MEDICINE UPDATES JOURNAL
Faculty of Medicine Port Said University
Volum: 18 No:3 PP:32 - 53

"Role of intraoperative neurophysiological monitoring during spinal deformity surgery"

Authors
Amr Abu Elfadle [1], Abdallah Saad Gad [2], Ahmed Samir Elshikhali [3], Esam Mokbel [3], Ebrahim Shamhoot [3]

[1] Neurosurgery department, Faculty of medicine, Port said university, Egypt

[2] Medical physiology department, Armed forces College of Medicine, Cairo, Egypt

[3] Neurosurgery department, Faculty of medicine, Tanta university, Egypt

Submitted: 11/04/2024
Accepted:08/05/2024

DOI: 10.21608/MUJ.2024.282476.1167

ISSN : 2682-2741

https://muj.journals.ekb.egdean@med.psu.edu.eg
vice_dean_postgraduate@med.psu.edu.eg

ABSTRACT:

Background: Intraoperative Neurophysiological Monitoring (IONM) is used in complicated spine surgeries, such as scoliosis and others which have the possibility of intraoperative and postoperative neurological complications. Multimodal IONM (MIOM) is more effective than a single modality for detection of intraoperative spinal cord injury. So, we evaluated the role of MIOM during the spinal deformity surgery.

Materials and methods: This study was conducted on 25 patients suffering from spinal deformity. During surgery, Motor evoked potential (MEP) stimulation was performed using corkscrew needle electrodes inserted in the C3-C4 position of the 10-20 system and recording needle electrodes were inserted in the appropriate muscles. Somatosensory evoked potentials (SSEPs) were recorded from corkscrew electrodes placed in the scalp after stimulation of the median nerve at the wrist and the posterior tibial nerve at the ankle.

Results: eight males (32%) and 17 females (68%) were included in the study, their ages ranged from 8-29 year with a mean (14.5 ± 4.8 year). Seven patients had congenital scoliosis (28%), 14 had idiopathic scoliosis (56%), 3 patients had kyphoscoliosis (12%), and 1 patient with neuromuscular scoliosis (4%). Hypotension, manipulation around the cord, presence of kyphosis, rigidity of the curve, removal of hemivertebrae, double curve, and manipulation around the apex affect MEP. Neurophysiological monitoring events observed in this study were classified into three categories: true positive, transient true positive, and transient false positive.

Conclusion: The use of intraoperative neurophysiological monitoring reduces the incidence of complications to the nervous systems after surgery.

Keywords: Intraoperative neuromonitoring, Spinal deformity surgery.

INTRODUCTION

Postoperative neurological complications of spinal deformity surgery can occur due to different causes such as direct trauma to the spinal cord, cord ischemia, and deformity correction [1]. Incidence of complications is related to type of deformity, combined anterior and posterior approach, intraoperative hypotension/bleeding, and revision surgery. Stagnara wakeup Test was the only method used for detection of intraoperative spinal injuries. This test needs reversal of general anesthesia and assessment of voluntary movements of the lower limbs [2]. This test has an accuracy of 100% but it has some limitations probably due to mental disability, young age and pre-existing neuro deficit. Moreover, this test may be used nowadays only when neurophysiological technician fails to obtain an IONM signal after exclusion of all technical, anesthetic, and surgical factors [3]. IOM is used nowadays to provide an immediate monitoring of spinal cord. multimodal IOM entails the combined use of somatosensory evoked potentials (SSEP), transcranial motor evoked potentials (TcMEP). and EMG. This multimodal IOM is helpful in early detection of neurological damage during surgery [4,5]. The aim of our study was to evaluate the role of multimodal IOM in patients undergoing deformity correction, to detect the types of neuromonitoring changes related to surgical events.

Material and methods:

This prospective cohort study was accomplished at Tanta University Hospitals between January 2021 and December 2023.All patients underwent spinal deformity correction surgery with instrumentation and multimodal IONM. Medical, surgical, and IOM records and postoperative complications were documented. Total Intravenous anesthesia (TIVA) protocol was used in all studied patients [6] before proceeding to neurophysiological monitoring.

After the insertion of the electrodes for intraoperative monitoring in the supine position, the patient was flipped to the prone position to allow surgery [7].

IOM was performed by a clinical physiologist who is present during the entire procedure using 32 -channel (Cadwell Elite system. Kennewick, Washington, United States) [8].

Prior to skin incision, baseline traces were obtained(Figure 1). Monitoring started when the patient was positioned and lasted for 20 minutes after the spinal instrumentation was completed [7].

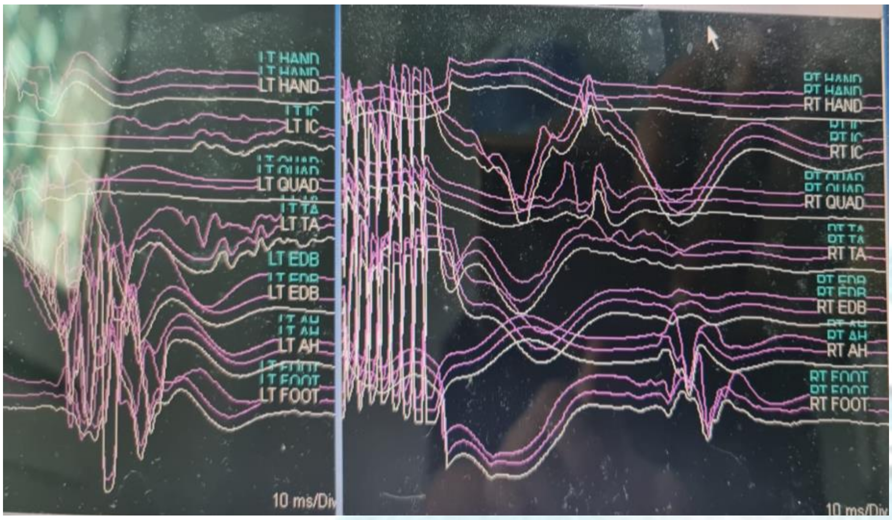


Figure (1): Baseline motor evoked potential (MEP) response at the start of surgery

1. **Motor Evoked Potentials (MEP):** was elicited by using two corkscrew electrodes positioned over the motor cortex at the C3 and C4 positions of the international 10-20 system. These electrodes delivered an anodal pulse train of 4-6 pulses and a 75-s pulse duration with a 2–4 ms interstimulus interval between pulses. The intensity of stimulation ranged between 200 and 500 V (fixed voltage system). Stimulation was alternated between the two corkscrew electrodes positioned over the motor cortex to stimulate both sides of the cortex [7]. MEPs were recorded using needle electrodes placed bilaterally in the rectus femoris, iliopsoas, quadriceps, tibialis anterior (TA), and abductor hallucis (AH) muscles in the lower extremities, as well as the abductor digiti minimi (ADM) muscle in the upper extremities. Filters were set at a bandpass of 30–1000 Hz. Bilateral ADM responses were employed as controls to distinguish between surgical and nonsurgical loss of limb responses, as well as to identify brachial plexus compromise caused by patient positioning. The recorded responses were termed muscle MEP responses, to be distinguished from compound muscle action potentials (CMAPs) that are recorded after direct nerve stimulation.
2. **Somatose**nsory evoked potentials: SSEPs were performed with stimulus intensities ranging from 8 to 15 mA in the upper extremities and 20 to 50 mA in the lower extremities [8]. Pulses were delivered at a frequency of 2.7 to 4.7 Hz and a pulse duration of 200 s. To elicit lower limb SSEPs, the posterior tibial nerve (PTN) in the ankle was stimulated on both sides. SSEPs were obtained from both upper limbs

through median nerve stimulation and used as a control. Cortical recording electrodes were placed in the C3-C4-CZ positions (2 cm behind the C3, C4, and CZ positions, as well as the Fz positions of the 10-20 system). For upper extremities, the SSEP C3'/C4'-Fz montage was used. For the lower extremity, SSEP Cz'-Fz and C3'-C4' montages were used. A ground electrode was placed at the shoulder. Upper extremities SSEP negative wave was recorded at 20 ms, followed by positive wave p23 at 23 ms, and latency was recorded. The peak-to-peak amplitude of the wave was measured, and any changes from baseline were reported. Lower extremities SSEP: the cortical wave consisted of a positive peak at 37 P37, followed by a negative peak at 45 ms N45. The latency of P37 was measured, the peak-to-peak amplitude of the wave form was measured, and any changes from baseline were reported and recorded. Filters were set at a bandpass of 30–1000 Hz. The lower limb SSEPs had a display time of 100 milliseconds, and the upper limb SSEPs had a display duration of 50 milliseconds.

3. **Electromyographic recording:** Free-running EMG (frEMG) continuously detects mechanical and/or metabolic irritation of the nerves during surgery. It can be recorded in the innervated muscles without electrical stimulation of the nerve as high-frequency bursts or trains of MUPs in monitored muscles [9]. Triggered EMG (tEMG) is performed by electrically stimulating the nerves or nerve roots and recording the resulting CMAP in the innervated muscle as highly complicated polyphasic responses with variable onset latencies and response amplitudes and durations.
4. **Triggered EMG (tEMG) on pedicle screws:** A new technique for detecting medial screw misplacement during thoracic pedicle screw insertion employs high-frequency Triggered EMG (tEMG) on pedicle screws and recording of evoked EMG responses in lower extremity muscles. Pulse threshold 6 mA or less indicates positive predictive value and pedicle screws must be removed; pulse threshold more than 10 mA indicates negative predictive value, which is not significant to remove screws; and pulse threshold more than 6 mA and less than 10 mA indicates screws must be checked again and may be removed [10].

Warning criteria for MEP included any sudden drop in amplitude of muscle MEP responses > 80% of baseline traces. SSEP alarm criteria included a unilateral or bilateral drop in the evoked potential response > 50% in amplitude with or without a corresponding increase in latency > 10% of baseline traces. Such changes were reported and investigated, and action was taken according to the cause [11].

Scoliosis is classified as non-structural (postural), transient structural and structural scoliosis. Structural scoliosis may be idiopathic, congenital and neuromuscular. Scoliosis curves may be non-structural which is flexible and corrected by bending towards convex side and structural which can't be corrected by bending. The side towards which the convexity is directed is named right or left.

Posterior approaches including decompression with instrumentation and fusion were used in all cases. After removing the inferior articular process of each facet joint bilaterally, the exposed superior articular process cartilage was removed to provide a greater surface for fusion. Then, the spinous process and ligamentum flavum were removed. The structure of all-pedicle screws is extremely strong and allows for extremely powerful correction. Compression-distraction, rod-derotation movements, in situ contouring, en bloc, or direct vertebral body derotation were all options for correction. These methods were used separately or in combination [12].(Figure 2)

A  B 

C 

Figure 2 : (A)preoperative AP X ray of female patient with scoliotic deformity.B and C Showing AP and Lateral X rays after correction of the deformity

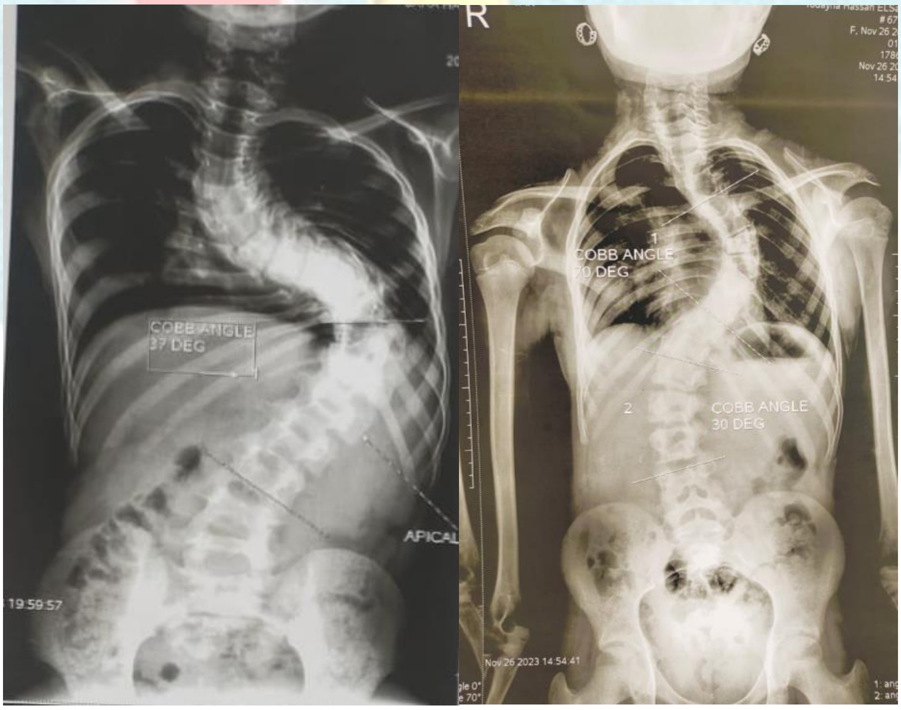
Statistical Analysis:

The sample size was estimated using Epicalc 2000 version 1.02 assuming power 80% and $\alpha = 0.05$

Analysis was performed using the Statistical Package of Social Science Software program, version 21 (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.). Data are presented as mean ± standard deviation for quantitative variables and frequency and as percentage for qualitative ones. Comparison between groups for qualitative variables was performed using the Chi-square test. $P \leq 0.05$ was considered statistically significant. The study was approved by Tanta Faculty of Medicine Ethical Review Committee.

Results:

This study included 25 patients with spinal deformities, 7 patients had congenital scoliosis (28%), 14 had idiopathic scoliosis (56%), 3 patients with kyphoscoliosis (12%), and one patient with neuromuscular scoliosis (4%) (Table 1). Single curve was found in 16 patients and double curve in 9 patients (Table 2). The mean value of the thoracic degree of scoliosis preoperatively was (58.4 ± 26.1 degree), ranging from 25 to 135 degree**.** The mean value of the lumber degree of scoliosis preoperatively was 42.8 ± 24.02 degree, ranging from 12 to 76 degree**.** Nine patients had rigid curve (36 %)(Figure 3 and 4) .Levels of surgery ranged from T1 to L5. Muscle activity was recorded from the rectus abdominis, Iliopsoas, Quadriceps, tibialis Anterior, Extensor digitorum brevis (EDB), and Flexor digitorum brevis (FDB) in all patients (100%).



(A) ***(B)***

Figure (3): Scoliotic patients; (**A)** with rigid curve, **(B)** with flexible curve

Intraoperative data of studied subjects: The studied patients had 4 events during surgery: decreased MEPs, decreased SSEPs, spontaneous EMG activity, and triggered EMG activity. These events may be due to decreased blood pressure, manipulation around the cord, abnormal position of the pedicle screw, cord compression, rigidity of the curve, abnormal size of the pedicle screw, cord traction, inhalation anesthesia, derotation of the vertebrae, insertion of the rod, possible, stretching of blood vessels, and others.

Postoperative data of studied subjects: the mean value of the thoracic degree of scoliosis postoperatively was (19 ± 7.9), ranging from 5 to 35 degree and the mean value of the lumber degree of scoliosis postoperatively was 13.4 ± 7.5, ranging from 2 to 25 degrees**.**

Table (1): Intraoperative events and their distribution among studied subjects

Intraoperative events	Number of subjects	Percentage
MEPs decreased	23	92%
SSEPs decreased	9	36%
Triggered EMG activity	7	28%
Spontaneous EMG activity	4	16%

Correlation between rigidity of the curve and MEP decrease

The patients in the present study who suffered from scoliosis deformity were categorized into nine patients with a rigid curve and 13 patients with a flexible curve. Data revealed that of the 9 patients with rigidity of curve, 7 of them had MEP decreases (77.8%), and 2 of them did not have MEP decreases. A significant positive correlation was shown between the rigidity of the curve and the decrease in MEP (P value 0.05)(Figure 5)

Table (2): Correlation between rigidity of the curve and motor evoked potential (MEP) decrease among studied subjects with rigid curve.

	MEP decrease		**P value**
	Present	**Absent**	
Rigidity of the curve (9)	7 77.8%	2 22.2%	$P<0.05$

Figure (4): Patient presented with rigid thoracic curve

(A) muscles of left side (B) muscles of right side

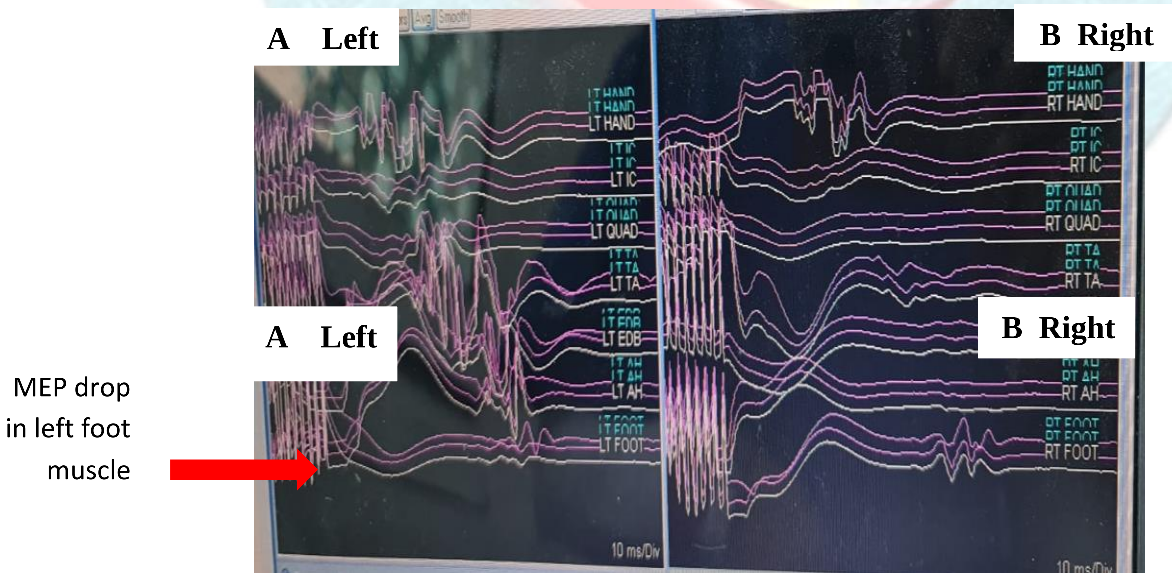


Figure (5): Left sided MEP drops mainly in left foot muscle more than right side during rigidity correction.

Correlation between blood pressure decrease and MEP decrease: The patients in the present study that had decreases in blood pressure intraoperatively were 14 patients, 10 of whom had decreased MEP and 4 without decreased MEP. A significant positive correlation was shown between decreased blood pressure intraoperatively and MEPs decreasing (P <0.01) (Table 3)(Figure 6 and 7)

Table (3): Correlation between blood pressure decrease and motor evoked potential (MEP) decrease among studied subjects with blood pressure decrease.

	MEPs decrease		P value
	Present	Absent	
Blood Pressure decrease (14)	10 71.4%	4 28.6%	P<0.01

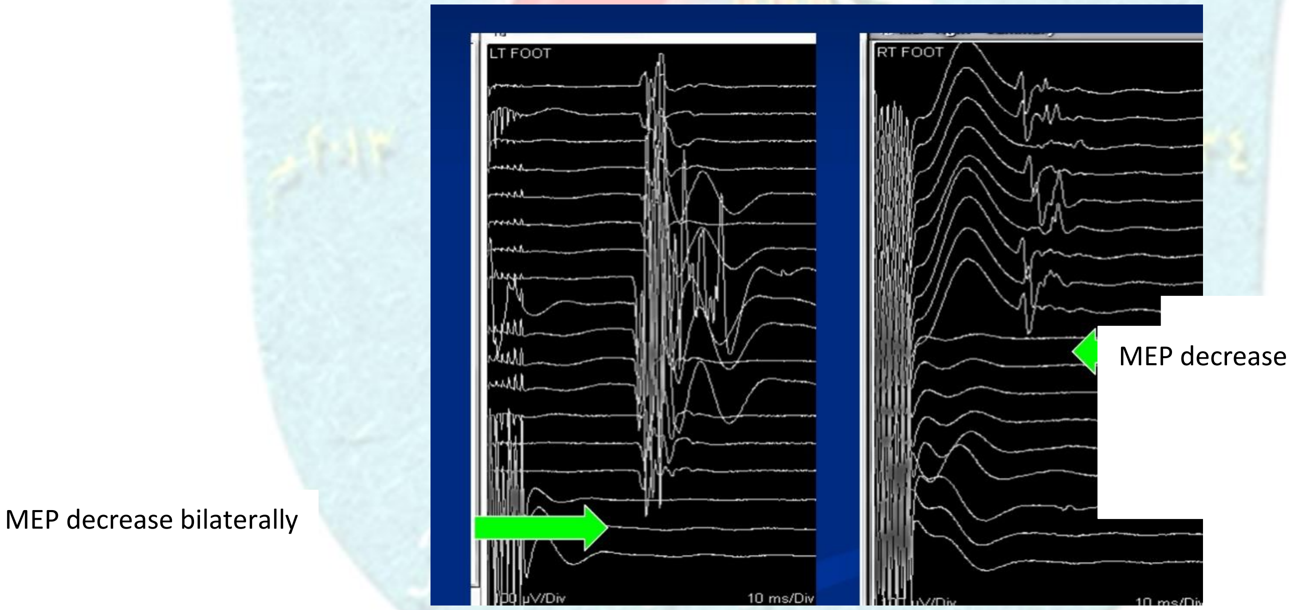


Figure (6): Decrease of motor evoked potential (MEP) at the start of blood pressure decrease.

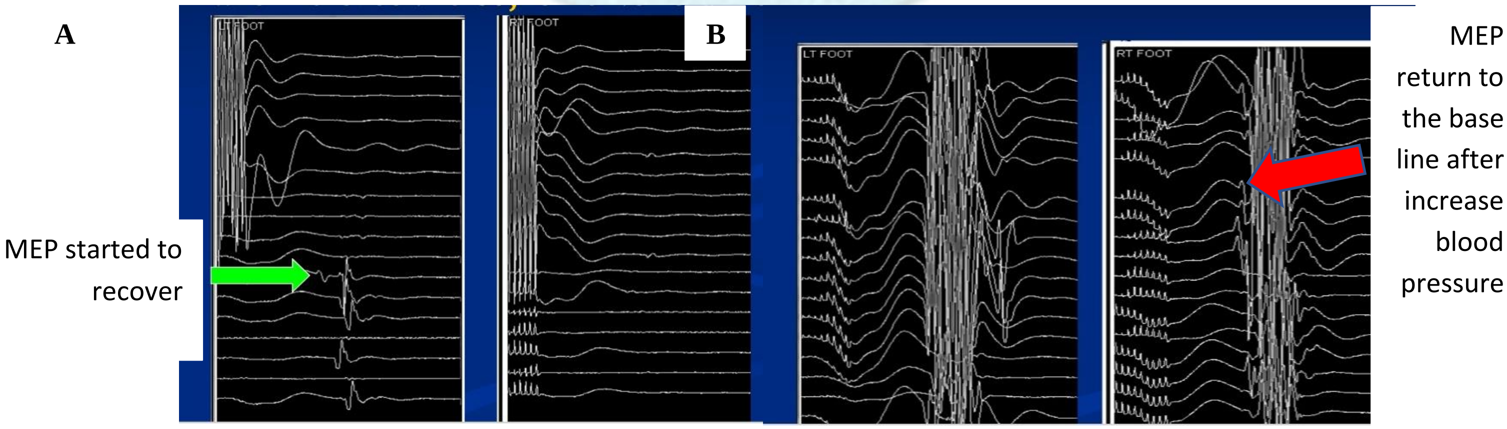


Figure (7): MEP recovery (A) start of MEP recovery during correction of blood pressure decrease. (B) completely recovery of MEP after restoration of basal blood pressure.

Correlation between manipulation around the cord and MEPs decrease

The patients in the present study that had manipulation around their cords were 11, of whom 9 had decreased MEP and 2 had no decrease. A significant positive correlation was found between manipulation around the cord and a decrease in MEPs (P <0.01).**(Table 4)(Figure 8)**

Table(4): Correlation between manipulation around the cord and MEPs decrease.

	MEPs decrease		**P value**
	Present	**Absent**	
Manipulation around the cord (11)	9 81.8%	2 18.2%	P<0.01

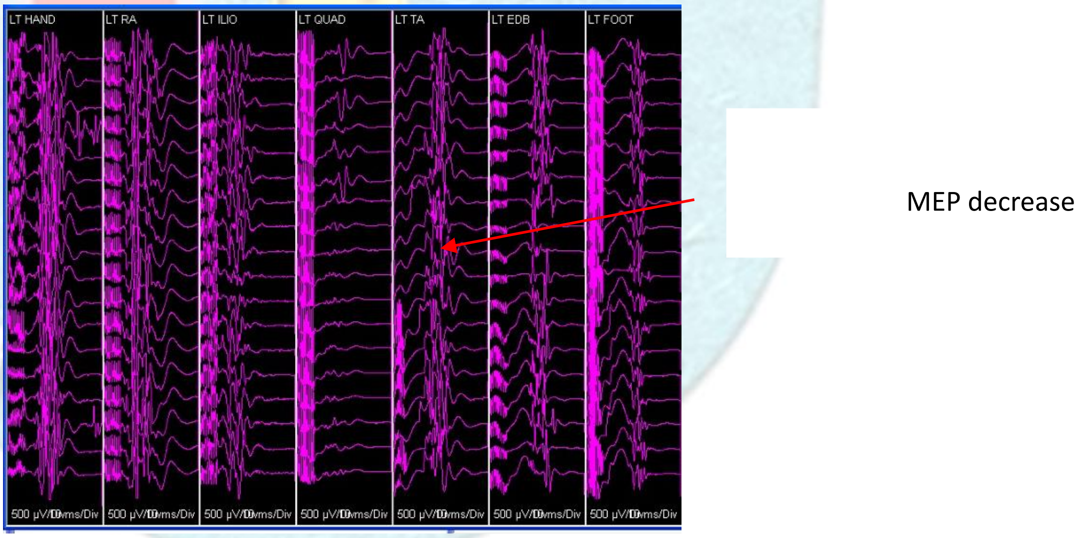


Figure (8): motor evoked potential (MEP) decreased during left manipulation around the cord.

Correlation between Triggered EMG and MEPs decrease The patients in the present study who had triggered EMG (tEMG) activity were 7, six of whom had MEP decreases, and one without MEP decreases. A significant positive correlation was shown between triggered EMG activity and MEP decrease (P <0.01) **.(Table 5)**

Table (5): Correlation between Triggered EMG and MEPs decrease

	MEPs decrease		P value
	Present	Absent	
Triggered EMG activity (7)	6 46.2%	1 8.3%	P<0.05

Correlation between double curve and MEPs decrease

The patients in the present study having a double curve were 9, 7 of whom had MEP decreases, and 2 did not have MEP decrease. There was a significant positive correlation with statistical significance between the double curve and MEPs decrease (P <0.05) **.(Table 6)**

Table (6): Correlation between Type of the curve and MEPs decrease

	MEPs decrease		P value
	Present	Absent	
Double curve (9)	7 78%	2 22%	NS

NS: not significant

The patients in the present study who had kyphosis with scoliosis were 3 patients. 2 of them had MEP decreases, and 1 did not have MEP decreases.(Table 7)

A statistically non-significant correlation between the presence of kyphosis and MEPs decreases

Table (7): Correlation between presence of kyphosis and MEPs decrease.

	MEPs decrease		P value
	Present	Absent	
Presence of kyphosis (3)	2 66.6%	1 32.4%	NS

NS: not significant

Correlation between removal of hemi vertebrae during surgery and MEPs decrease

The patients in the present study who underwent the removal of hemivertebrae during surgery were 5 patients. 3 of them had MEP decreases, and 2 did not have MEP decreases. A statistically non-significant correlation was found between the presence of kyphosis and MEPs decrease. (Table 8).

Table (8): Correlation between removal of hemi vertebrae during surgery and MEPs decrease

	MEPs decrease		**P value**
	Present	**Absent**	
Removal of hemi vertebrae during surgery (5)	3 60%	2 40%	NS

NS: not significant

Correlation between types of scoliosis and motor evoked potential (MEP) decrease

Within each type of scoliosis, cases of congenital scoliosis with MEP decrease were 3 out of 7 (42.8%), cases of idiopathic scoliosis with MEP decrease were 7 out of 14 (50%), cases of Kyphoscoliosis with MEP decrease were 2 (66.6%) out of 3, and cases of Neuromuscular scoliosis were 1 out of 1 (100%). A statistically non-significant correlation was found between types of scoliosis and MEP decrease.

Neurophysiological monitoring changes:

The present study showed that 13 patients presented with transient MEP changes with identifiable exposure to neurological causes. In total, 13 cases were regarded as true-positive MEP changes. 12 patients were intact postoperatively without neurological deficiency; only one patient had a transient neurological deficit for 3 months. There were 9 patients that had transient SSEP drops; 5 of them had combined SSEP decreases and MEP decreases, and 4 of them had only SSEP decreases (false positive events). These were detected by neurophysiologists, and SSEPs were returned to baseline again. These changes were detected and corrected by the surgeon and anesthetic team, so MEPs and SSEPs returned to baseline without any changes.

All patients underwent MEP monitoring and simultaneous SSEP monitoring. The monitoring was considered successful when it was able to conduct repeatable signals on the Tc MEP or SSEPs monitoring intraoperatively. In summary, MEP monitoring was successful in all 25 patients included in the study.**(Table 9)**

Table (9): Intraoperative neurophysiological monitoring changes and neurological events:

Monitoring Modality	Number Of alarms detected	Positive monitoring changes			
		Transient Changes		permanent changes	
		With neurological event	Without neurological event	With neurological event	Without neurological event
MEP (25)	13	1	12	0	0
SSEPs (25)	9	0	9	0	0
MEP/SSEPs (25)	5	0	5	0	0

MEP: Motor evoked potential. **SSEPs: somatosensory evoked potentials.**

Triggered EMG activity:

Invasion of the spinal canal was intraoperatively confirmed in 7 of the pedicle screws. The triggered EMG (tEMG) technique detected 7 misplaced screws. There were 3 misplaced screws when using a threshold greater than 12 mA (negative predictive value), so the surgeon did not need to take any action. When using a triggered EMG on pedicle screws with a threshold of < 6 mA (the positive predictive value), 2 misplaced pedicle screws were confirmed, so the surgeon removed the screws and inserted them in another tract. When using tEMG on pedicle screws using pulse thresholds greater than 6 mA and less than 12 mA, 2 misplaced screws were detected, so the surgeon removed the screws and inserted them in another track (Table 10).

Table (10): Triggered Electromyography (tEMG) activity

	Green zone threshold (above 12mA)	Yellow zone threshold between (6-12mA)	Red zone threshold (Below 6mA)	Level	Action
		Present		RT L2	Surgeon reported and changed screw site
		Present		RT L1	Screw removed
	Present			RT L2	No action because it on safe margin.
			Present	RT L3	screw was removed and re inserted in another place
	Present			RT T10	No action because it

					on safe margin
			Present	LT L2	Screw was removed and reinserted in another place

RT: Right **LT: left**

No permenant post operative complication was reported only transient neurophysiological changes during surgery and corrected immediately

Discussion

In our study, 4 different alarm criteria were recorded: MEP decrease, SSEP decrease, occurrence of spontaneous EMG activity, and response to pedicle screw stimulation using Triggered EMG activity. Those alarm events occurred due to variable causes such as blood pressure decrease, cord compression, manipulation around the cord, cord traction, derotation of the vertebrae, abnormal position of the pedicle screw, insertion of the rod, and stretch on blood vessels.

The present study showed that 12 patients presented with reversible MEP changes .In total, 12 cases were regarded as true-positive MEP changes with an intraoperative neurological event. There were 5 patients presenting with both MEP and SSEP alterations when both modalities displayed changes. SSEPs had a transient drop in 9 patients with reversible transient deficiencies. MEP decrease, SSEP decrease, or combined decrease were alarming and needed action for correction, There were 14 patients presenting with decreased blood pressure; 10 of these patients had drops in MEP, and 4 had no changes in MEP. Insertion or adjustment of instruments has a significant role in MEP decrease; 1 patient presented with a drop in MEP after the insertion of a retractor, and 11 patients had a drop in MEP after manipulation around the cord due to cord ischemia and stretching of blood vessels. There was 1 patient presenting with a drop in MEP due to abnormal positioning during correction surgery. In the case of Patients with SSEPs or MEP changes intraoperatively, the neurophysiologist detects the cause of these events and gives advice on how to correct the alarm events to reduce postoperative neurological impairments. These events were assumed to be true positives. MEP's sensitivity value is 100%.

SSEP waveform drop during surgery results from both peripheral stretch and inhalation anesthesia, which cause MEP drop and SSEP drop. In the present study, 4 patients showed a transient drop in SSEPs. Such a transient drop was attributed to a different cause in each patient. In one patient, the transient drop of SSEPs could be explained by the wrong site of a warmer on the head of the patient, which reflects the central recording of SSEPs. In another patient, the SSEPs decreased because the patient was suffering from cerebral palsy. In the third patient, the transient drop of SSEPs was due to peripheral stretching of blood vessels. In the fourth patient, transient SSEP decreases are explained by manipulation around the cord that causes ischemia of the posterior part of the cord. In the present study, SSEP's value is 88.8%. The current findings agree with Kundnani et al. [13] who stated that SSEP's sensitivity for the diagnosis of motor loss during scoliosis surgery was 65% because SSEP's monitoring is of minimal value when approached above conus level and does not express the condition of the anterior cord and its vascular supply, which is vital in osteotomies procedures. SSEP's drop indicates a greater risk to the posterior cord only.

In the present study, combined MEP/SSEP monitoring was demonstrated to have a sensitivity of 100%. These findings were in line with Hilibrand et al. [14] who reported that multimodal intraoperative neurophysiological monitoring (MIONM) has 100% sensitivity.

In addition, the present study revealed that the decrease of blood pressure intraoperatively during scoliosis deformity corrections caused a significant decrease in MEP, which disappeared when blood pressure was increased. These findings were supported by the study of Yang et al. [15] which demonstrated that hypotension decreased MEP amplitude, whereas increasing the mean arterial pressure (MAP) above 85 mmHg restored MEP to baseline in all patients. Also, the author increased the voltage threshold by about 30% to get the MEP baseline.

The drop in MEP in the present work could be explained in accordance with Kobayashi et al. [16] who stated that rotation maneuver, causes compression on the spinal cord, decrease blood flow and neural plasticity, and induce ischemic or circulation impairments and compressive insults of the spinal cord. That led to the MEP drop.

This present study proved that manipulation around the cord causes a significant decrease in MEP during scoliosis deformity corrections. These findings were consistent with Novak et al. [17] who demonstrated that significant intraoperative alteration of MEP was observed in patients who had manipulation around the cord. The changes were detected immediately after manipulation of the cord. These present findings could be explained by the study of Haavik et al. [18] which reported that spinal manipulation alters short-term changes in cortical excitability, causes chronic spinal artery vasoconstriction, or causes a decrease in radicular-medullary arteries in the thoracic area, both of which raise the risk of cord ischemia.

The present study revealed that there was a strong positive correlation between Triggered EMG (t EMG) activity and MEP decrease. This finding is in line with Min et al. [19] who studied triggered EMG activity in lumbosacral vertebrae and suggested that EMG activity on pulse thresholds < 6 mA was associated with an increased risk of cortical violation, postoperative neurologic complications, and MEP decrease.

The present study showed a significant positive correlation between the rigidity of the curve and the decrease in MEP. These data are supported by the study of Hu et al. [20] which demonstrated that motor evoked potential was severely affected more than once during osteotomy in patients with rigid curves.

Patients in the present study responded to hemodynamic improvement (raising blood pressure), removal of traction if present, and insertion of a stabilizing rod. After decompression was finished, closure of the osteotomy was believed to provide spinal cord decompression because reducing the curve decreases the stretch on the spinal cord, improving MEP decrease, so during the performance of posterior spinal osteotomies to a rigid curve, significant MEP decreases are common (Simon M V [21].

The present study demonstrated that there was a strong positive correlation between the type of curve and the MEP decrease. These findings are consistent with those of Pastorelli et al. [22] who demonstrated that possible factors associated with the severity of neurological deficits following scoliosis surgery were represented by the severity of the curve (S-shaped curve). In addition, the present data are in accordance with Pastorelli et al. [22] who demonstrated that MEP latency was affected by the morphology of the curve, so double curves increase latency, which may not cause a decrease in MEP amplitude (false negative event) and cause a post-operative neurological deficit.

The present study revealed that invasion of the spinal canal was intraoperatively confirmed in 7 of the pedicle screws. 3 misplaced screws with a pulse threshold greater than 12 mA (negative predictive value), so the surgeon did not need to take any action. When using tEMG stimulation on pedicle screws using a pulse threshold of < 6 mA (positive predictive value), there were 2 pedicle screws misplaced as indicated by EMG activity, so the surgeon removed the screws and inserted them in another track. When using tEMG stimulation on pedicle screws using pulse thresholds greater than 6 mA and less than 12 mA, there were 2 misplaced screws as indicated by EMG activity, so the surgeon removed the screws and inserted them in another track. These data were consistent with Min et al. [19].

This present study revealed an insignificant correlation between the presence of kyphosis and MEP decrease, which could be attributed to the small sample size used, as only 3 patients had kyphoscoliosis, although 2 patients out of 3 presented with MEP drops. On the contrary, Patel et al. [23] stated that during kyphosis correction, the spinal cord was stretched, general loss of MEP muscles occurred, and SSEPs showed delayed posterior column conduction. When one unit of blood was transfused to overcome the hypotension that occurred and the stretching of the spinal cord was stopped, the neurophysiological monitoring signals were maintained.

This present study revealed an insignificant correlation between patient dependent side and MEP decrease, which could be explained by the small sample size used as only one patient experienced dependent side during surgery and this patient revealed MEP drop. However, Graham et al. [24] mentioned that there were a lot of reports about positioning-related changes in evoked potentials, which showed that head position has a significant impact on intraoperative signals.

This present study revealed an insignificant correlation between removal of hemivertebrae and MEP decrease that could be due to the small sample size used, as only 5 patients experienced removal of hemivertebrae, although 3 patients out of 5 presented with MEP drops. However, Bixby et al. [25] reported that removal of hemivertebrae has a significant effect on intraoperative neuromonitoring changes because 14% of his patients had a decrease in MEP. Only 5% had postoperative transient deficiencies, which improved after 4 months. Hemivertebra (HV) can cause progressive scoliosis or kyphosis at a young age, so it needs surgical intervention. HV resection is a technically difficult procedure that involves the removal of bony elements in order to expose the dura mater and nerve roots. As might be expected, the complication and reoperation rates of HV resection in patients who have a spine deformity caused by HV are significantly higher than those without HV. So, IONM has a significant role in HV resection to decrease post-operative neurological complications. In addition, Wing et al. [26] mentioned that post-operative neurological complications were more common in hemivertebrae resection, and IONM has a golden role in congenital scoliosis with hemivertebrae resection.

In the present study, true positive events occurred in 13 patients (52%). They are categorized into 4 groups: congenital scoliosis (CS): 3 cases (23.1%); idiopathic scoliosis: 7 cases (53.9%); kyphoscoliosis: 2 cases (15.3%); and neuromuscular scoliosis: 1 case (7.7%). This data is consistent with Magampa et al. [27], who stated that true positive events occurred in idiopathic scoliosis more than other types, and congenital scoliosis follows idiopathic scoliosis. Idiopathic scoliosis has a high rate of MEP drop due to a high Cob's angle, a doubled curve, the rigidity of the curve, and the patient's age. All those are risk factors that cause MEP drops during surgery.

According to the present study, IONM true events are classified into true positive, transient true positive, and transient false positive. True positive events, which cause loss of IONM linked to surgical events, e.g., kyphosis correction, spinal osteotomies, decrease of blood pressure, and manipulation around the cord, return after surgical action or rising blood pressure, aiming to prevent postoperative neurological deficit.

Transient True positive events are events that cause loss of IONM with no postoperative sequale but are not linked to surgical events, e.g., events that occur following instrument insertion and patient positioning on the surgical table. Responses may return after the surgical event directly without a postoperative neurological deficit, but a long-standing decrease in MEP without action may cause a postoperative neurological deficit. Transient false positive events are events that cause loss of IONM not linked to surgical events, e.g., those associated with an anaesthetic, technical, or metabolic cause. These responses return after appropriate action (change in anaesthetic agents, check the connections) without postoperative deficit.

Conclusion

The use of intraoperative neurophysiological monitoring reduces the incidence of complications of the sensory and motor nervous systems after surgery, the surgical team must do the best with the aid of neurophysiologist and anesthetic team to prevent postoperative neurological deficit.

Abbreviations

IONM: Intraoperative Neurophysiological Monitoring

MIOM: Multimodal intraoperative neurophysiological monitoring

SSEP: Somatosensory evoked potentials

TcMEP: Transcranial motor evoked potentials

MEP: Motor evoked potentials

References

1. Vitale MG, Skaggs DL, Pace GI, Wright ML, Matsumoto H, Anderson RC, et al. Best practices in intraoperative neuromonitoring in spine deformity surgery: development of an intraoperative checklist to optimize response. Spine Deform. 2014;2(5):333-9.
2. Diab M, Smith AR, Kuklo TR. Spinal Deformity Study Group. Neural complications in the surgical treatment of adolescent idiopathic scoliosis. Spine. 2007;32(24):2759-63.
3. Girardi FP, Boachie-Adjei O, Rawlins BA. Safety of sublaminar wires with Isola instrumentation for the treatment of idiopathic scoliosis. Spine (Phila Pa 1976) 2000;25:691-5.
4. Pelosi L, Lamb J, Grevitt M, Mehdian SM, Webb JK, Blumhardt LD. Combined monitoring of motor and somatosensory evoked potentials in orthopaedic spinal surgery. Clin Neurophysiol. 2002;113(7):1082-91.
5. Sutter M, Eggspuehler A, Grob D, Jeszenszky D, Benini A, Porchet F, et al. The diagnostic value of multimodal intraoperative monitoring (MIOM) during spine surgery: a prospective study of 1,017 patients. Eur Spine J. 2007;16:162-70.
6. Ahn H, Fehlings MG. Prevention, identification, and treatment of perioperative spi-nal cord injury. Neurosurg Focus. 2008;25(5):15.
7. Minahan RE. Intraoperative neuromonitoring. *Neurologist* 2002;8:209-26.
8. Ziewacz JE, Berven SH, Mummaneni VP, Tu TH, Akinbo OC, Lyon R, et al. The design, development, and implementation of a checklist for intraoperative neuromonitoring changes. Neurosurg Focus. 2012;33(5):11.
9. Leong JJ, Curtis M, Carter E, Cowan J, Lehovsky J. Risk of Neurological Injuries in Spinal Deformity Surgery. Spine. 2016; 41(12): 1022-7.

10. Montes, E., de Blas, G., Barrios, C., Mariscal, G., Burgos, J., Regidor, I. and Hevia, E. Pulse-train versus single-pulse t-EMG stimulation for intraoperative neurophysiologic monitoring of thoracic pedicle screws in adolescent idiopathic scoliosis. Clinical Neurology and Neurosurgery, 2022; 215, 107-207.

11. 11.Calancie B and Molano M R. Alarm criteria for motor-evoked potentials: what's wrong with the "presence-or-absence" approach. Spine. 2008; 33(4).406-14.

12. Vavruch L, Brink R C, Malmqvist M, Schlösser T P, van Stralen M, Abul-Kasim K, Ohlin A, Castelein R M and Tropp H. Surgical outcomes of anterior versus posterior fusion in Lenke type 1 adolescent idiopathic scoliosis. Spine. 2019; 44(14). 823-2.

13. Kundnani V K, Zhu L, Tak H H and Wong H K. Multimodal intraoperative neuromonitoring in corrective surgery for adolescent idiopathic scoliosis: evaluation of 354 consecutive cases. Indian journal of orthopaedics, 2010;44(1): 64-72.

14. Hilibrand A S, Schwartz D M, Sethuraman V, Vaccaro A R and Albert T J. Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery. JBJS. 2004;86(6):1248-53.

15. Yang J, Skaggs D L, Chan P, Shah S A, Vitale M G, Neiss G, Feinberg N and Andras L M. Raising mean arterial pressure alone restores 20% of intraoperative neuromonitoring losses. Spine. 2018; 43(13):890-4.

16. Kobayashi K, Imagama S, Ito Z, Ando K, Hida T, Ito K, Tsushima M, Ishikawa Y, Matsumoto A, Nishida Y and Ishiguro N. Transcranial motor evoked potential waveform changes in corrective fusion for adolescent idiopathic scoliosis. Journal of Neurosurgery. Pediatrics. 2017;19(1):108-15

17. Novak K, Widhalm G, De Camargo A B, Perin N, Jallo G, Knosp E and Deletis V. The value of intraoperative motor evoked potential monitoring during surgical intervention for thoracic idiopathic spinal cord herniation. Journal of Neurosurgery. Spine, 2012; 16(2):114-26.

18. Haavik H, Niazi I K, Jochumsen M, Sherwin D, Flavel S and Türker K S. Impact of spinal manipulation on cortical drive to upper and lower limb muscles. Brain sciences. 2016; 7(1):2.

19. Min W K, Lee H J, Jeong W J, Oh C W, Bae J S, Cho H S, Jeon I H, Cho C H and Park B C. Reliability of triggered EMG for prediction of safety during pedicle screw placement in adolescent idiopathic scoliosis surgery. Asian spine journal. 2011;5(1):51.

20. Hu H M, Hui H, Zhang H P. The impact of posterior temporary internal distraction on stepwise corrective surgery for extremely severe and rigid scoliosis greater than 130°. Eur Spine J. 2016: 25, 557-68.

21. Simon M V. Neurophysiologic Tests in The Operating Room. In: Intraoperative Clinical Neurophysiology A Comprehensive Guide To Monitoring And Mapping. Demos Medical Publishing. New York. first edition, 2010;27-32.

22. Pastorelli F, Di Silvestre M, Plasmati R, Michelucci R, Greggi T, Morigi A, Bacchin M R, Bonarelli S, Cioni A, Vommaro F and Fini N. The prevention of neural complications in the surgical treatment of scoliosis: the role of the neurophysiological intraoperative monitoring. European Spine Journal. 2011; 20(1):105-14.

23. Patel B K and Bapat M R. Ventriculoperitoneal shunt malfunction, a rare cause of paraplegia after kyphosis correction: a case report and literature review. Spine. 2021; 46(5):344-8.

24. Graham R B, Cotton M, Koht A and Koski T R. Loss of intraoperative neurological monitoring signals during flexed prone positioning on a hinged open frame during surgery for kyphoscoliosis correction: case report. Journal of Neurosurgery Spine. 2018; 29(3):339-43.

25. Bixby E C, Skaggs K, Marciano G F, Simhon M E, Menger R P, Anderson R C and Vitale M G. Resection of congenital hemivertebra in pediatric scoliosis: the experience of a two-specialty surgical team. Journal of Neurosurgery: Pediatrics. 2021;28(3):250-9.

26. Wing-hay H Y and Chun-kwong E C. Introduction to intraoperative neurophysiological monitoring for anaesthetists. General Anaesthesia. World Federation of Societies of Anestesiologist 2019.

27. Magampa R S and Dunn R. Surgeon-directed transcranial motor evoked potential spinal cord monitoring in spinal deformity surgery: a review of viability, safety, and efficacy. The Bone & Joint Journal. 2021: 103(3):547-52.