported that in approximately 6%–10% of patients undergoing transcranial MEP monitoring without neuromuscular blockade, recording was impossible during microsurgery because of electrostimulation-induced muscle contraction or failure to elicit a baseline motor response from muscles that were intact in the preoperative period (20, 27). Quiñones-Hinojosa et al. (22) reported good success obtaining transcranial MEPs in a small group (N = 30) of patients with aneurysms. However, they noted that MEPs elicit patient movement, and they emphasized the need for communication to coordinate brief surgical pauses for MEP monitoring to avoid potential movement during microsurgery. Other authors have reported difficulty in consistently obtaining transcranial MEP responses in the lower extremities without using a stimulus intensity that produces unacceptable twitching artifact (6, 20); this did not seem to be problematic in our patients.

More recently, other investigators have had better success rates with transcranial MEP monitoring during intracranial aneurysm clipping, but they have used very high stimulus intensity with a continuous infusion of muscle relaxant for partial neuromuscular blockade, or they have monitored only upper extremities (10, 18, 31). The use of muscle relaxant in these patients has several drawbacks. It does not eliminate the risk of movement, it increases technical complexity (muscle relaxation must be incomplete and carefully controlled), and it introduces a potential confounding factor at critical times in surgery (as could occur if a bolus of drug or fluid is inadvertently infused through the line administering the muscle relaxant) (13). The presence of neuromuscular blockade necessitates a higher stimulus intensity, and use of neuromuscular blockade has been recommended against for monitoring MEPs in neurovascular surgery (5, 6). Too high of a stimulus intensity can activate the deep subcortical motor pathways and bypass higher cortical levels, which can lead to generation of myogenic MEPs from contralateral limbs despite possible cortical ischemia. Subcortical motor pathway ischemia also could be missed if corticospinal tract activation occurred even more caudally (2, 5, 6, 13, 20). Transcranial MEPs are made more accurate by decreasing stimulation intensity, and it is recommended that the lowest possible stimulation intensity be used (5, 8, 20, 28).

The improved success rate of MEP monitoring in this series compared with other reports in which muscle blockade was also avoided has several possible causes. The stimulus intensity used for our

patients was at least as high and sometimes higher than other case series (although stimulus duration may have been shorter at times) (Table 2). Increased stimulus intensity may contribute to an improved success rate in monitoring capability, but it would also be expected to contribute to movement-related problems. We ensure use of the lowest stimulation intensity that results in detectable MEPs, as described earlier. In addition, sterile stimulating needles are used to avoid sacrificing optimal needle position because of the sterile field, and this helps minimize required stimulation intensity (14).

The anesthetic regimen used may have contributed to more successful MEP monitoring ability. Many previous investigations do not specifically define their anesthetic doses, but they often report using a total intravenous anesthetic technique, opioid boluses, or less opioid than what is commonly used at our institution (20, 22, 27). At our institution, we rely on moderate opioid doses with lower hypnotic anesthetic doses to provide adequate anesthesia and amnesia and yet allow neurophysiologic monitoring (3, 32).

Because the other investigators used low doses of opioid (effect-site concentration <1 ng/mL of remifentanil equivalents), the regimens involved a lower relative effect-site concentration of opioid than our technique (7). Based on response surface models, 0.5 minimum alveolar concentration of volatile anesthetic combined with 0.19 μg/kg/min of remifentanil infusion is needed to obtain a ≥95% probability of no movement or hemodynamic response to surgical incision (16). Because the most intense level of noxious stimulation during craniotomy occurs from the time of skin incision through the opening of the dura, the effect-site concentration of opioid required during intracranial dissection and aneurysm clip ligation is significantly lower (17, 32). We titrate remifentanil based on the hemodynamic responses to surgical stimulation, and because a moderate dose of remifentanil is required to provide analgesia while the patient is in Mayfield head pins, the remifentanil is generally maintained at ≥0.1 μg/kg/min. To provide adequate cerebral perfusion, close attention is paid to volume status, and a phenylephrine infusion is added as needed. Because much of the anesthetic regimen is via intravenous infusion, attentiveness is required to ensure that intravenous delivery problems, such as mechanical obstruction or extravasation, do not occur (which could result in spontaneous patient movement) (8). Also, the addition of a low dose of volatile anesthetic should substantially minimize the risk of nociceptive-induced movement by a synergistic interaction with the opioid and an additive interaction with propofol.

Because our study is retrospective, accurate data reporting is limited by the thoroughness of documentation in the neurophysiology event logs and anesthetic records. Specific notes of patient movement are not routinely made in the anesthetic record, but possible movement, or suspected "light" anesthesia, is often reflected by a bolus of intravenous anesthetic followed by increased infusions of anesthetic or opioid or both. Specific patient movement is routinely noted in neurophysiology event logs followed by a temporary suspension in MEP monitoring or a decrease in MEP intensity. It is standard practice at our institution to document and explain any interruption of MEP monitoring or any change in the intensity of MEP stimulation. The neurophysiology event logs should be a high-fidelity record of patient movement during intracranial surgery.

This study does not attempt to capture slight microsurgical field movements because these are normal and expected with MEPs; it is important that MEPs are

Table 2. Comparison of Delivered Transcranial Motor Evoked Potential Stimuli

Study	Stimulator Equipment	Stimulation Site*	Stimulation Pulse	Stimulation Duration (μsec)	Stimulation Interval (msec)	Stimulation Intensity
Hemmer et al. (present study)	TCS-1 (Cadwell Laboratories, Inc, Kennewick, WA, USA)	2 cm anterior to C3-C4 (or, if not working, C3-C4)	3—7 square-wave, monophasic, anodal, constant current	50	2	100—500 V†
Neuloh et al., 2004 (20)	Viking-IV P (Nicolet Biomedical, Madison, WI, USA)	1—2 cm anterior to C3-C4 or C1-C2	4—7 square-wave, monophasic, anodal, constant current	200—500	2—4 (500 Hz and 250 Hz repetition frequency)	200 mA maximum
Szelenyi et al., 2005 (27)	Axon Sentinal-4 EP Analyzer (Axon System, Inc, Hauppauge, NY, USA)	C1-C2 (or, if not working, C3-C4 or Cz/Fz)	5 rectangular-wave	500	4 (2-Hz train repetition rate)	240 mA maximum
Quiñones-Hinojosa et al., 2004 (22)	Digitimer D-185 (Digitimer Ltd, Welwyn Garden City, UK)	C1-C2	5—6 constant voltage	50	2.5—3.5	184—459 V

*Refers to the international 10—20 electroencephalography system.
†Cascade recording system also reports mA (in terms of peak current), and this is often in the range of 500—1100 mA.

coordinated with surgical pauses (22). During these pauses, unless instrument exchange is occurring, the neurosurgeons usually keep their instruments in the microsurgical field and maintain their microscopic view. Although active surgical manipulation is briefly suspended, the time required is brief (a few seconds), and avoiding excessive field movement helps to preserve the flow of surgery and minimize interruptions.

As noted earlier, MEPs have been found to be superior to SEPs in many situations during cerebral aneurysm surgery. This superiority is especially true for predicting pure motor deficits (hemiplegia) owing to subcortical ischemia from compromised perforating arteries. Perforating arteries are commonly encountered during surgery for many different aneurysmal locations, and multiple studies have reported infarction secondary to perforating artery ischemia (6). Prospective, randomized controlled trials of MEP monitoring in aneurysm clip ligation are lacking, and with the ethical considerations involved in withholding a potentially beneficial intervention, such a study is unlikely. However, Guo and Gelb (6) more recently reviewed available case series, and they found that the positive predictive value (PPV) of a permanent MEP loss during aneurysm surgery is 1.0 (i.e., permanent MEP loss is followed by permanent postoperative motor deficit). The PPV of a transient loss or deterioration of MEPs is lower at 0.31 (i.e., transient loss or deterioration is followed by various clinical findings, including no postoperative motor deficit, transient deficit, or mild permanent motor deficit). Yeon et al. (31) reviewed the literature and similarly found PPV reaches 1.0 for permanent MEP loss. The negative predictive value for unchanged MEPs throughout surgery is 0.9–1.0. The probability of no postoperative motor deficit in the setting of transient MEP changes was 0.4–0.9 (the variation was thought to be partly due to inclusion of ruptured aneurysms in some series and differences in stimulation methods and warning criteria).

Preliminary analysis of the predictive value of MEPs from 132 craniotomies for aneurysm clipping (a subset of patients reported in this study) is consistent with prior studies: The positive predictive for irreversible MEP change is 100%; the negative predictive value for no MEP change is 100% (compared with a PPV for irreversible SEP change of about 64% and a negative predictive value of no SEP change of 100%) (11).

Although the benefit of the PPV is obvious, the negative predictive value of evoked potential recordings in aneurysm clipping also has been praised for permitting safer temporary or permanent occlusion and more extensive dissection for an improved surgical approach when such steps may have been previously prematurely discontinued in the absence of reassurance from neuromonitoring (19). It has also been shown that combined MEP/SEP monitoring altered the surgical strategy in 20% of surgeries, with MEPs leading to surgical strategy changes in 16% and SEPs MEPs leading to surgical strategy changes in only 4% (19, 20). From our own preliminary observational data, we have seen that maneuvers that correct a change in the evoked potentials (i.e., a temporary change) prevent neurologic morbidity, which is likely the predominant reason that the PPV for transient MEP changes is <100%.

CONCLUSIONS

This retrospective review demonstrates the feasibility of monitoring both upper and lower extremity transcranial MEPs in the absence of muscle relaxants during intracranial aneurysm surgery with minimal risk of unacceptable movement when a suitable anesthetic and monitoring regimen is used. MEPs, along with other routine neuromonitoring modalities, can be instituted during neurovascular surgery and should be considered potentially to decrease neurologic morbidity (11).

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