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Original Article

Somatosensory- and motor-evoked potential monitoring during spine and spinal cord surgery

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Study design: Prospective, observational study.
Setting: Regional Trauma Center, Torino, Italy.
Objectives: Complex spinal surgery carries a significant risk of neurological damage. The aim of this study is to determine the reliability and applicability of multimodality motor-evoked potentials (MEPs) and somatosensory-evoked potentials (SEPs) monitoring during spine and spinal cord surgery in our institute.
Methods: Recordings of MEPs to multipulse transcranial electrical stimulation (TES) and cortical SEPs were made on 52 patients during spine and spinal cord surgery under propofol/fentanyl anaesthesia, without neuromuscular blockade.
Results: Combined MEPs and SEPs monitoring was successful in 38/52 patients (73.1%), whereas only MEPs from at least one of the target muscles were obtained in 12 patients (23.1%); both MEPs and SEPs were absent in two (3.8%). Significant intraoperative-evoked potential changes occurred in one or both modalities in five (10%) patients. Transitory changes were noted in two patients, whereas three had persistent changes, associated with new deficits or a worsening of the pre-existing neurological disabilities. When no postoperative changes in MEP or MEP/SEP modalities occurred, it was predictive of the absence of new motor deficits in all cases.
Conclusion: Intraoperative combined SEP and MEP monitoring is a safe, reliable and sensitive method to detect and reduce intraoperative injury to the spinal cord. Therefore, the authors suggest that a combination of SEP/MEP techniques could be used routinely during complex spine and/or spinal cord surgery.
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Keywords: spine surgery; spinal cord surgery; intraoperative neurophysiologic monitoring; transcranial, electrically elicited motor-evoked potentials; somatosensory-evoked potentials

Introduction

Spine and spinal cord surgery carries a significant risk of neurological impairment.[1] The incidence of severe post-operative neurologic sequelae has been reported to be 0.46% for anterior cervical discectomy,[2] 0.25–3.2% for scoliosis surgery[3,4] and 23.8–65.4% for intramedullary spinal cord tumour surgery.[5,6]

Over the last decade, intraoperative monitoring with somatosensory-evoked potentials (SEPs) has proven to be a reliable tool in the assessment of the spinal cord function during complex surgery. Moreover, it is also possible to identify any evolving iatrogenic spinal cord injury, thus reducing the risk of postoperative deficits.[7] However, as SEPs are mediated primarily by the dorsal sensory spinal cord tracts, they cannot assess the spinal motor pathways, which may be independently damaged.[8] Consequently, the use of transcranial, electrically-elicited, motor evoked potentials (MEPs) has been introduced so as to assess the integrity of the motor pathways during such procedures as the removal of spinal cord tumours, correction of scoliosis and cervical spine surgery.[8–15]

This study sought to determine the reliability and applicability of multimodality MEP and SEP monitoring during spine and spinal cord surgeries in our institution.

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Materials and methods

MEP and SEP monitoring was attempted on a total of 52 patients (30 men, 22 women, average age 50.9±19.6 year, range 16–81 years).

The surgery was carried out for trauma in 10 cases, tumour resection in 20, spondylosis in 14, scoliosis in five, correction of vascular abnormality of the spinal cord in two cases and multiple dorsal echinococcus cysts in one. Table 1 reports the procedures used, 25 cervical (48.08%), 20 (38.46%) thoracic and seven (13.46%) lumbosacral.

Preoperative mild to severe neurological disability was present in 32 (61.5%) of the 52 patients, whereas 20 (38.5%) had a normal preoperative neurological examination.

All patients gave their informed consent after being informed that potential risks included seizures, skin burns from stimulating electrodes, tongue bites, inadvertent injury caused by transcranial electrical stimulation (TES)-induced patient movement.

Continuous spinal cord monitoring was performed, as from the induction of anaesthesia until the end of surgical manoeuvres.

The anaesthetic protocol used during surgery included a combination of the two drugs, remifentanil and propofol, with total intravenous anaesthesia (TIVA). Induction was obtained with a continuous infusion of remifentanil at 0.15–0.25 μg/kg/min and maintained with 0.25–0.40 μg/kg/min. Target-controlled infusion was used for propofol with a plasma concentration for induction of 3–4 μg/ml and maintenance with 3–4.5 μg/ml. No muscle relaxants were used after induction and intubation.

Cortical SEPs were elicited by a 100 or 200 μs square-wave electrical pulse presented sequentially to the posterior tibial and/or median nerves at a rate of 7.1/s. Stimulus intensity was adjusted individually and ranged from 14 to 40 mA. Cortical potentials were recorded from monopolar needle electrodes placed at Cz′ for posterior tibial nerve stimulation, C3′ or C4′ for median nerve stimulation and referenced to Fpz (international 10–20 EEG system). Commercially available neurophysiology instrumentation (Nicolet Endeavor; Nicolet Biomedical, Madison, WI, USA) was used for SEPs stimulation and recording. Filtering was typically 30–1000 Hz, with a 50 or 100 ms analysis time; averaging was stopped manually at such times as potentials were clearly reproducible and the responses repeatedly compared to that of the baseline (after induction and positioning).

Table 1 Diagnostic categories of the 52 patients

Pathology	*Total*		*Level*		
	No.	*%*	*Cervical*	*Thoracic*	*Lumbo-sacral*
Trauma	10	19.2	8	2	
Tumour	20	28.5	5	10	5
Spondylosis	14	26.9	12	2	
Scoliosis	5	9.6		4	1
AVM	2	3.9		1	1
Echinococcus	1	1.9		1	
Total	52				

MEPs were elicited with a brief duration of transcranially applied electrical pulses (pulse width = 50 μs), high-voltage (200–700 V) anodal electrical stimulus train (N = 3–5, interstimulus interval 4 ms), delivered with two corkscrew-type electrodes inserted over motor cortex regions at C3 and C4 (international 10–20 EEG system). Stimuli were delivered through a commercially available IOM electrical stimulator (D185; Digitimer, Welwyn Garden City, UK) with responses recorded on the same system used for monitoring SEPs. In order to avoid bite or tongue bites, a bite block consisting of rolled gauze were used.

Right extremity MEPs were monitored after left-cranium anodal stimulation and *vice versa*. MEPs were recorded with a needle electrode placed in the muscle with a belly-tendon montage. Although the choice of muscles used differed according to the pathology, those most commonly chosen were responses from the abductor pollicis brevis or the first dorsal interosseus muscle in the upper extremities and both tibialis anterior and abductor hallucis muscles in the lower extremities. The time base was 100–200 ms and the filter bandpass 30–3000 Hz, occasionally making use of a restricted bandpass so as to reduce artefacts. Cortical SEP amplitude change was defined as an amplitude alteration occurring abruptly or as a trend clearly exceeding trial-to-trial variability, excluding technical problems that is, a persistent unilateral or bilateral amplitude loss of at least 50% was used as a warning criteria.

MEPs were interpreted in a similar manner, but as there was a large trial-to-trial variability of the normal background, persistent amplitude decrements of more than 60% of baseline values were considered indicative of significant change.

The surgical team was immediately informed of any significant EP change.

Results

Successful combined MEP and SEP monitoring was obtained in 38 (73.1%); only MEPs from at least one of the target muscles were obtained in 12 patients (23.1%).

Both MEPs and SEPs were absent in two patients (3.8%), who presented marked preoperative lower-limb weakness and cannot walk without assistance.

It was possible to record both SEPs and MEPs in the 20 patients who had a normal preoperative neurological examination; whereas SEPs were unsuitable for intraoperative monitoring in 12 (37.5%) and MEPs in two (17.8%), in the neurologically compromised group of patients, no patient with absent MEP had preserved SEP; therefore, the data herein reported refer to the 50 patients in whom it was possible to carry out some form of monitoring.

During the procedure, as the bite block had been intraoperatively misplaced, two patients had a minor injury, one a tongue bite and the other a lip bite; there were no skin burns at stimulation sites, no cardiac arrhythmias occurred nor did intraoperative or postoperative seizures or epilepsy attacks.

Although the TES-induced movements were slight and, on the whole, did not disturb the surgical manoeuvres, in some cases it was considered better to evoke only MEPs at intervals during surgery.

No monitoring changes were observed in 45/50 patients (90%): none of these subjects had postoperative deficits.

Persistent SEP and/or MEP alteration was observed in three patients (6%). One patient (2%; Figure 1) had a persistent drop in amplitude associated with loss of complexity of the left lower limb MEPs, with postoperative worsening of the pre-existing motor deficit (SEPs were absent), a finding that was still present at a 6-month follow-up (diagnosis D1 metastasis). Another patient (2%) had a persistent complete loss of SEPs and MEPs, during an intramedullary spinal cord tumour removal, with postoperative complete spinal transection syndrome; SEPs disappeared during myelotomy in another case (2%) and the patient presented a postoperative ataxic syndrome (see Table 2). The clinical picture remained substantially unchanged in all two patients at a 12-month follow-up.

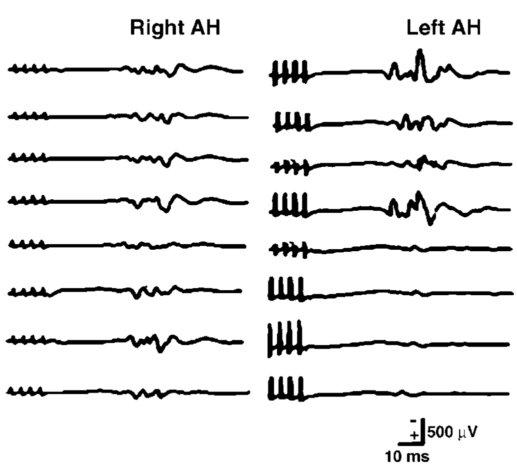

Figure 1 A marked drop in amplitude and loss of MEPs complexity from left abductor hallucis (AH) in patient No. 1, during surgical treatment of a D1 metastasis. A postoperative worsening of a pre-existing left leg motor deficit was observed. Posterior tibial nerve SEPs were absent bilaterally.

Transient combined intraoperative MEP and SEP modifications were observed in two patients (4%; Figure 2). No postoperative deficit was observed in either of these patients.

There was an 8.3% intraoperative change rate (1/12) in subjects where it was possible to monitor only MEPs and 10.5% (4/38) in patients where both SEPs and MEPs were monitored.

Discussion

The aetiology of neurological damage during spine or spinal cord surgery includes direct or indirect trauma to neural elements,[16,17] ischaemia, compression, over-distraction,[3] intraoperative or postoperative hypotension,[18,19] bleeding[20] or metabolic imbalances.[21] Consequently, the use of intraoperative neurophysiologic monitoring allows for the identification of any change at a still reversible stage, permitting a prompt correction of the cause avoiding permanent neurological impairment.

Although the past few years have witnessed the wide use of intraoperative SEPs recording, which has, on the whole, proven to be a reliable mean of monitoring the integrity of the spinal cord during spine and spinal cord surgery, several reports[7,8,22–27] have documented the inadequacy of SEPs when assessing motor pathway functional integrity in the spinal cord.

Another disadvantage of using SEPs is that they must be averaged and this takes at least 10–40 s for updating, an acquisition delay, which, in turn, delays warning the surgical team and thus the prompt implementation of corrective measures. Moreover, during intramedullary tumour surgery, SEPs are frequently lost during myelotomy.[28] Finally, SEPs, in particular those obtained by tibial nerve stimulation, are frequently altered in subjects with clinical evidence of altered spinal cord function.[29] Indeed, the percentage of absent or poorly defined SEPs in our series was 38.7%.

MEPs can be easily recorded from muscles by stimulating the motor cortex transcranially with short high-frequency trains of stimuli, producing several corticospinal volleys that summate to depolarize spinal motor neurons.[10,30–36]

This technique has several advantages:

(a) it monitors the whole of the motor system from the cortex down to the neuromuscular junction;
(b) it allows for an individual limb assessment; and

Table 2 SEP and MEP changes and clinical results

No.	*Diagnosis*	*Technique*	*Event*	*Outcome*
1	D1 metastasis	MEPs	Decreased MEP amplitude	Motor worsening
2	Cervical myelopathy	SEPs/MEPs	Transitory loss of SEPs/MEPs	Unchanged
3	Scoliosis	SEPs/MEPs	Transitory loss of SEPs/MEPs	Unchanged
4	C5-T5 ependimoma	SEPs/MEPs	Persistent loss of SEPs/MEPs	Paraplegia/sensory deficit
5	C3-T3 ependimoma	SEPs/MEPs	Persistent loss of SEPs	Sensory deficit

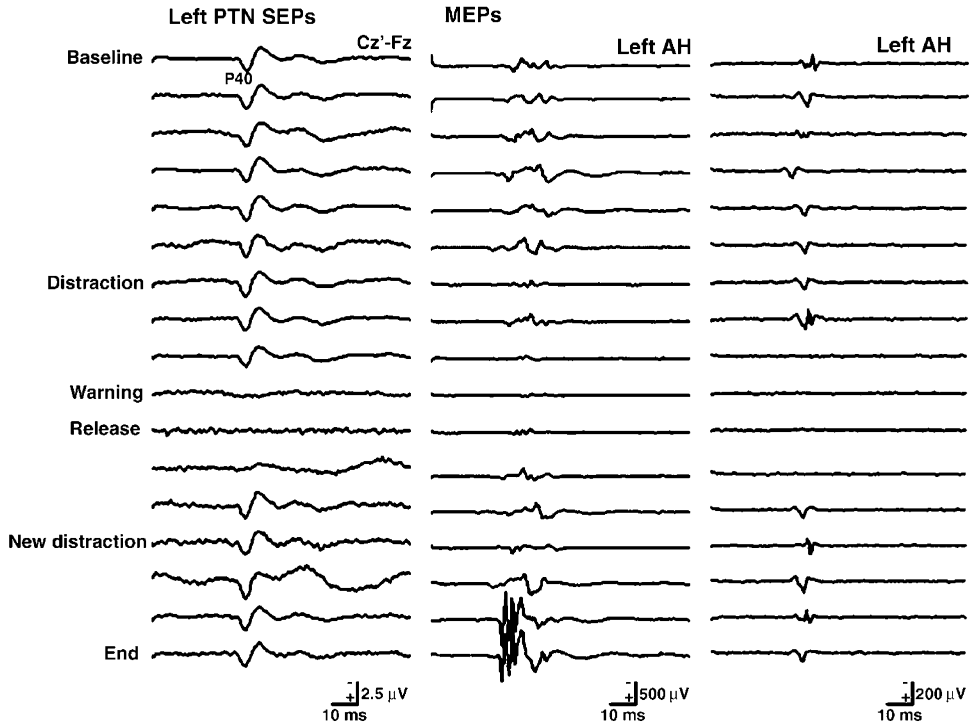

Figure 2 Transient disappearance of SEPs and MEPs during spine distraction in patient No. 3, who underwent surgery for correction of scoliosis. The patient awoke with no deficit: note that MEPs disappear before SEPs. Left PTN-SEPs: SEPs from left tibial nerve. MEPs: motor evoked potentials. TA: tibialis anterior muscle; AH: abductor hallucis.

(c) as MEPs have a larger amplitude than SEPs, no averaging is required and it is, therefore, possible to carry out real-time updating.

Finally, MEPs may be present even when SEPs are either lost or poorly defined, thus allowing for the monitoring of a larger percentage of patients.

The application of intraoperative MEPs monitoring is therefore rapidly expanding in neurosurgical,[10,31,34,36–38] spinal endovascular,[39] thoracoabdominal aneurysm[40–43] and orthopaedics procedures.[13,14,44–46]

No patient with absent MEPs had preserved SEPs in our series and the percentage of overall intraoperative monitoring rose from 73.1% (patients in whom a combination of SEP/MEP monitoring was possible) to 96.2% (subjects with absent or poorly defined SEPs and recordable MEPs): this percentage is similar to the majority of pre-existing studies.[30,38,45,47]

No false negatives were observed and the number of false positives, true positives and true negatives is quite similar to those found in previous studies.[13–15,45] In agreement with other authors,[13–15,45,48] the persistence of MEPs and/or SEPs correctly predicted the motor or sensory postoperative outcome in our study cohort.

A 50% drop in cortical SEP amplitude, whether associated with an increase in latency or not, is the universally accepted warning criteria.[49,50] Conversely, different warning criteria for MEPs have been proposed, ranging from changes in the thresholds that elicit muscle MEPs[30,47] to the pure presence or absence of responses,[10,38,51,52] amplitude variation[15,45,53,54] or a combination of change in threshold and amplitude variation.[55]

As it is sometimes necessary to increase stimulus intensity to maintain stable responses owing to depth or accumulation of anaesthetics, we did not consider an elevation of the threshold to elicit MEPs as a warning criteria. The yes/not criteria is probably the best choice when a combined recording of epidural D wave is possible; in fact, when the D wave decreases by less than 50% and muscle MEPs are lost, it indicates that patient will suffer a so-called 'transient paraplegia' but will ultimately recover.[28,56,57] The combined use of epidural and muscle MEPs is probably the best way of assessing the motor pathways during spinal cord surgery. When it is not possible to carry out an epidural D wave recording, we think that an amplitude criteria based on a significant reduction in amplitude persistent in time can be the best solution, in order to judge motor pathway integrity.

Changes in amplitude and the number of MEP phases were associated with a worsening of pre-existing deficit: in our cohort, results that corroborate the findings that a decrease in MEP amplitude associated with their reduction in the waveform complexity correlate to the motor outcome.[55]

No isolated changes in MEPs without SEP changes were observed, a pattern suggesting an increased sensitivity of MEPs to spinal cord ischaemic injury.[8,58,59] This is probably owing to the fact that a larger number of patients monitored showed either poor quality SEPs or none at all and were consequently only monitored with MEPs.

Our study is in line with the general agreement as to the safety of MEPs:[8,60] indeed, the only adverse events were minor tongue–lip bites, probably owing to the site of stimulation (C3/4), which may directly activate the temporalis muscles and to intraoperative misplacement of the bite block.

Conclusions

Combined SEP and MEP intraoperative monitoring is a safe, reliable and sensitive method to detect and reduce injury to the spinal cord. Sensory and motor pathways can be independently assessed during surgery, the number of false negative is reduced to zero and there is probably a positive influence on the final postoperative outcome. In the case of absent or poorly defined SEPs, MEPs are generally recordable, thus making it possible to monitor larger numbers of patients successfully. A combined use of SEP and MEP techniques would be advisable as routine practise during complex spine/spinal cord surgery.

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