Original Clinical Article

JOURNAL OF CHILDREN'S ORTHOPAEDICS

Positional disappearance of motor evoked potentials is much more likely to occur in non-idiopathic scoliosis

M. Rizkallah[1,2]
R. El Abiad[1,2]
E. Badr[3]
I. Ghanem[1,2]

Abstract

Purpose This study evaluates intraoperative disappearance of motor waveforms related to patient positioning in neurologically asymptomatic patients with spinal deformity.

Methods This is a retrospective review of 190 neurologically asymptomatic patients aged seven to 17 years planned for posterior instrumentation under neuromonitoring. There were 159 patients with adolescent idiopathic scoliosis and 31 patients with secondary scoliosis. Patients underwent surgery with transcranial electric stimulation motor evoked potentials (TES-MEPs). In case of abnormal findings, surgery was temporarily discontinued and necessary measures undertaken. In case of permanent signal disappearance surgery was definitively discontinued.

Results Six patients showed permanent loss of signal during early stages of surgery. These patients had a mean major curve of 64° Cobb angle and a mean thoracic kyphosis (D2 to D12) of 72°. The 184 remaining patients had a mean major curve of 50° Cobb angle and a thoracic kyphosis of 35°. A retrospective descriptive review of the patients' radiographs shows hyperkyphosis to be the common ground between the six secondary scoliosis cases. Gradual preoperative traction maintained during the surgery applied in two of these patients taken back to surgery six months later was associated with maintenance of TES-MEP signals throughout the surgery.

Conclusion This study shows that positional permanent loss of neuromonitoring signals is more likely to occur in patients with secondary scoliosis and hyperkyphosis shown to have sharper spine deformity and suspected to have a more vulnerable spinal cord. Gradual skeletal traction performed in two of these patients and maintained during surgery showed promising results.

Level of evidence: IV

Cite this article: Rizkallah M, El Abiad R, Badr E, Ghanem I. Positional disappearance of motor evoked potentials is much more likely to occur in non-idiopathic scoliosis. *J Child Orthop* 2019;13:206-212. DOI: 10.1302/1863-2548.13.180102

Keywords scoliosis; neuro-monitoring; motor evoked potential; neurologic deficit

Introduction

Iatrogenic spinal cord injury is the most dreaded complication in scoliosis surgery.[1] Neurological complications can range from loss of sensation to complete loss of voluntary muscle contraction and paraplegia.[2] According to the Scoliosis Research Society (SRS), these complications occur in 1% of single approach surgeries.[2,3] Prior to 1970s, the only method for detecting spinal cord injury during corrective scoliosis surgery was the Stagnara wake-up test, consisting of waking up the patient intraoperatively and observing voluntary lower-extremity movement.[4] As well as the dangers associated with awakening the patient during surgery, the wake-up test is also reproached for the long interval from the time of the insult to the detection of the motor deficit.[4] This may not only delay timely intervention to reverse the injury, but may also interfere with accurate identification of the responsible surgical manoeuvre.[4]

Since it was first introduced in mid-1970s, the use of intraoperative neurophysiological monitoring of spinal cord function was found to reduce risk of motor deficit and neurologic dysfunction and is now standard.[5-7] Neuromonitoring is, therefore, recommended by the SRS and the American Academy of Neurology in spinal surgeries incurring a risk of damage to the spinal cord.[8] Somatosensory evoked potentials (SEPs) were the first to show good results in reducing rates of intraoperative spinal cord injuries.[9] However, the use of SEPs alone may be ineffective in detecting motor tract deficit.[10,11] Therefore, the most commonly used stimulation technique is actually

[1]Faculty of Medicine, Saint-Joseph University, Beirut, Lebanon
[2]Department of Orthopedic Surgery, Hôtel-Dieu de France University Hospital, Saint-Joseph University, Beirut, Lebanon
[3]Electrophysiology Department, Hôtel-Dieu de France University Hospital, Saint-Joseph University, Beirut, Lebanon

Correspondence should be sent to Maroun Rizkallah, M.D., Faculty of Medicine, Saint-Joseph University and Department of Orthopedic Surgery, Hôtel-Dieu de France University Hospital, Saint-Joseph University, Alfred Naccache Street, Achrafieh, Beirut, Lebanon.
E-mail: maroun.rizkallah@gmail.com

the transcranial electric stimulation motor evoked potentials (TES-MEPs) consisting of a transcranial primary motor cortex stimulation by corkscrew electrodes placed in the scalp, to produce myogenic contractions.[7] Recordings are made through subcutaneous or intramuscular needle electrodes placed in multiple muscles in the arms and legs.[7] TES-MEPs provide feedback almost instantaneously and thus have a good ease of applicability.[12]

Diagnostic accuracy of this modality has been repeatedly evaluated, with a recent systematic review showing 91% of sensitivity and 96% of specificity in detecting neurologic deficits in patients undergoing surgery for idiopathic scoliosis.[13] Combination of TES-MEPs and SEPs when possible offers the patient and the surgeon the highest level of safety.[14]

Confidence in neuromonitoring data not only provides safety to the patient but also allows surgeons to proceed with surgery even after an alert, assuming the recovery of signals.[15]

Many recordings are performed during an indexed surgery, starting with a baseline drawing before or after induction of anaesthesia.[13] Crucial moments of surgery that need to be monitored include: positioning, incision, complete exposure, instrumentation, correction of deformity and closure.[16] The majority of waveform changes occur during rotation and translation manoeuvres for correction of deformity.[16] Some of the changes occur at patient positioning before incision and exposure of the spine. To our knowledge, there is a paucity of studies targeting this section of neuromonitoring, especially in scoliosis surgery.[17]

The aim of this study is to evaluate intraoperative disappearance of MEPs related to patient positioning in neurologically asymptomatic patients with spinal deformity planned for posterior instrumentation with or without fusion.

Material and methods

This is a single centre retrospective study that was performed after the approval of the ethics committee of our institution.

Patient population

Patients aged between seven and 17 years who were planned for posterior instrumentation with or without fusion for scoliosis in our institution between January 2014 and December 2016 with normal preoperative clinical neurologic assessment were included in this study. Patients within the same age bracket, planned for the same surgery within the same period but having any abnormal finding on the clinical neurologic exam (asymmetric cutaneous-abdominal reflexes, motor deficit, Babinsky sign, sensatory deficit) were excluded from this study.

All patients were operated on by the senior author of this paper (IG) and underwent general anaesthesia by the same anaesthesiology team using the same anaesthesia protocol according to general guidelines.

Anaesthesia protocol

Anaesthesia was induced with IV target-controlled infusion (TCI) propofol (Schnider model) 5 µg/ml, IV TCI remifentanil (Minto model) 5 ng/ml and IV suxaméthonium 1 mg/kg for tracheal intubation. Anaesthesia was maintained with TCI propofol 2.5 µg/ml to 4 µg/ml and TCI remifentanil 2 ng/ml to 8 ng/ml to maintain a bispectral index (BIS) value of 40 to 60 during surgery.

An arterial line was placed after induction of anaesthesia with an aim to keep mean arterial pressure above 65 mmHg. End-tidal concentration of carbon dioxide was kept between 30 mmHg and 35 mmHg.

Normothermia with core temperature of 36° to 37°C was maintained using a fluid- and blood-warming device along with a forced air warming device throughout surgery.

In order not to interfere with MEP signal quality, volatile anaesthetics, nitrous oxide, midazolam and reinjections of neuromuscular blockers were avoided.

Stimulation and record methods

TES-MEP recordings were performed in all patients using constant current multi-pulse transcranial electrical stimulation (NIM ECLIPSE, E4 module, Medtronic, Louisville, Denver, Colorado) delivered through a pair of corkscrew electrodes (MEP1001 KEYED CORKSCREW, Medtronic, Louisville, Denver, Colorado) placed 1 cm anterior to C3/C4 (international 10 to 20 system). Stimulation was bipolar between C3 and C4 using biphasic square wave electrical pulses of 50 msec. Trains of five pulses were delivered with an inter-stimulation interval of 2 msec. Stimulus intensity was gradually increased to obtain robust and reproducible MEPs. Recordings were performed simultaneously from the abductor digiti minimi, extensor carpi ulnaris, tibialis anterior and abductor hallucis muscles bilaterally using a pair of intradermal needle electrodes inserted 2 cm apart. The time base was 100 msec and the filter bandpass 30 Hz to 1500 Hz. TES-MEP amplitude was measured peak to peak between the two largest peaks of opposite polarity. A baseline was established once the effect of the neuromuscular agent had completely worn off (four bars of comparable amplitude on the train of four test). Ongoing recordings were stacked and compared with the baseline recording.

Monitoring and alert parameters

TES-MEPs were recorded ten times on average for each patient. Of note, all 190 patients were positioned similarly, in a prone position over chest and iliac sand bags as

classically performed in scoliosis surgery. Baseline recording was always performed in the supine position, after induction of anaesthesia. Signals were checked at positioning, at surgical exposure, at unilateral thoracic instrumentation, at bilateral thoracic instrumentation, at unilateral lumbar instrumentation, at bilateral lumbar instrumentation, at derotation and translation manoeuvres of the spine for correction, after definitive deformity correction, after closure and finally after turning back the patient. In cases where intraoperative traction was used, weights were only applied if signals were normal after patient positioning.

Surgeons were immediately interrupted and informed of acute change in waveform. Reductions of ≥ 50% of the wave's amplitude, together with ≥ 10% decreased wave latency compared with the baseline were considered as significant changes.

Once the alert was given, necessary measures were immediately undertaken to reverse the change in the waveform according to the guidelines developed by Vitale et al.[18] These measures included but were not limited to: warming the patient, warming the operating room, increasing blood pressure and reversing hypotensive anaesthesia. Technical aspects were also checked: screw position, reversal of correction and untightening of screw heads. If necessary, a wake-up test was performed. In case of permanent loss of signal with no gross motor function during the wake-up test, surgery was definitively discontinued.

Patients with permanent loss of MEP signal requiring definitive surgery discontinuation were thoroughly reviewed and represent the core of this study.

Statistical analysis

In this manuscript all statistical data is descriptive. No comparison or analytical statistics have been made between different groups of patients.

Results

After excluding 25 patients with abnormal clinical neurological exam, a total of 190 patients were included. Mean age at surgery was 12.2 years (7 to 17). Mean preoperative major curve Cobb angle reached 55° (SD 12°; 35° to 74°). There were 159 patients with adolescent idiopathic scoliosis (AIS), four patients with neurofibromatosis, six patients with connective tissue disease, six patients with skeletal dysplasia, six with metabolic disorder including muccopolysaccharidosis and nine patients with idiopathic early onset scoliosis or kyphoscoliosis.

Six of the 190 patients (3.16%) showed permanent loss of TES-MEP signals early during the surgery. Four of the six losses happened upon prone positioning of the patient even before skin incision. The remaining two occurred after surgical exposure. Wave loss was irreversible in all six patients after warming the operating room and the patient, adjustment of hemodynamic variables to normal values and waiting. Prone wake-up test showed loss of lower extremities movement in all of these six patients. These changes, when they occurred after completion of surgical exposure, were not reversed by skin closure. Five of the six losses were completely reversed by only turning the patients back to the dorsal decubitus position.

Patients with permanent loss of signal

Mean age of the six patients with permanent loss of signal was 9.8 years (SD 2.3; 7 to 12) and their mean major curve was 64° (SD 6°; 58° to 72°) Cobb angle. Table 1 shows scoliosis aetiology in each of these six patients with permanent loss of signal, together with their preoperative major curve Cobb angle, preoperative thoracic kyphosis and their neurological recovery after supine positioning (Table 1). Figure 1 shows the TES-MEPs drawings in the patient with Ehlers-Danlos syndrome.

All of these patients resumed normal motor function after dorsal decubitus positioning and waking up, except for the case with congenital progressive anterior bloc who woke up paraplegic but regained ambulation with crutches one year later.

In the postoperative setting, an extensive work-up was undertaken in these patients including upper and lower extremities electromyogram (EMG) and full spine MRI,

Table 1 Table showing scoliosis aetiology in each of the six patients with permanent loss of signal, together with their preoperative major curve Cobb, preoperative thoracic kyphosis and their neurological recovery after supine positioning

Patient	Aetiology of scoliosis	Preoperative major curve frontal cobb angle (°)	Preoperative D2/D12 thoracic kyphosis (°)	Signal restauration after supine positioning
1	Idiopathic early onset kyphoscoliosis	60	68	Yes
2	Neurofibromatosis	58	87	Yes
3	Morquio (muccopolysaccharidosis)	70	70	Yes
4	Hurler (muccopolysaccharidosis)	72	61	Yes
5	Ehlers Danlos	66	65	Yes
6	Congenital scoliosis	60	80	No

JOURNAL OF CHILDREN'S ORTHOPAEDICS

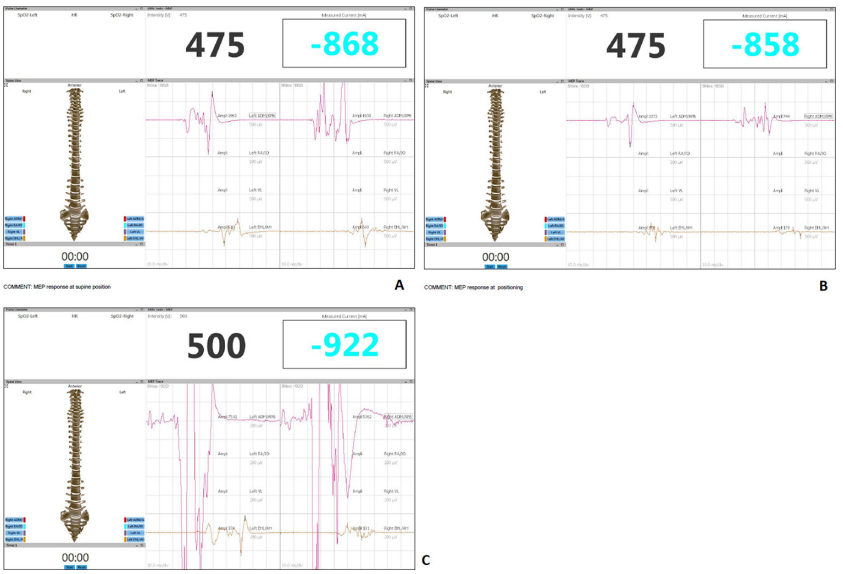

Fig. 1 Figure showing the transcranial electric stimulation motor evoked potentials drawings in a patient with Ehlers-Danlos syndrome: (**a**) baseline drawing after anaesthesia induction in supine position; (**b**) waveform changes after patient positioning showing alteration in lower extremity response; (**c**) restoring of waveforms comparable with baseline drawings after putting the patient back to supine position.

looking for an organic anomaly that could account for the loss of signal witnessed during surgery. This extensive work-up was negative in all patients. Also, a thorough review of these patient's radiographs showed that all six curves in patients with secondary scoliosis were hyperkyphotic. Their mean thoracic kyphosis (D2 to D12) reached 72° (SD 9.8°; 61° to 87°).

Two of the patients (the one with idiopathic early onset kyphoscoliosis and the one with neurofibromatosis) were taken back to the operating room six months after the initial index surgery that witnessed the early disappearance of signals. This was done after thoroughly explaining the surgical risk to the patients' caregivers and obtaining their consent to operate. Patients were put under progressive skeletal traction for three weeks preoperatively, and the traction was maintained during surgery especially while positioning patients in the classic prone position over chest and pelvis sandbags. Surgery was performed under TES-MEP neuromonitoring with no loss of signal recorded (Fig. 2).

The remaining four patients' caregivers refused surgical re-intervention.

Patients without permanent loss of signals

The remaining 184/190 patients did well after surgery and did not have any permanent loss of signal intraoperatively. These patients had a mean major curve of 50° (SD 10°; 35° to 74°) Cobb angle. Their D2 to D12 thoracic kyphosis averaged 35° (SD 12°; 17° to 72°). In all, 24 patients (13.04%) had a transient loss of signal that was reversed by the previously described methods. Four losses (2.17%) occurred after surgical exposure, five (2.71%) after instrumentation and 15 (8.15%) during curve correction. All of these were reversed using one of the previously cited methods and surgery was resumed. Of these 24 patients, there were 19 patients with AIS, two with skeletal dysplasia, one with connective tissue disease, one with neurofibromatosis and one with early onset scoliosis. Mean major curve Cobb angle in this group was 62° (SD 7°; 40° to 74°), compared with 48 (SD 8°; 35° to 71°) in patients without transient loss of signal. Mean thoracic kyphosis in these patients averages 38° (SD 5°; 26° to 58°) compared with 34° (SD 9°; 17° to 72°) in patients without transient loss of signal.

Discussion

This retrospective study stresses the importance of good patient positioning with the results showing that early operative waveform deterioration in patients with scoliosis may be due to the patient's malposition and is more likely to occur in non-idiopathic, sharp and hyperkyphotic deformities. This study focused on clinically neurologically intact children and adolescent patients with idiopathic or secondary scoliosis scheduled for posterior instrumentation with TES-MEPs monitoring. The main emphasis of this work was to analyze the intriguing irreversible loss of signal that happens early during scoliosis surgery, whether immediately or shortly after patient prone positioning.

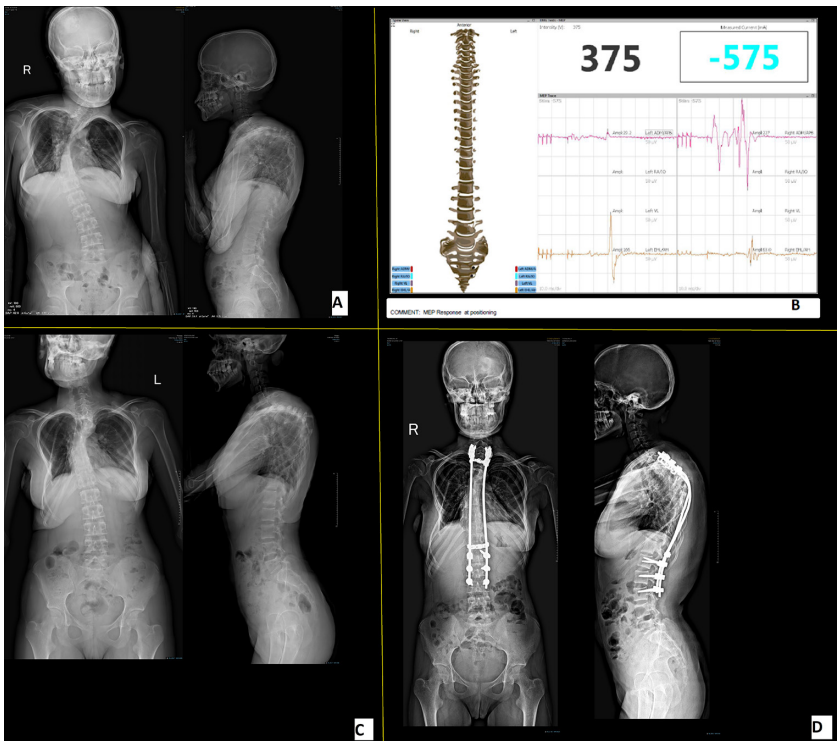

Fig. 2 Figure showing the case of the patient with neurofibromatosis, taken back to surgery after four weeks of skeletal traction: (**a**) anteroposterior (AP) and lateral full spine radiographs of a 14-year-old patient with neurofibromatosis; (**b**) transcranial electric stimulation motor evoked potentials drawings showing early waveform changes in this patient during surgery, upon positioning; (**c**) AP and lateral full spine radiographs of the same patient after four weeks of skeletal traction; (**d**) postoperative standing AP and lateral full spine radiographs of the same patient after performing surgery, six months after the first surgery, after four weeks of skeletal traction and with maintained traction during surgery.

To our knowledge, this is the first cohort in the available medical literature that evaluates this outcome.

Among the 190 patients in this series, one patient had a permanent paraplegia raising the incidence of neurological injury in this series to 0.52%, comparable with the 1% reported in the medical literature.[2,3] The negative extensive postoperative work-up performed in these patients with secondary scoliosis raises the hypothesis of positional temporary suffering of a more vulnerable spinal cord in this patients group.

All 190 patients were positioned similarly in a prone position over chest and iliac sand bags as classically performed in scoliosis surgery. Therefore, it is rather a subtle compression between the patient's spinal cord and the patient's spinal deformity than a malposition that explains the early loss of signal in the six patients with secondary scoliosis.

Descriptive statistical analysis shows patients with permanent loss of signal, who have secondary scoliosis, had sharper curves both in the frontal (64° versus 50°) and sagittal (72° versus 35°) planes then those of patients with transient or no loss of signal.

Patients with secondary scoliosis tend to have sharper curves or more deformations in the spinal canal together with a more susceptible cord when compared with patients with AIS. These, and other factors may apply more pressure on the spinal cord when in the classic prone position producing electrophysiological changes recognized during positioning or the early phases of the procedure through neuromonitoring. More subtle vascular ischemia may elicit similar changes in these patients when the compression is predominantly anterior and may also account for the perceived neurological changes.

A retrospective thorough analysis of the involved six patients' charts and radiographs looking for a common pattern, found that the curves of these patients were comparable for hyperkyphosis. This gave the authors the idea of performing a preoperative progressive skeletal traction and of maintaining it during surgery. This should hypothetically soften the sharpness of the spine curvatures and prepare gradually the vulnerable spine cord to the lordotic prone positioning during surgery. Skeletal traction should also be maintained peroperatively while in the prone position to reduce position dependent spinal curve

modifications that would increase stresses on the vulnerable spinal cord. This strategy was applied to two patients that were taken back to the operating room and led to promising results with maintenance of TES-MEP signals after positioning the patient and exposing the spine.

Therefore, patient positioning during posterior instrumentation for spinal deformity is of utmost importance and should, therefore, be undertaken under the strict control of the spine surgeon or his most trained assistants. When the hyperkyphotic sharp angled curve is present in patients with secondary scoliosis, progressive skeletal traction started three weeks preoperatively and maintained during the surgery might be an option to reduce the risk of loss of TES-MEP signals during patient positioning. More optimal hemodynamic monitoring with optimal room and body temperature are also requested.

For the remaining patients without permanent deficits imposing on the interruption of the surgery, the incidence as well as the timely distribution of reversible waveform modifications were comparable with similar data previously published in the medical literature.[16,19,20]

The main limitation of this study resides in its retrospective design. However, the low incidence of occurrence of early permanent waveform deterioration (3.15% in our series) and the paucity of dedicated articles in the literature led us to believe that our findings are worth reporting. A second possible limitation is the absence of statistical comparison between patients with transient waveform modification and those with permanent signal disappearance or those without any waveform disturbance. However, the large discrepancy between patient numbers in each group makes statistical comparison less clinically relevant; also, possible risk factors for waveform deterioration (curve severity, presence of kyphosis, number of vertebrae to fuse, duration of surgery) are well known and were extensively studied in the available medical literature.[1,15,19] Descriptive statistical analysis is here to provide a preliminary impression of what analytical statistical comparison would show if more patients could be included in further multi-centric studies.

Conclusion

Intraoperative neuromonitoring, whether in its TES-MEPs form or its combined form, is a tool that increased safety for both patient and surgeons undergoing corrective surgery for scoliosis. In neurologically intact patients, our series showed that AIS was rarely, if ever, associated with intraoperative neurological risk, even the that related to patient position. Early waveform deterioration in patients with scoliosis, after prone positioning or soon after spinal exposure, may be due to a patient's malposition. This is much more likely to occur in patients with secondary scoliosis together with kyphotic sagittal alignment, suspected to have sharper spinal curvatures with a vulnerable spinal cord. In these patients, progressive skeletal traction started at least one week before the surgical intervention and was maintained during the surgery together with optimal hemodynamic monitoring seems to be of significant help.

Received 24 June 2018; accepted after revision 28 February 2019.

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

OA LICENCE TEXT

This article is distributed under the terms of the Creative Commons Attribution-Non Commercial 4.0 International (CC BY-NC 4.0) licence (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed.

ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

ICMJE CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

MR: study design, measurements, drafting the manuscript.
REA: study design, measurements, reviewing the manuscript.
EB: data collection and extraction, drafting the manuscript.
IG: study design, performing the surgical intervention and reviewing the manuscript.

REFERENCES

1. **Pastorelli F, Di Silvestre M, Plasmati R, et al.** The prevention of neural complications in the surgical treatment of scoliosis: the role of the neurophysiological intraoperative monitoring. *Eur Spine J* 2011;20:S105-S114.

2. **Hamilton DK, Smith JS, Sansur CA, et al.** Rates of new neurological deficit associated with spine surgery based on 108,419 procedures: a report of the scoliosis research society morbidity and mortality committee. *Spine* 2011;36:1218-1228.

3. **Diab M, Smith AR, Kuklo TR.** Neural complications in the surgical treatment of adolescent idiopathic scoliosis. *Spine* 2007;32:2759-2763.

4. **Schwartz DM, Auerbach JD, Dormans JP, et al.** Neurophysiological detection of impending spinal cord injury during scoliosis surgery. *J Bone Joint Surg [Am]* 2007;89-A:2440-2449.

5. **Middleton J, Tran Y, Craig A.** Relationship between quality of life and self-efficacy in persons with spinal cord injuries. *Arch Phys Med Rehabil* 2007;88:1643-1648.

6. **Dawson EG, Sherman JE, Kanim LE, Nuwer MR.** Spinal cord monitoring. Results of the Scoliosis Research Society and the European Spinal Deformity Society survey. *Spine (Phila Pa 1976)* 1991;16:S361-S364.

7. **Pajewski TN, Arlet V, Phillips LH.** Current approach on spinal cord monitoring: the point of view of the neurologist, the anesthesiologist and the spine surgeon. *Eur Spine J* 2007;16:S115-S129.

8. **Nuwer MR, Emerson RG, Galloway G, et al.** Evidence-based guideline update: intraoperative spinal monitoring with somatosensory and transcranial electrical motor evoked potentials. *J Clin Neurophysiol* 2012;29:101-108.

9. **Tamaki T, Noguchi T, Takano H, et al.** Spinal cord monitoring as a clinical utilization of the spinal evoked potential. *Clin Orthop Relat Res* 1984;184: 58-64.

10. **Luk KD, Hu Y, Wong YW, Cheung KM.** Evaluation of various evoked potential techniques for spinal cord monitoring during scoliosis surgery. *Spine* 2001;26:1772-1777.

11. **Sutter M, Deletis V, Dvorak J, et al.** Current opinions and recommendations on multimodal intraoperative monitoring during spine surgeries. *Eur Spine J* 2007;16:S232-S237.

12. **Acharya S, Palukuri N, Gupta P, Kohli M.** Transcranial motor evoked potentials during spinal deformity corrections-safety, efficacy, limitations, and the role of a checklist. *Front Surg* 2017;4:8.

13. **Thirumala PD, Crammond DJ, Loke YK, et al.** Diagnostic accuracy of motor evoked potentials to detect neurological deficit during idiopathic scoliosis correction: a systematic review. *J Neurosurg Spine* 2017;26:374-383.

14. **Zuccaro M, Zuccaro J, Samdani AF, Pahys JM, Hwang SW.** Intraoperative neuromonitoring alerts in a pediatric deformity center. *Neurosurg Focus* 2017;43:E8.

15. **Samdani AF, Bennett JT, Ames RJ, et al.** Reversible intraoperative neurophysiologic monitoring alerts in patients undergoing arthrodesis for adolescent idiopathic scoliosis: what are the outcomes of surgery? *J Bone Joint Surg [Am]* 2016;98:1478-1483.

16. **Kobayashi K, Imagama S, Ito Z, et al.** Transcranial motor evoked potential waveform changes in corrective fusion for adolescent idiopathic scoliosis. *J Neurosurg Pediatr* 2017;19:108-115.

17. **Schwartz DM, Sestokas AK, Hilibrand AS, et al.** Neurophysiological identification of position-induced neurologic injury during anterior cervical spine surgery. *J Clin Monit Comput* 2006;20:437-444.

18. **Vitale MG, Skaggs DL, Pace GI, et al.** Best practices in intraoperative neuromonitoring in spine deformity surgery: development of an intraoperative checklist to optimize response. *Spine Deform* 2014;2:333-339.

19. **Kamerlink JR, Errico T, Xavier S, et al.** Major intraoperative neurologic monitoring deficits in consecutive pediatric and adult spinal deformity patients at one institution. *Spine* 2010;35:240-245.

20. **Kundnani VK, Zhu L, Tak H, Wong H.** Multimodal intraoperative neuromonitoring in corrective surgery for adolescent idiopathic scoliosis: evaluation of 354 consecutive cases. *Indian J Orthop* 2010;44:64-72.