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REVIEW ARTICLE

SOME PROS AND CONS OF THE NEUROMONITORING DURING THE SCOLIOSIS SURGERY. A NARRATIVE REVIEW

NIEKTÓRE ZALETY I WADY NEUROMONITORINGU PODCZAS OPERACJI SKOLIOZY. PRZEGLĄD NARRACYJNY

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ABSTRACT
Introduction. Apart from the undisputable advantages of intraoperative neuromonitoring using the recording of motor evoked potentials (MEPs) used during spine surgery, there are certain limitations of this method that may give rise to doubts about its actual reliability. The presented narrative review aims to discuss some pros and cons of neuromonitoring during scoliosis surgery. Methods and results. The anaesthesiology-related influences, like neuromuscular blockade (0.5 mg/kg of Rocuronium bromide), seem to moderate evoke the diminishing of the MEPs amplitude parameters, especially when they are recorded from nerves in comparison to the muscles recordings in lower extremities. The proper communication between the anesthesiologist and the neurophysiologist in maintaining the relationship between Bispectral Index Monitor (BIS, 40–60) and applied transcranial electrical stimulation stimulus strength (TES, 130–95 mA) is crucial. The non-invasive approach for paediatric purposes of using the surface electrodes during MEP recordings in scoliosis surgery has been proven to be as precise enough as the needle approach. Disadvantages of using surface electrodes may include technical aspects related to their higher resistance than needle electrodes and their possible displacement from the bioelectric signal source, effectively resolved by adhesive, hermetic, and sterile protection tape. Conclusions. "Real-time neuromonitoring", intraoperative neuromonitoring mainly based on simultaneous recording, inspection and comparison of evoked potential and camera parameters by neurophysiologists, reduces surgery duration

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and minimizes anaesthesia's impact on cardiac and vascular systems and the nervous system. This requires advanced knowledge of the neuromonitoring person regarding the subsequent steps of the surgical procedure during scoliosis correction.

Keywords: neurophysiological neuromonitoring, motor evoked potentials recordings, advantages and disadvantages, pitfalls

STRESZCZENIE
Wprowadzenie. Oprócz niewątpliwych zalet śródoperacyjnego neuromonitoringu z wykorzystaniem rejestracji ruchowych potencjałów wywołanych (MEP) stosowanych podczas operacji kręgosłupa, istnieją pewne ograniczenia tej metody, które mogą budzić wątpliwości co do jej faktycznej niezawodności. Przedstawiony przegląd narracyjny ma na celu omówienie niektórych zalet i wad neuromonitoringu podczas operacji skoliozy według opinii innych ekspertów i naszych własnych doświadczeń. Metody i wyniki. Wpływy związane z anestezjologią, takie jak blokada nerwowo-mięśniowa (0,5 mg/kg bromku rokuronium), wydają się nieznacznie zmniejszać parametr amplitudy MEP, zwłaszcza gdy są rejestrowane z nerwów w porównaniu do rejestracji z mięśni kończyn dolnych. Właściwa komunikacja między anestezjologiem a neurofizjologiem w utrzymaniu odpowiedniej zależności między Bispectral Index Monitor (BIS, 40–60) a zastosowaną siłą bodźca przezczaszkowej stymulacji elektrycznej (TES, 130–95 mA) ma kluczowe znaczenie. Nieinwazyjne podejście do celów pediatrycznych polegające na stosowaniu elektrod powierzchniowych podczas rejestracji MEP w chirurgii skoliozy okazało się równie precyzyjne jak podejście igłowe, nawet jeśli amplituda sygnału rejestrowanego z mięśnia była o połowę mniejsza. Wady stosowania elektrod powierzchniowych mogą obejmować aspekty techniczne związane z ich wyższą opornością niż elektrod igłowych oraz ich możliwym przesunięciem od źródła sygnału bioelektrycznego, skutecznie rozwiązywanym przez klejącą, hermetyczną i sterylną taśmę ochronną. Wnioski. „Neuromonitoring w czasie rzeczywistym", śródoperacyjny neuromonitoring oparty głównie na jednoczesnym rejestrowaniu, badaniu i porównywaniu potencjałów wywołanych i parametrów z kamery przez neurofizjologa, skraca czas trwania operacji i minimalizuje wpływ znieczulenia na układy sercowo-naczyniowy i nerwowy. Wymaga to zaawansowanej wiedzy od osoby neuromonitorującej, dotyczącej kolejnych etapów procedury chirurgicznej podczas korekcji skoliozy. Wreszcie zwiększa bezpieczeństwo operacji poprzez ograniczenie komunikacji chirurg-neurofizjolog i uniknięcie ryzyka dekoncentracji.

Słowa kluczowe: neuromonitoring neurofizjologiczny, rejestracja ruchowych potencjałów wywołanych, zalety i wady, pułapki

Introduction

Adolescent idiopathic scoliosis (AIS) surgery aims to distract and derotate the spine pathological curvature with no neurological side effects as well as to improve the spine biomechanical abilities and silhouette aesthetic. The incidence of neurological complications following scoliosis surgery was identified at 3.2% in 2010 (Malhorta and Shaffrey 2020), and in 2020 it was already 8.2%, due to the need for more AIS surgeries and increasingly complex techniques bringing the increase of risk following the curvature correction.

Motor evoked potentials (MEP) are considered as more useful for neurophysiological intraoperative monitoring than somatosensory evoked potentials (SEP) in cases of surgeries applied for patients with AIS (Daroszewski *et al.*, 2023). Somatosensory evoked potentials from the very beginning of its clinical intraoperative used to verify the conduction of afferent pathways were burdened with the instability of parameters, mainly amplitude of recording at subsequent stages of surgical procedures and the influence of changes in the anaesthesia level (Padberg *et al.*,1998). The principles of their utilization are recordings at different levels of afferent transmission in peripheral and central nervous systems following electrical stimulation of lower extremity nerves. The average amplitude of SEP in normal conditions ranges from 2–10μV, but in AIS patents at about 1–2μV. On the other hand, the motor evoked potentials induced with magnetic field transcranially and recorded at different levels of efferent transmission in central and peripheral nervous systems, mainly from muscles, do not require averaging. The amplitude of MEP ranges in normal conditions at 500–4000μV, while in AIS patients at 200–1500μV. It is evident that utilization of the latter is easier because no averaging is required, however MEP can be affected by anaesthesia and relaxation procedures applied during AIS surgery (Charalampidis *et al.* ,2020). The solution to this problem is to record MEPs from nerves along their anatomical course rather than from muscles (Garasz *et al.* 2023), avoiding the effect of anaesthetic relaxation at the level of the neuromuscular synapse; one of the best candidates is the peroneal nerve at the level of the popliteal fossa (Daroszewski *et al.,* 2024).

Apart from the undoubted advantages of intraoperative neuromonitoring using the recording of motor evoked potentials during spine surgery, there are certain limitations of this method. They may be related to the effects of transcranial electrical stimulation (TES), related to the effects of muscle relaxation and anaesthesia, related to the interpersonal relationship between the anaesthesiologist and the surgeon and related to the patient's health status as well as intraoperative neuromonitoring (IONM) technical issues. This review is devoted to the abovementioned aspects as the pros and cons of the IONM utilization.

Patients, methods, results and discussion

Exclusion criteria for TES application to evoke MEPs during the neuromonitoring include pregnancy, which is usually rare because of the AIS patient's young age. The same holds for epilepsy as the possible iatrogenic TES-induced exogenic effect; therefore, multiple brain stimulation in a short period with trains of the electrical pulses in epileptic-treated patients is forbidden (MacDonald 2002). Patients with past cortical lesions or skull surgeries, convexity skull vault defects, raised intracranial pressure, cardiac diseases, applied proconvulsant medications or anaesthetics, implanted intracranial electrodes, vascular clips or shunts, cardiac pacemakers, and other implanted biomedical devices are of the special precautions or even abandoned for TES (Pastorelli *et al.,* 2011).

The success of scoliosis correction without complications in the functioning of the nervous system depends primarily on the masterful skills of the surgeons and nursing staff. The significant influence comes from good cooperation between the neurophysiologist and anaesthesiologist performing neuromonitoring at every stage of the surgical procedure. The appropriate communication between the anesthesiologist and the neurophysiologist in maintaining the suitable depth of anaesthesia employing a relationship between Bispectral Index Monitor (BIS, 40–60) and applied transcranial electrical stimulation stimulus strength (TES, 130–95 mA) is crucial for good neuromonitoring conditions and stable MEP amplitude recording (Daroszewski *et al.,* 2023a).

The anaesthesiology-related influences, like neuromuscular blockade (0.5 mg/kg of Rocuronium bromide), seem to moderate evoke the diminishing of the MEPs amplitude parameters, especially when they are recorded from nerves in comparison to muscles of lower extremities (Daroszewski 2023).

Our experience relating to the concept of "Surgeon -neurophysiologist" (neuromonitoring based on interactive verbal reports) versus the concept of "Real-time neuromonitoring" (based on the simultaneous MEPs recordings with the direct visual inspection of the operation field via the camera, without verbal reports) confirms a safer and shorter course of scoliosis correction surgery in cases where the latter was used. A greater increase in the surgeon's concentration was demonstrated, due to lower bidirectional communication with about 1 hour shorter averaged time of surgery (Daroszewski 2023a).

One of the most important aspects limiting the difficulties of intraoperative neuromonitoring is the precise diagnosis of the neurological condition of the patient with scoliosis, with particular emphasis on the transmission of the spinal cord pathways conducting efferent neuronal impulses (Iorio *et al.* 2016). This can be achieved by estimating more the amplitude than latency parameters of MEP recordings performed preoperatively following transcranial single-pulse magnetic stimulation (TMS). The similar amplitude parameters in recordings from analogous muscles and nerves on the left and right sides should be observed following TMS and TES (Figure 1).

In a significant percentage of operated scoliosis patients, improvement in the efferent transmission is visible immediately after the application of corrective instrumentation (33% of 525 operated scolioses), postoperatively the day after surgery in 45%, a week after the surgery in 65%, and half a year after the surgery in 92%.

In parallel with bilateral intraoperative MEP recordings, EMG recordings of spontaneous activity can provide valuable information about the effects of anesthesia or the effect of performed surgical procedures. An increased amplitude parameter in EMG recordings above 100 μV characterizing increased muscle tension, can be a sign of "shallow anesthesia". In addition, visible "burst-like" spontaneous activity in EMG recordings correlates with a deterioration of the MEP amplitude parameter, being a sign of neural structures irritation (Figure 2).

The non-invasive approach for paediatric purposes of using the surface electrodes during MEP recordings in scoliosis surgery has been proven to be as precise enough as the needle approach (Daroszewski *et al.,* 2023, Gadella *et al.,* 2023, Dulfer *et al.,* 2023), even if the amplitude of the signal recorded from muscle or nerve was about half as small in normal conditions. Disadvantages of using surface electrodes may include technical aspects related to their higher resistance than needle electrodes and their possible displacement from the bioelectric signal source, effectively resolved by hermetic, sterile tape protection (Daroszewski *et al.,* 2024). The lack of bruising and extravasation following the use of needle (Darcey *et al.,* 2016) versus surface electrodes is a convincing argument for neuromonitoring performed in children with scoliosis.

MEP recordings may be distorted by signals from devices generating the external electric and magnetic fields, cauterizers, coagulators, X-ray devices, operating lamps, and anaesthesia unit systems (Carl *et al.,* 2010).

MEP recording aberrations caused by accidental electrode disconnection or body movement artifacts are rare. Occasional protrusion of subcutaneous needle-stimulating electrodes implanted overcranially caused by movement artifacts can lead to false alarms due to the lack of MEP potential recordings (Deletis 2007, Kobayashi *et al.,* 2017, Mac Donald 2006).

Heating bone and muscle structures with a cautery during surgical spine exposure in the MEP recordings can be temporarily expressed by slowing down the conduction of nerve impulses within the fibers of the spinal pathways, usually eliminated by cooling the surgical field with a physiological saline solution (Daroszewski 2023a). Moreover, accidental contact of the cautery with the transpedicular screw can cause a massive movement artifact caused by the stimulation of the root structures or the spinal cord itself with electrical charges, affecting the temporary decrease in the amplitudes of the recorded MEP.

According to our observations, the paradoxical distribution of motor centres located

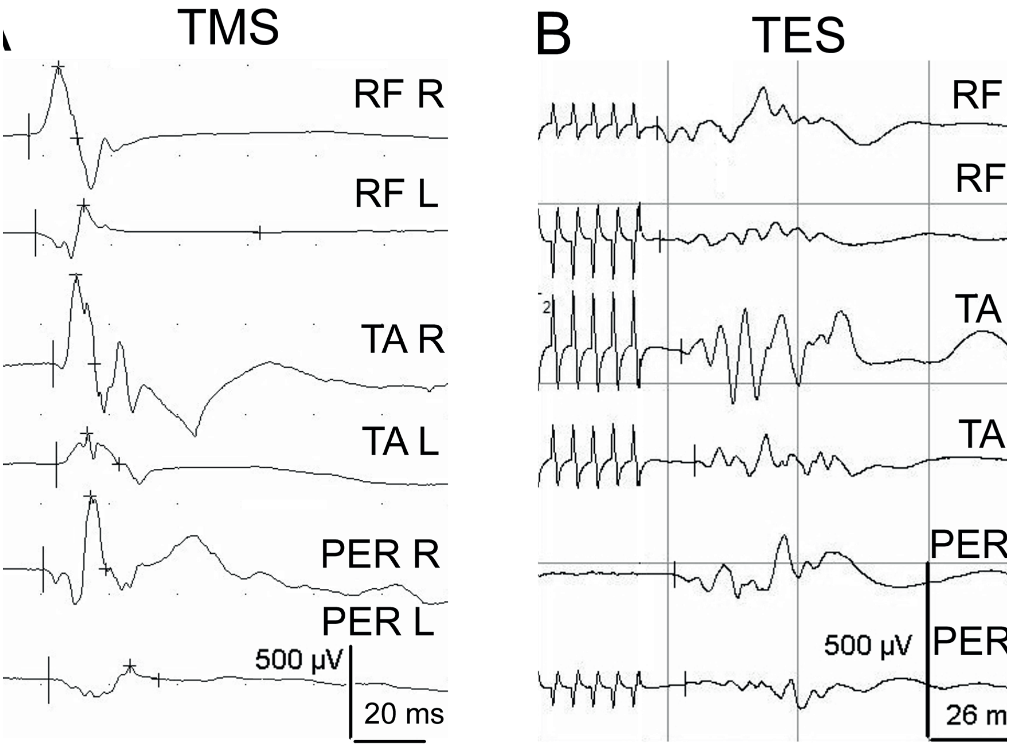

Figure 1. Comparison of motor evoked potential recordings from muscles and nerves preoperatively (A) and intraoperatively (B) before implantation of corrective instrumentation. The potentials were induced transcranially with magnetic field stimuli (A, TMS) and electrical stimuli (B, TES). Note the similar amplitude parameters in recordings from analogous muscles and nerves on the left and right sides. Abbreviations: R – right side, L – left side, RF – rectus femoris muscle, TA – tibialis anterior muscle, PER – peronal nerve

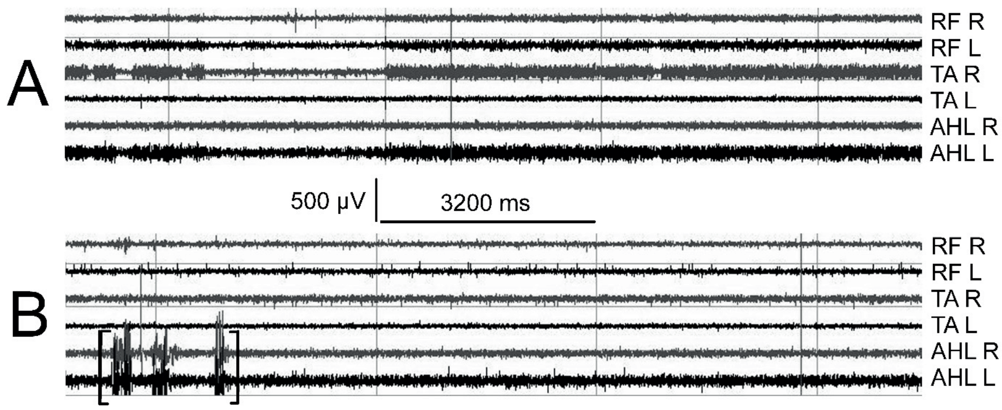

Figure 2. Examples of intraoperatively recorded EMG with amplitude parameters exceeding 100 μV could be a sign of low anaesthesia level (A) and "burst-like" spontaneous activity (B, indicated by the bracket) correlates with a deterioration of the MEP amplitude parameter, being a sign of neural structures irritation. Abbreviations: R – right side, L – left side, RF – rectus femoris muscle, TA – tibialis anterior muscle, AHL – abductor halluces longus muscle

rostrally to the Rolandic sulcus (in 9% of 525 scoliotic patients) may not be consistent with the 10–20 system calculation. Still, it can be verified by preoperative MEP recordings and marking the stimulation electrodes insertion sites for TES purposes.

Despite the significant development of equipment for recording evoked potentials during neuromonitoring during scoliosis correction, using motor rather than somatosensory evoked potentials seems more justified, especially in patients with a large lateral curvature angle of the spine. Although initial attempts to involve AI in intraoperative neuromonitoring services in spine surgery are already reported in the media, too many variables resulting from external factors mentioned in this review that may affect the procedure's success indicate moderate involvement in the future.

Conclusions

Intraoperative neuromonitoring, using the recording of motor evoked potentials during scoliosis surgery provides more pros than cons. Limitations of this method may be related to the effects of transcranial electrical stimulation (TES), the effects of anaesthesia procedures, the interpersonal relationship between neurophysiologists, anesthesiologists and the surgeon, and rarely the neuromonitoring technical issues. "Real-time neuromonitoring" shortens the duration of surgery, minimizes the impact of anesthesia on the cardiovascular and nervous systems, and increases the safety of surgery for patients with scoliosis. However, this requires advanced knowledge of the neuromonitor regarding the neurophysiology of the nervous and muscular systems and the subsequent stages of the surgical procedure during scoliosis correction. This strategy provides comfort to the operating team, reducing the risk of attention disorders during the necessary communication between the surgeon and neurophysiologist.

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