

# Intraoperative neurophysiological monitoring during spine surgery: an update

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## Purpose of review

Intraoperative neurophysiological monitoring (IONM) during spine surgery has dramatically evolved over the past decade. A number of techniques have been recently proposed to monitor motor evoked potentials (MEPs), but contradictory results have been published, questioning their reliability to assess specifically the functional integrity of the motor pathways. The aim of the review is to present the state of the art of spinal cord monitoring and the different, complementary roles played by somatosensory evoked potentials (SEPs) and MEPs.

## Recent findings

The authors focused on recent publications analyzing the reliability of SEPs and different MEP techniques during surgeries for spine deformities, anterior-posterior stabilization or decompression, vertebrectomy, and discectomy. Finally, publications on nonsurgically induced changes in IONM parameters during spine orthopedic surgery, such as hypotension and hypothermia, are reviewed to emphasize their importance.

## Summary

The authors suggest that a combination of SEPs and transcranially elicited MEPs should be used during spine surgery because there is no scientific justification to favor either one of the two. Spinal epidural MEP recordings may be added in selective cases. Nonsurgically induced changes in IONM should be recognized and corrected to avoid misleading information on surgery-related evoked potential changes.

## Keywords

motor evoked potentials, somatosensory evoked potentials, intraoperative monitoring, orthopedic surgery

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## Abbreviations

IONM intraoperative neurophysiological monitoring  
MEP motor evoked potential  
mMEPs muscle motor evoked potentials

NMEP neurogenic motor evoked potential  
SEP somatosensory evoked potential  
TES transcranial electrical stimulation

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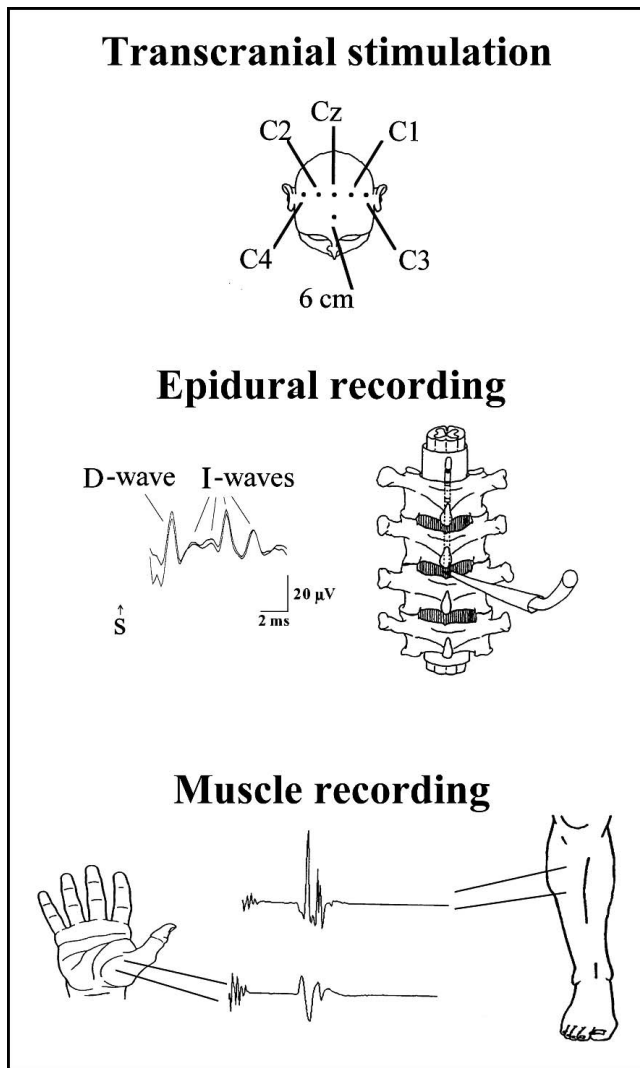
## Introduction

Within the last 5 years there have been significant developments in the field of intraoperative neurophysiology. This is particularly true for methods of monitoring the motor tracts during spine and spinal cord surgeries. Multiple authors have recognized that the use of somatosensory evoked potentials (SEPs) merely to monitor the dorsal columns of the spinal cord is neither sufficient nor reliable enough to detect or prevent lesion of the corticospinal tracts. After years of routine use of intraoperative neurophysiological monitoring (IONM) during spine or spinal cord surgeries, it has become increasingly obvious that a combination of SEP and motor evoked potential (MEP) monitoring produces the best results for prevention or documentation of intraoperatively induced neurologic injury to the spinal cord (injury related to surgery itself or nonsurgically induced injury such as prolonged hypotension). Therefore, the combination of transcranial multipulse electrical stimulation of the motor cortex with recording of MEPs from limb muscles and a standard way of eliciting and recording subcortical and cortical SEPs should become the standard of care for monitoring spine or spinal cord surgeries. The costs of IONM do not approach the lifetime expenses (both financial and emotional) incurred by paraplegic or quadriplegic patients.

This review covers results from recently published articles that support the value of combined monitoring during IONM for spine surgery.

## Description of motor evoked potential methodology

The IONM technique of monitoring MEPs elicited by transcranial electrical stimulation with recording from limb muscles (mMEPs), or from the epidural space of the spinal cord, or from both, is a valuable tool not commonly considered by orthopedic surgeons. Therefore, the authors present schematics of this technique with a brief explanation for easy interpretation of the studies reviewed (Fig. 1).

**Figure 1. Monitoring techniques for eliciting MEPs**

(A) Transcranial stimulation. Schematic illustration of electrode positions for transcranial electrical stimulation of the motor cortex according to the International 10-20 EEG system. The site labeled "6 cm" is 6 cm anterior to Cz. (B) Epidural recording. Schematic diagram of the positions of the catheter electrodes (each with three recording cylinders) placed in the epidural space through a flavectomy/flavotomy with recordings of D and I waves. (C) Muscle recording. Recording of muscle motor evoked potentials from the thenar and tibial anterior muscles after eliciting them with a short train of stimuli applied either transcranially or over the exposed motor cortex. Adapted with permission [1a].

### Surgery for spine deformities (eg, scoliosis, kyphosis)

Patients needing surgery for spine deformities (excluding neuromuscular scoliosis and cerebral palsy) are neurologically intact, and most are children. Therefore, iatrogenic neurologic injury is a profoundly striking event. Furthermore, when it happens, it can be serious enough to result in paraplegia (paraparesis).

At least two possible mechanisms for neurologic injury during this type of surgery have been proposed: (1) excessive stretching of the anterior spinal artery during cor-

rection of the spine curvature, and (2) prolonged hypotension and blood loss in lengthy surgeries.

In spite of the introduction of a method for intraoperative monitoring with SEPs 25 years ago, serious neurologic complications still occur [1•,2•]. The authors believe this is a result of the ability of SEPs to monitor only the functional integrity of the dorsal columns (which conveys aspects of sensory modalities). Thus, the anterolateral columns (corticospinal tracts) remain unmonitored and at risk.

Furthermore, a multicenter survey conducted by the Scoliosis Research Society involving more than 50,000 surgeries [3] showed that 0.127% of patients (64) had postoperative neurologic deficits in spite of unchanged intraoperative SEPs. In the same study, the rate of true-positive results (0.423%) represents the cases in which SEPs documented but did not prevent (or only partially prevented) a neurologic deficit. SEP recording relies on the averaging of responses. This delays the acquisition of a reliable signal and impedes the implementation of corrective measures that can be taken in time to reverse an injury to the spinal cord. Because mMEPs can be recorded online and without averaging, they provide a chance for prompt feedback to the surgeon. Therefore, this is one of the reasons why using only SEPs for monitoring the functional integrity of the entire spinal cord is no longer considered sufficient.

To attempt to overcome the limitations of SEPs for monitoring the corticospinal tracts, neurogenic MEP (NMEP) monitoring has been introduced. This method has been used extensively for the last decade and has been thought to reflect the functional integrity of the motor pathways. In a recent survey on the use of MEP monitoring, 15 of 30 centers still described the use of spinal cord stimulation with recording of neurogenic or myogenic MEPs as their preferred technique to elicit MEPs during spinal cord monitoring [4]. Unfortunately, there has not been a solid scientific background established to support such a statement. Recently, Toleikis *et al.* [5] showed that NMEPS are generated by the antidromic stimulation of the dorsal columns of the spinal cord. Minahan *et al.* [1•] recorded NMEPs in two patients who intraoperatively became paraplegic. Moreover, both paraplegic patients described by Minahan *et al.* [1•] were without intraoperative SEP changes. Based on these findings, an editorial in *Clinical Neurophysiology* [6] stated that use of this kind of monitoring should be limited to the evaluation of sensory, but not motor, pathways within the spinal cord.

With regard to sensitivity of MEPs and SEPs to derangements in the functional integrity of the spinal cord, it is noteworthy that in the survey by Legatt [4] of 7844 procedures, most of which were for orthopedic spine sur-

gery, the rate of adverse MEP changes without SEP changes was 4.1%, compared with 1.5% of adverse SEP changes without MEP changes. Similarly, Dong *et al.* [7] observed that, during descending thoracic and thoracoabdominal aneurysm surgery, only 25% of 16 patients who showed MEP evidence of spinal cord ischemia had congruent—although delayed—SEP changes. These data suggest an increased sensitivity of MEPs to spinal cord ischemic injury.

Recent studies using a combination of transcranially elicited MEPs (using a multipulse technique) with SEPs showed promising results that should give surgeons more confidence in the reliability of IONM. Pelosi *et al.* [2•] reported results from the monitoring of 126 orthopedic operations in 97 patients (79 with spinal deformities and 18 with miscellaneous spinal disorders). The authors concluded, “Normal MEPs at the end of surgery correctly predicted the absence of new motor deficit in all cases whereas in 3 patients (who had MEP changes) SEPs remained unchanged and they had new postoperative motor deficit. Combined SEP/MEP methods may enhance the impact of neuromonitoring on the intraoperative management of the patient and favorably influence neurologic outcome.”

An article published by MacDonald *et al.* [8••] demonstrated the benefits of the combined use of SEPs and MEPs in scoliosis surgery, using an obvious example in a single patient monitored with both modalities.

DiCindio *et al.* [9•], using combined evoked potential monitoring (MEPs and SEPs) in children with mild and moderate forms of cerebral palsy undergoing corrective surgeries for the spine deformities, showed that 100% of the patients could be monitored. SEPs could be used to monitor only 70% of children with a severe form of cerebral palsy, whereas MEPs could be used in 90% of these cases. In the same study, the authors showed that 86% of children with neuromuscular-type scoliosis could be monitored.

The question has been raised about the reliability of IONM as an indicator for irreversible versus reversible lesions to the spinal cord during orthopedic surgery. It is very reasonable to presume that the nature of the spinal cord injury and the time frame from the initial moment of injury to the point of irreversible injury are crucial indicators in predicting reversibility versus non reversibility. Pelosi *et al.* [2•] presented patients who, during correction of their spinal deformity, had both MEPs and SEPs disappear, indicating a lesion to the spinal cord. Their wake-up tests later revealed that the patients had become paraplegic. After removal of instrumentation, their SEPs were partly restored, and their second wake-up tests revealed a left leg monoplegia. Postoperative

neurologic examination indicated left leg weakness with sensory deficit.

The safety of intraoperative MEP monitoring using TES has been well documented by MacDonald [10]. Twenty-nine tongue-lip lacerations, one mandible fracture, five seizures, five cardiac arrhythmias, two scalp burns, and one intraoperative awareness were documented in a review of more than 15,000 cases based on a literature review, unpublished clinical experience, and personal communication.

#### **Surgery for anterior-posterior stabilization and for decompression including vertebrectomy and discectomy**

The inadequacy of intraoperatively monitoring the spinal cord by using only SEPs to cover the functional integrity of motor tracts during anterior cervical discectomy has recently been published by Jones *et al.* [11••]. These authors report two cases of postoperatively quadriplegic patients who were without intraoperative changes in the monitored parameters of SEPs (of 2000 patients operated on in their institution).

In another article, Deutsch *et al.* [12] reported a 9% rate of false-positive results of 44 patients undergoing anterior thoracic vertebrectomy using only SEPs monitoring. They also described patients who developed postoperative paraplegia in spite of intraoperatively unchanged SEPs.

#### **Other nonsurgically induced changes in intraoperative neurophysiological monitoring parameters during orthopedic surgery for spine (hypotension, hypothermia, and so forth)**

Besides ischemic or direct mechanical injury inflicted to the spinal cord by surgical maneuvers, a number of other factors can affect evoked potentials and result in unreliable or misleading IONM [13•].

The spinal cord is very sensitive to ischemia, and even subtle variations in blood pressure can have significant effects on perfusion pressure and, ultimately, the propagation of evoked potentials through the cord. Wiedemayer *et al.* [14] reported that in 11 of 423 neurosurgical operations, the operative team tried to correct a threshold change in SEPs, BAERs, or both by increasing perfusion pressure. In nine of 11 patients, a rise in systemic blood pressure resulted in recovery of the evoked responses, and only two patients had postoperative deficits. Interestingly, in only two cases was systolic blood pressure less than 90 mm Hg when IONM changes occurred. Similarly, Owen [15] observed significant SEP changes with mean blood pressure dropping below 60 mm Hg, and some of these patients experienced postoperative deficits. Noonan *et al.* [16] observed higher rate of false-

positive results in patients with higher variability of blood pressure through the procedure.

Polo *et al.* [17] reported one patient in whom both SEPs and MEPs disappeared during scoliosis surgery when mean arterial blood pressure fell to 60 mm Hg.

The role of MEPs in detecting spinal cord ischemia and, consequently, the relation between MEPs and blood pressure has been investigated mainly in thoracic and aortic surgery [7,18]. Dong *et al.* [7] attributed to distal hypotension the disappearance of MEPs in seven of 16 patients who had MEP changes during surgery for thoracoabdominal surgery. MEP recovered after distal blood pressure was raised above 60 mm Hg in six patients and above 90 mm Hg in one patient.

The influence of body temperature on spinal cord monitoring has been investigated mainly on SEPs [13•]. Luk *et al.* [19], in a study on 90 patients undergoing scoliosis surgery, interestingly observed a significant drop (>50%) in the cervical and cortical component of SEPs after exposure of the spine, but before any surgical instrumentation or distraction was performed. Based on the fact that some of these changes were reverted by irrigating the spine with warm saline, the authors concluded that a drop in temperature was most likely the explanation for the SEP amplitude drop and suggested taking baseline SEPs after exposure of the spine rather than before skin incision [19]. With regard to MEPs, Sakamoto *et al.* [20] investigated the effect of hypothermia on myogenic MEPs elicited by electrical stimulation of the motor cortex. They concluded that, although MEP latency increased linearly with the reduction of core temperature, MEP amplitudes were not affected during cooling to 28°C as long as a multipulse (train of stimuli) technique was used. Meylaerts *et al.* [21] reported that moderate subdural hypothermia did not affect myogenic MEP after TES; progressive cooling to 28°C resulted in increased amplitude of MEPs, whereas cooling lower than 28°C decreased MEP amplitude. Again, latency of MEPs increased linearly with the reduction of temperature.

### Considerations of cost effectiveness of IONM

For a representative person in 1988, the lifetime cost of living with complete paraplegia after injury at age 33 years was estimated to be US\$500,000. For a complete quadriplegia incurred at age 27 years, the cost rose to US\$1 million [22]. In 1995, Nuwer *et al.* [3] estimated that the cost for monitoring scoliosis surgery with SEPs in the United States was approximately US\$600. In the same study, the rate of paraparesis or paraplegia was 0.245 considering false-negative (postoperative neurologic deficits in spite of unchanged SEPs) and true-positive (postoperative neurologic deficits predicted but not—or only partially—prevented by intraoperative SEP changes) results. More recently, Kombos *et al.* [23] has

suggested that the cost of IONM in Europe for a complex spinal operation is approximately US\$350. We can therefore assume that the use of IONM during spine surgery is justified from a cost analysis perspective as long as it prevents severe permanent motor deficits in approximately 0.12% of the monitored patients (*ie*, dividing the lifetime cost of living with complete paraplegia [US\$500,000] by the cost of monitoring one patient with scoliosis [US\$600], it turns out that IONM is cost effective if it prevents paraplegia in at least one out of every 833 procedures [0.12%]). Interestingly, this corresponds to the rate of false-negative SEP results in the study by Nuwer *et al.* [3]. Considering that, so far, there has not been a single report in the literature of postoperative paraplegia in spite of intraoperatively preserved MEPs, these arguments strongly support the use of a combination of SEPs and MEPs during scoliosis surgery.

### Conclusion

A combined use of SEP and MEP techniques for intraoperative monitoring should be implemented during orthopedic procedures of the spine to detect or prevent injury to the spinal cord. Single modality of evoked potentials is not sufficient to fulfill this role. This is a cost-effective and rational neurophysiological approach. In the operating room, communication among the surgeon, neurophysiologist, and anesthesiologist is the key to avoid false alarms and to recognize specific, surgically-induced derangements to the spinal cord promptly. This attitude will eventually result in reliable and therefore successful neurophysiological monitoring.

### References and recommended reading

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This is a comprehensive article that uses MEPs and SEPs for monitoring with obvious examples of their benefits.

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