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# Impact of multimodal intraoperative neurophysiological monitoring of the spinal cord during spine and spinal cord surgeries

Walaa Elwakil<sup>1\*</sup> , Mohamed Imam<sup>1</sup>, Marwa Hassan<sup>1</sup> , Waleed Elsaadany<sup>2</sup> and Omnia Gaber<sup>1</sup>

## Abstract

**Background** There is growing evidence of the valuable role of multimodal intraoperative neurophysiological monitoring (IONM) during spine and spinal cord surgeries, as it provides an opportunity to recognize functional changes of the neural elements, usually in the reversible stage, during complex surgical manipulations. Therefore, it may reduce the risk of postoperative neurological dysfunction and improve functional outcomes. The aim of the current study was to evaluate the efficacy of multimodal IONM for preventing and predicting iatrogenic neurological dysfunction during spinal cord and spine surgeries.

**Results** Significant alerts had occurred in 9 out of 24 patients; however, all the changes were reversible and did not contribute to postoperative clinical deterioration. Only one case got worsened in the early postoperative follow-up period, with stable intraoperative monitoring.

**Conclusion** Intraoperative monitoring is a valuable tool in spine and spinal cord surgeries. Combined transcranial motor-evoked potential (TcMEP), somatosensory-evoked potential (SSEP), and spontaneous electromyography (EMG) monitoring may prevent permanent motor deficit and enhance the postoperative outcomes.

**Keywords** Intraoperative neurophysiological monitoring, Motor-evoked potentials, Somatosensory-evoked potentials, Spontaneous electromyography, Spine

## Background

Recent years have witnessed remarkable advancements in the technology of intraoperative neurophysiological monitoring (IONM). Its use during spine and spinal cord surgeries allows assessment of spinal cord function through real-time feedback from sensory tracts, motor tracts, and individual nerve roots, thus reducing the risk of iatrogenic damage to the nervous system and providing functional guidance to the surgeon and anesthesiologist [1, 2]. The most commonly utilized IONM techniques

include, but are not limited to, somatosensory-evoked potentials (SSEPs), transcranial motor-evoked potentials (TcMEPs), and electromyography (EMG) [3].

Monitoring SSEPs is one of the most common intraoperative spinal monitoring modalities. The fact that they can be recorded continuously and safely throughout the procedure gives them the distinct advantage of providing information on signal transmission along the dorsal columns of the spinal cord. SSEPs accurately reflect postoperative sensory findings and, indirectly, motor function due to the proximity of the dorsal column and corticospinal tract [4, 5].

TcMEPs provide direct monitoring of the lateral and ventral corticospinal tracts and are highly sensitive to any minute change in the neural structures, especially in spine surgeries [6, 7]. In order to activate motor pathways, a series of high-voltage stimuli is applied to

\*Correspondence:

Walaa Elwakil

walaa.ali@alexmed.edu.eg

<sup>1</sup> Physical Medicine, Rheumatology and Rehabilitation, Alexandria University, Alexandria, Egypt

<sup>2</sup> Alexandria University, Neurosurgery, Alexandria, Egypt

electrodes on the surface of the head to produce either a motor contraction (muscle MEP) or a nerve action potential (D-wave) that can be recorded [8].

Spontaneous or free-running EMG is frequently used to monitor selective nerve root function during spinal cord surgery [9]. In contrast to SSEPs, EMG is a “real-time” recording from the peripheral musculature. Spontaneous EMG can aid in the prevention of postoperative radiculopathy after spinal instrumentation surgery, such as pedicle screw placement [10].

The use of SEPs, MEPs, and spontaneous EMG in combination provides the tools required to optimize the functional integrity of the neural pathway during a broad spectrum of routine and complex spinal surgeries while maximizing the efficacy of monitoring mild changes suggestive of early reversible damage to the neural structures [11–14].

This prospective study aimed to evaluate the efficacy of multimodal IONM during spinal cord and spine surgeries for preventing and predicting iatrogenic postoperative neurological dysfunction.

## Methods

### Subjects

Intraoperative TcMEP, SEP, and spontaneous EMG monitoring were done for 24 patients who underwent spinal cord or spine operations. All operations were performed by neurosurgeons with extensive experience in these types of spinal surgeries. Exclusion criteria include history of previous neurosurgery; any neurological disorders that interfere with EMG signal, for example, myasthenia gravis, botulism, dystonia, and muscle dystrophy [14–16]; and contraindications to MEP like epilepsy, vascular clips, cardiac pacemakers, and convexity skull defects [17].

### Patient's assessment

A preoperative and 1-week postoperative full neurological examination was performed for all the patients. All patients were evaluated clinically using the Japanese Orthopaedic Association (JOA) score [18]. Data were compared to assess any postoperative neurological deficit.

### Anesthesia

All patients were anesthetized using the total intravenous anesthesia protocol (TIVA), which consists of propofol infusion (sedative-hypnotic) and fentanyl, which is mostly used for analgesia. Some inhalation anesthetics were used in induction, like isoflurane or sevoflurane, only at low concentrations (0.6% or 0.8% minimal alveolar concentration MAC). A single dose of 0.1 mg/kg of atracurium (a short-acting muscle relaxant) was

also administered to facilitate endotracheal intubation [19]. It is important to note that early replacement of blood loss was critical to avoid MEP changes induced by hypotension.

### Neurophysiological monitoring technique

Multimodal monitoring was used in spine and spinal cord operations, including SSEP, Tc-MEPs, and EMG. However, in some surgeries, like selective dorsal rhizotomy operations, only EMG and MEP were recorded to monitor the nerve root at risk. Monitoring was done using Inomed (Emmendingen, Germany).

Baseline recordings were carried out after the skin incision to allow the muscle relaxant effect to wear off and the depth of anesthesia to stabilize. They served as references for the remainder of the surgery's monitoring period [20, 21].

SEPs were recorded throughout the surgeries. In the upper extremity, a peripheral nerve (median or ulnar nerve) was stimulated near the wrist and recorded via subdermal needles or adhesive surface electrodes on the scalp/parietal and frontal cortices at cp3 (2 cm behind c3) and cp4 (2 cm behind c4). While in the lower extremity, the posterior tibial nerve at the foot was stimulated, and recording was made from the scalp/cortex cpz (2 cm behind cz)/fz in the lower extremities (according to the 10–20 international electrode system). The ground electrode was placed at the base of the neck [22]. A decreased amplitude by 50%, with associated increased latency of more than 10% in comparison to the patient's baseline values, constitutes a warning sign [23].

TcMEPs were monitored by placing stimulating cork-screw electrodes in the scalp. The stimulus points were C3, C4, C1, C2, and Cz in accordance with the 10–20 international electrode system [24]. Needle electrodes were used to record compound muscle action potentials (CMAPs) from targeted muscles. Muscles are selected based on the surgical procedures and spinal levels involved.

High voltage (up to 1000 V) was applied using a train of three to five stimuli with an interstimulus interval of 1 to 3 ms. Before administering an MEP stimulus, the surgeon and nearby staff were informed in order to prevent unexpected patient movements from interfering with the procedure. Every 2 to 5 min, MEPs were conducted. During the dissection of the spinal cord lesion, particularly when addressing important areas, even more trials were attained. A significant intraoperative change was defined as a 50% reduction in amplitude [25].

It is worth mentioning that SEP and MEP in children may differ from those in adult patients. The configuration of SEPs becomes identical with that of adults after the age of 3 years; however, the peak latencies are shorter than

those of adults, which depend largely on the patient's height. This is due to the fact that the myelination of the dorsal columns is not complete until about 8 years of age [26]. Compared with older patients, stronger stimulation is needed to produce MEP responses in children, reflecting the immaturity of their motor pathway, which does not fully develop until about 13 years of age [27]. This wide range of normal values according to patients' ages highlights the importance of the baseline evaluation to predict significant intraoperative changes.

Spontaneous EMG monitoring was done on different muscles (at least two) according to the type of surgery and nerve root at risk. It was done throughout the operation; the surgeon was warned if a discharge of high frequency and high amplitude was detected. Parameter changes may be related to cauterization, surgical manipulation, traction, or neurological injury. The surgeon was immediately warned about changes to reverse the cause and avoid any postoperative neurologic deficit [28].

**Statistical analysis**

The statistical analysis was done using SPSS Statistics Version 20.0 (Armonk, NY: IBM Crop). Qualitative data were represented as numbers and percentages. Quantitative data were described as range (minimum and maximum), mean, standard deviation, and median.

**Results**

The current study included 24 patients who underwent IONM during their spine or spinal cord surgeries. A total of 45.8% were males, while 54.2% were females. The age of patients at the time of surgery ranged from 3 to 60 years (mean age = 16.21 ± 17.33 years) (Table 1).

The most frequent spine operation was selective dorsal rhizotomy (SDR) representing 33.3% of cases, followed by scoliosis; 16.7%, tethered cord; 8.3%, spinal cord

neurofibromatosis; and 4.2% for each of the remaining spine operations (Table 2).

During monitoring, stable IONM was observed in 15 patients (62.5%). Intraoperative changes were recorded in nine patients; three patients had SEP changes, while MEP changes occurred in six operations, three of which were accompanied by changes in spontaneous EMG (Table 3).

Figure 1 demonstrates a significant drop in amplitude of MEP recorded from the left lower limb during surgical correction of dorsal kyphosis. Fortunately, all the IONM changes were repaired immediately after informing the surgeons. No cases showed persistent, unrepaired intraoperative changes (Table 4).

By comparing neurological examination using JOA preoperatively versus postoperatively, the JOA scores preoperatively were 12.88 ± 2.5 (ranged from 8 to 16) and postoperatively were 13.25 ± 2.6 (ranged from 9 to 16). We found that 14 patients (58.3%) showed the same examination, 9 patients (37.5%) showed some improvement (mean = 1.1 ± 0.3), and only one patient (4.2%)

**Table 1** Distribution of the studied cases according to their demographic data (n = 24)

Demographic data	No.	%
<b>Sex</b>		
Male	11	45.8
Female	13	54.2
<b>Age (years)</b>		
< 5	5	20.8
5–10	10	41.7
> 10	9	37.5
Min.–max.	3.0–60.0	
Mean ± SD	16.21 ± 17.33	
Median (IQR)	7.0 (5.0–21.50)	

SD Standard deviation, IQR Interquartile range

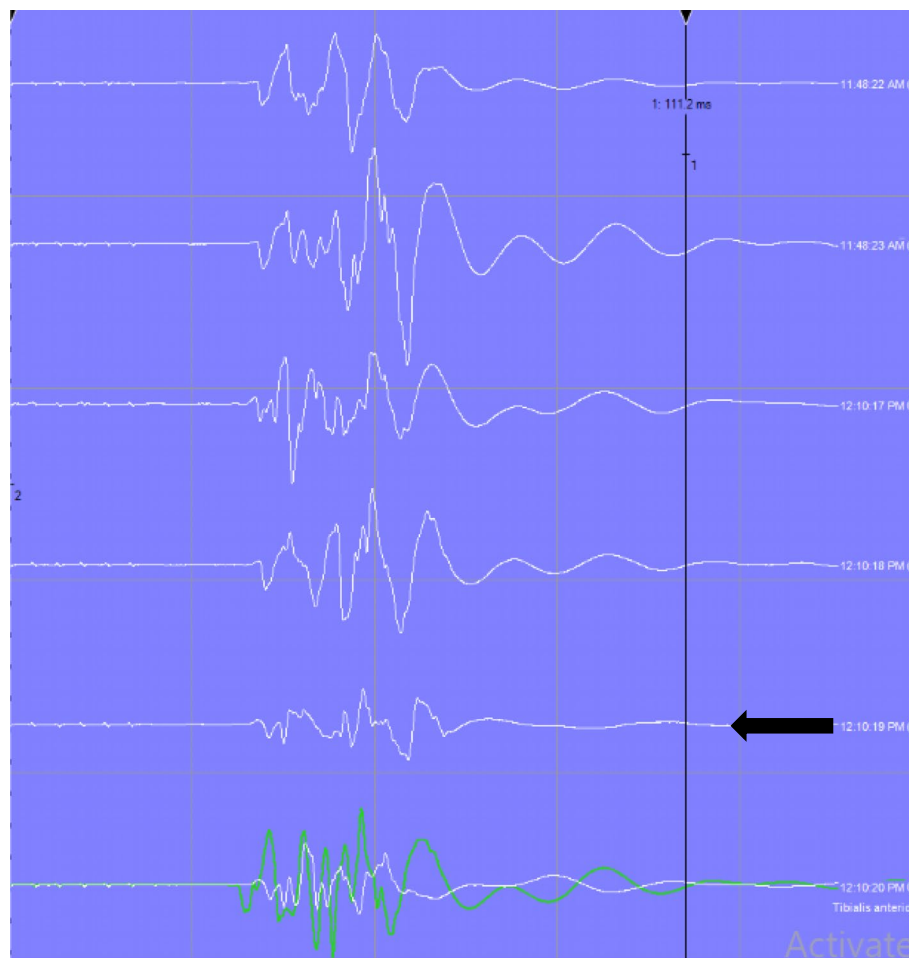
**Table 2** Distribution of the studied cases according to the spine operation (n = 24)

Operation	No.	%
Cervical disc	1	4.2
Cervical lesion resection	1	4.2
D12-L3 lipoma	1	4.2
Dorsal kyphosis	1	4.2
Dorsal lesion	1	4.2
Dorsal spine tumor	1	4.2
Myelomeningocele	1	4.2
Spinal cord neurofibromatosis	2	8.4
Scoliosis	4	16.7
Selective dorsal rhizotomy	8	33.3
Spine cervical tumor C4–C5	1	4.2
Tethered cord	2	8.3

**Table 3** IONM changes during spine/spinal cord surgeries

Operation	Change in intraoperative parameters		
	SEP (n = 3)	MEP (n = 6)	EMG (n = 3)
Cervical lesion resection	0	1	1
D12-L3 lipoma	1	0	0
Dorsal kyphosis	0	1	0
Dorsal lesion	1	0	0
Scoliosis	1	0	0
Selective dorsal rhizotomy	0	1	1
Spinal cord neurofibromatosis	0	2	0
Spine cervical tumor C4–C5	0	1	1

IONM Intraoperative neurophysiological monitoring



**Fig. 1** MEP traces recorded from the left tibialis anterior muscle during surgical correction of dorsal kyphosis demonstrate a significant drop in MEP amplitude (back arrow)

**Table 4** Distribution of the studied cases according to intraoperative changes

	Repaired change		Unrepaired	
	No.	%	No.	%
SEP (n = 16)	3	18.8	0	0.0
MEP (n = 24)	6	25.0	0	0.0
EMG (n = 24)	3	12.5	0	0.0

SEP Sensory-evoked potential, MEP Motor-evoked potential, EMG Electromyography

showed some worsening after the SDR operation (deteriorates by 1 point postoperatively) (Table 5). It is worth mentioning that all cases that improved clinically (9 patients) did not experience IONM changes.

Surprisingly, the only case that deteriorated clinically in the postoperative evaluation did not experience IONM changes during the surgical procedures.

**Table 5** Distribution of the studied cases according to JOA clinical evaluation (n = 24)

Pre versus postoperative JOA clinical evaluation	No.	%
Worsen	1	4.2
The same	14	58.3
Improved	9	37.5

JOA Japanese Orthopaedic Association

### Discussion

Multimodal intraoperative neurophysiological monitoring provides a great deal of information for spinal surgeries. In this study, we monitored 24 patients and could observe IONM changes in nine patients and postoperative neurological deficits in only one patient. Most of the changes were recorded during MEP monitoring (6/9 cases), followed by SEP changes (3/9 cases) and EMG

(3/9 cases), which highlights the importance of MEP monitoring during spine surgeries. Park et al. [23] proposed the advantages of more sensitive MEP alerts for preventing early neural damage as MEPs change earlier than the SEP signal, which facilitates a quicker diagnosis of impending spinal-cord injury [29]. This is especially important for tumors where complete resection is the most important prognostic factor, such as intramedullary spinal cord ependymomas. Choi et al. used a 75% amplitude reduction cutoff in their study [30], whereas the current study used a 50% amplitude reduction cutoff. Although Choi et al.'s 75% reduction cutoff value eliminated many false positives, it also resulted in one false-negative case. Contrarily, setting the baseline at 50% for surgery on 29 patients with cervical kyphosis resulted in more false-positive MEP changes, thus reducing the specificity of the monitoring modality [13].

In the current study, SEP was not monitored in selective dorsal rhizotomy (SDR) operations. This was related to the limited ability of SEP monitoring to detect motor symptoms and its associated false-positive alerts, as it covers the dorsal sensory tract rather than the ventral motor tract [31]. Moreover, Weinzierl et al. stated that SEPs are less sensitive at detecting nerve root injuries and thus could miss injuries caused by the process of pedicle screw placement or nerve root traction [32]. Such problems can limit the use of SEPs as a standalone monitoring tool.

In the study conducted by De Vloo et al., free-running EMG was found to be valuable in identifying the ventral or dorsal nature of the root during SDR operations, where gentle tapping of the ventral roots resulted in a clear EMG activity that was absent on gentle manipulation of the dorsal root. Moreover, EMG was useful to identify the level of the dorsal root to be divided, and the stimulation threshold was crucial to detecting the rootlets that were resected. Candidate rootlets for transection showed abnormal stimulation responses with no or minimal anal sphincter involvement [33]. Additionally, another recent study demonstrated the importance of TcMEPs recording in SDR operations after each sensory rootlet sectioning in order to reassure surgeons about the maintained integrity of pathways after each sectioning and to provide information to the neurosurgeon about any possible muscular motor loss that may happen during the root dissection process, where some motor fibers are carried along with the sensory ones [34].

All the IONM alerts recorded during spine operations were repaired. This highlighted the fact that in the current study, all changes occurred in a reversible state of damage. Therefore, they serve as critical alerts that the surgeon can rely on to prevent irreversible harm to the neural elements. Our findings coincide with those of Park

et al. [23], as they demonstrated that a decrease in MEP amplitude is not always associated with a postoperative neurologic deficit but is useful in assessing early ischemic or mechanical traction of the spinal cord. Deletis et al. [35] also emphasized that the disappearance of MEPs does not always imply permanent dysfunction.

The current study demonstrated only one false-negative case that showed no IONM changes, but clinical and functional worsening was noticed directly after SDR operation. However, a significant reduction in muscle tone was observed immediately after SDR operations, which unmasks weakness and difficulties in coordination movements, and may contribute to worsening in postoperative clinical evaluation. Therefore, a specially tailored rehabilitation program focusing on learning new movement patterns is recommended in such cases [36]. No true-positive or false-positive cases were reported. This may be attributed to the small sample size of cases, as multimodal IONM is not widely adopted in Egypt. In a study conducted by Eggspuehler et al., 2 out of 246 cases were false negatives, while 10 cases were true positives and 2 were false-positive cases [37].

In this study, significant IONM alerts were dealt with by immediate communication with the surgeon, investigating the cause, and working upon it. Park et al. [23] found that IONM changes could result from several factors, such as hypotension, prolonged tumor resection, excessive cord manipulations, local hypothermia, and dural flap traction. Correcting the cause was useful for promoting recovery for most of the deteriorated or lost MEPs. After investigating all the previously mentioned factors, if the neurophysiologic abnormality persists, stopping further surgical resection or removal of the implant may be considered.

The study has some limitations. The relatively small number of patients, in addition to the heterogeneity of the operation sites and nature, may have had some impacts on the type and magnitude of the intraoperative neuromonitoring changes. Moreover, there is a lack of long-term follow-up of cases to assess signs of clinical and functional improvement.

### **In conclusion**

IONM has remarkably impacted the surgical management of the spine and the spinal cord. Its use allows monitoring different pathways and neural structures. The multimodal data complement each other and are valuable in decision-making during complex surgical procedures, as safety is the primary concern in spine surgeries. It can minimize the possibility of a new onset postoperative neurological deficit with subsequent favorable postoperative outcomes. It also constitutes an element of evidence to detect the time and type of neurological damage that influence medicolegal defensibility.

**Abbreviations**

CMAP	Compound muscle action potential
EMG	Electromyography
IONM	Intraoperative neuromuscular monitoring
JOA	Japanese Orthopaedic Association
MAC	Minimal alveolar concentration
MEP	Motor-evoked potential
SDR	Selective dorsal rhizotomy
SSEP	Somatosensory-evoked potential
TcMEP	Transcranial motor-evoked potential
TIVA	Total intravenous anesthesia protocol

**Supplementary Information**

The online version contains supplementary material available at <https://doi.org/10.1186/s43166-023-00201-0>.

**Additional file 1: Supplementary 1.** Type of changes IONM changes during spine/ spinal cord surgeries.

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**Authors' contributions**

MI, WS, and MH performed the conceptualization and idea generation; OG wrote the original draft; MH, WW, and OG analyzed the results; and all authors shared in writing the manuscript.

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**Availability of data and materials**

The data sets used are available from the corresponding author on reasonable request.

**Declarations****Ethics approval and consent to participate**

This study was approved by the Ethics Committee, Faculty of Medicine, Alexandria University, serial number 0106904, date: September 16, 2021. A written informed consent form was signed by each participant.

**Consent for publication**

Not applicable

**Competing interests**

The authors declare that they have no competing interests.

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