

ANAESTHESIA AND INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING IN SURGICAL CORRECTION OF IDIOPATHIC SCOLIOSIS IN CHILDHOOD

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Abstract

The objective of this study is to compare the effectiveness of intraoperative neurophysiological monitoring (IONM) using two types of anaesthesia: combined anaesthesia and total intravenous anaesthesia (TIVA).

This retrospective study included 155 paediatric patients undergoing surgery for idiopathic scoliosis. The patients were divided into two groups based on the administered anaesthesia type: combined (inhalation and intravenous) anaesthesia group ($n = 63$) and TIVA group ($n = 92$). Multimodal neurophysiological monitoring techniques were applied, including somatosensory evoked potentials (SSEP), transcranial motor evoked potentials (TCMEP), spontaneous and triggered electromyography, and electroencephalography. Specificity and sensitivity of IONM were calculated for individual modalities as well as in total (SSEP + TCMEP).

In the postoperative period 7 patients (4.5%) were diagnosed with neurological complications. Only one case, a patient from the TIVA group, exhibited irreversible neurological complications. No statistically significant difference was found between the types of anaesthesia in terms of difficulties in recording baseline SSEP and TCMEP responses. False-positive SSEP potentials recorded under sevoflurane anaesthesia were three times more frequent than false-positive responses under TIVA, and this difference was statistically significant.

There was no statistically significant difference in the number of registered TCMEP changes between the two anaesthesia types. The specificity and

sensitivity for the inhalation anaesthesia group were 90.38% and 90.91%, respectively. For patients receiving TIVA, the specificity and sensitivity were 97.5% and 100%, respectively.

This study concludes that IONM is applicable to both types of anaesthesia – combined and TIVA – if the type and dosage of anaesthetics are chosen correctly. Conducting IONM by the anaesthesia team enhances the interpretation of monitoring data, thereby increasing the effectiveness and reliability of IONM.

Key words: intraoperative neurophysiological monitoring, anaesthesia, idiopathic scoliosis

Introduction. Scoliosis is a disease associated with deformity of the spine and thorax, the progression of which can lead to serious disorders in the functions of the respiratory and cardiovascular systems, to psychological and social problems.

The most common is idiopathic scoliosis – 80% of all cases of scoliosis. Surgical correction is required when the angle of scoliotic curvature is greater than 45°.

Surgical correction is associated with a high risk of neurological complications. Intraoperative neurophysiological monitoring (IONM) is used to prevent them. IONM includes the recording of spontaneous activity – electroencephalography, spontaneous electromyography (EMG), and of responses as a result of stimulation – somatosensory evoked potentials (SSEP), transcranial motor evoked potentials (TCMEP), triggered EMG. Anaesthetics have a suppressive effect on the SSEPs and TCMEPs. For maximal sensitivity and specificity of the IONM, a good knowledge of both the anaesthetic and the effect of the administered dose and the technical parameters for stimulation and recording of evoked potentials is required. It is possible to use combined balanced anaesthesia (inhalational and intravenous anaesthetics) or total intravenous anaesthesia (TIVA). The performance of IONM by the anaesthesia team facilitates the interpretation of the results and improves the reliability of the method. The aim of this study is to compare the effectiveness of IONM using the two types of anaesthesia – TIVA and combined, and to validate anaesthesia protocols for surgical correction of scoliosis in childhood.

Materials and methods. Patients. This is a retrospective study; 155 paediatric patients with idiopathic scoliosis, aged 5 to 18 years, who underwent surgical intervention for the period 2009 to 2022 at Acibadem City Clinic, Tokuda University Hospital were included. IONM was performed by the same trained anaesthesia team.

Anaesthesia. Patients were divided into two groups depending on the anaesthesia. In the first group, combined inhalation and intravenous anaesthesia was used ($n = 63$) and in the second group, TIVA was used ($n = 92$). Mean arterial tension > 60 mmHg and systolic blood pressure > 80 mmHg were maintained. Temperature was maintained in the range 36–37 °C. Postoperative neurological

complications, reversibility of complications and duration of the period in which they were observed were recorded.

Anaesthesia protocol for general combined anaesthesia includes: premedication with Midazolam 0.3 mg/kg orally, 30 min before induction of anaesthesia; induction with Propofol 2.5–3 mg/kg i.v.; Succinylcholine 1–1.5 mg/kg i.v.; Sevoflurane $MAK \leq 0.5$; infusion with Propofol 40–75 mcg/kg/min; Fentanyl boluses: 1–2 mcg/kg/h i.v.; relaxant Tracrium 0.4 mg/kg, at induction into anaesthesia, same repeat dose after recording baseline SSEP and MEP curves.

Anaesthesia protocol for general TIVA includes: premedication with Midazolam 0.3 mg/kg orally; induction with Propofol 2.5–3 mg/kg i.v.; Succinylcholine 1–1.5 mg/kg i.v.; intravenous infusion with Propofol 80–150 mcg/kg/min; Remifentanyl 0.1–0.3 mcg/kg/min; relaxant Tracrium 0.4 mg/kg, at induction into anaesthesia, same repeat dose after recording baseline SSEP and MEP curves.

IONM. The technical equipment includes a 32-channel unit with Xltek Protector hardware and EPWorks software. From June 2021 we have been using a 32-channel NIM Eclipse instrument.

Multimodal neurophysiological monitoring has been implemented, including SSEP, TCMEP, EMG – spontaneous and triggered, EEG.

Depending on the neuromonitoring technique used for TCMEP, stimulation parameters were:

- Stimulation type: slow, direct current; pulse duration 0.5 ms, stimulation intensity up to 200 mA; number of pulses in a series 7 to 9; frequency 250 Hz, ISI (inter stimulus interval) 4 ms.

- Stimulation type: fast, constant voltage; pulse duration 75 μ s, stimulation intensity 250 V to 400 V in paediatric patients, number of pulses in a series 5 to 9, stimulation frequency 1 stim/s; ASI (after stimulus interval) 1000 ms.

We considered significant changes of SSEP to be a decrease in EP amplitude $> 50\%$ and a prolongation of latency $> 10\%$. For significant changes of TCMEP, we considered a decrease in the amplitude of responses $> 80\%$.

Difficulties were recorded in obtaining baseline SSEP and MEP curves for both types of anaesthesia. For each of the two groups, the obtained SSEP and MEP responses were divided into: true positive (T+), true negative (T–), false positive (F+), and false negative (F–). IONM specificity and sensitivity were calculated both for the individual modalities and summed (SSEP+TSMEP).

Significant irreversible changes in IONM followed by recording of postoperative neurological deficit were defined as true positives. To this group, we have added the changes signalling neurological damage that have undergone reversal as a result of action by the surgical team. False positives are changes in the IONM due to the influence of anaesthetics, changes in physiological parameters and technical problems.

True negatives are cases in which there are no significant changes in the recorded electrophysiological activity and no postoperative neurological deficit.

False negatives are cases with no recorded change in IONM, and the presence of postoperative neurological complications.

Data collection, systematization and statistical processing were performed using IBM SPSS 23. The methods of descriptive statistics, correlation analysis, regression analysis, comparison of groups with *T*-test, analysis of variance and non-parametric methods were used.

Results. Patients included in the study ranged in age from 5 to 18 years, mean 13.6 ± 0.52 years. The gender distribution was 129 females and 26 males.

Of the 155 patients included in the study, 153 underwent surgical intervention with posterior approach, in one patient the intervention was a combination of posterior and lateral approach, lateral approach was used in one of the children. Combined anaesthesia was used in 63 patients and TIVA in the remaining 92 patients. None of the patients required a switch from combined anaesthesia to TIVA. In the postoperative period, 7 patients (4.5%) of all 155 studied were diagnosed with neurological complications (Table 1). In only one case, a patient from the TIVA group, neurological complications were irreversible. This was postoperative Brown-Séquard Syndrome, characterized by impairment of motor function on the ipsilateral side of the lesion due to involvement of the corticospinal pathway and loss of sensation for pain and temperature on the contralateral side due to involvement of the spinothalamic pathway. In the remaining patients, the neurological complications were resolved within 6 months.

T a b l e 1
Neurological complications in the postoperative period

N	Anaesthesia	SSEP changes	Reversibility of SSEP changes	T+ T- F+ F-	TCMEP changes	Reversibility of TCMEP changes	T+ T- F+ F-	Postoperative neurological complications	Reversibility of complications
1	combined	no		F-	no		F-	1	yes
2	combined	yes	yes	T+	yes	1	T+	1	yes
3	combined	yes	yes	T+	yes	1	T+	1	yes
4	TIVA	yes	no	T+	yes	1	T+	1	yes
5	TIVA	yes	no	T+	yes	2	T+	1	yes
6	TIVA	no		F-	yes	2	T+	1	no
7	TIVA	yes	no	T+	yes	2	T+	1	yes

When comparing the T1 stimulation intensity required to obtain baseline MEPs, a statistical dependence was found in both groups. The mean value of T1

in combined anaesthesia was 136.9 and in TIVA 92.3, the difference between them 44.5 was statistically significant. *T*-test $t = 8.49$, Sign.0.001.

The T2 stimulation intensity that was required to obtain MEP at the end of surgery was also different in the two groups and was 174.2 in anaesthesia involving Sevoflurane and 114.8 in TIVA and the difference between them (59.4) was statistically significant. *T*-test $t = 10.22$, Sign.0.001.

In terms of difficulty in recording baseline curves, there was no statistically significant difference between type of anaesthesia and obtaining baseline SSEP (Pearson χ^2 0.948; Sig. 0.330; CI95%) and TCMEP (Pearson χ^2 0.948; Sig. 0.330; CI95%), (Table 2).

T a b l e 2
Type of anaesthesia – SSEP and TCMEP baselines

Anaesthesia	SSEP baseline – no problem	SSEP baseline – problem	TCMEP baseline – no problem	TCMEP baseline – problem
Combined anaesthesia	$n = 57$ (90.5%)	$n = 6$ (9.5%)	$n = 60$ (95.2%)	3 (4.8%)
TIVA	$n = 87$ (94.6%)	$n = 5$ (5.4%)	$n = 90$ (97.8%)	2 (2.2%)

Significant changes in SSEP responses were reported in 26 patients in the combined anaesthesia group and in 19 of the TIVA patients (Table 3).

T a b l e 3
Type of anaesthesia – SSEP and TCMEP changes

Anaesthesia	SSEP changes				TCMEP changes			
	T+	T–	F+	F–	T+	T–	F+	F–
Combined anaesthesia	$n = 15$ (23.8%)	38 (60.3%)	9 (14.3%)	1 (1.6%)	$n = 5$ (7.9%)	$n = 56$ (88.9%)	$n = 1$ (1.6%)	$n = 1$ (1.6%)
TIVA	$n = 15$ (16.3%)	$n = 72$ (78.3%)	$n = 4$ (4.3%)	$n = 1$ (1.1%)	$n = 9$ (9.8%)	$n = 83$ (90.2%)	$n = 0$ (.0%)	$n = 0$ (.0%)

The recorded SSEP responses were divided into the following groups: true positives due to nerve structure involvement; true negatives; false positives and false negatives.

The registered false positive SSEP potentials in sevoflurane anaesthesia were three times more compared to TIVA, and the difference was statistically significant (14.3%:4.3%; obs/exp 9:5.3;4:7.7).

During IONM, significant changes in MEP were reported in 6 (9.5%) patients with combined and 9 (9.8%) with TIVA.

There was no statistically significant difference between the number of TCMEP changes recorded for the two types of anaesthesia. Pearson χ^2 3.06; Sig. 0.38; CI 95%; N155, (Table 3).

In the present study, for the applied multimodal IONM in both groups, we calculated specificity and sensitivity for the individual components, SSEP and MEP, and for their combined application, SSEP+MEP (Table 4).

T a b l e 4
Sensitivity and Specificity of IONM in combined anaesthesia and TIVA

Anaesthesia	Sensitivity and specificity	SSEP	MEP	SSEP + MEP
Combined anaesthesia	Sensitivity	93.75%	83.33	90.91%
	Specificity	80.85%	98.25%	90.38%
TIVA	Sensitivity	100%	100%	100%
	Specificity	94.81%	100%	97.5%

False negative results for SSEP and MEP were reported in only one patient in the combined anaesthesia group. This refers to a 17-year-old female patient with a Cobb angle of 130°, correction degree of 63°. Surgery was performed in two consecutive stages with right lateral and posterior approach with a duration of 600 min. No intraoperative changes in the SSEP and MEP were reported. However, abnormalities in spontaneous and triggered EMG were recorded. In the postoperative period, hypoesthesia for pain and touch were observed at L1, L2, L3, L4, and discreetly L5 dermatomes for the right leg, weakened right knee reflex, and decreased muscle strength on flexion in the knee crease. The changes resolved completely within 1 month. This is most likely a lumbar plexus injury with lateral approach spinal stabilization [1]. As it is a peripheral root injury the only electrophysiological changes recorded are in the EMG.

Discussion. Electrophysiologic monitoring has been shown to be effective in preventing neurologic complications during scoliosis surgery [2]. The Scoliosis Research Society (SRS) recommends the standard use of IONM for surgeries associated with risk of spinal cord injury [3]. Most anaesthetics cause dose-dependent suppression of synaptic activity. The greater the number of synapses involved in the monitored neural structures, the greater the effect of anaesthetics on the IONM [4]. This explains the marked effect of anaesthesia on cortical SSEP responses and TCMEPs and the minimal effect on subcortical and peripheral SSEPs, and spontaneous EMG.

In our study, both types of anaesthesia allowed recording of baseline evoked potentials with good amplitude and latency, allowing correct interpretation of monitoring data. In no patient was it necessary to switch from combined inhalation anaesthesia to TIVA in order to obtain informative responses with the required amplitude and latency. Studies investigating the effect of inhalational anaesthetics on the SSEP found a decrease in the amplitude and an increase

in the latency of the SSEP with increasing MAC [5, 6]. The suppressive effect on SSEP under inhalation anaesthesia is more pronounced compared to that of Propofol [7, 8]. This explains the three times more false positive SSEP changes observed in our study using combined anaesthesia. SSEP changes resulting from anaesthesia were observed bilaterally and were more pronounced in cortical leads. Knowing this, it is not difficult to distinguish false-positive from true-positive SSEP changes. It should be kept in mind that with inhalation anaesthesia, SSEP changes occur more rapidly in a dose-dependent manner, and the recovery time for potentials is also shorter [9]. Thus, recovery after anaesthesia is faster and patient cooperativity is better. This is of particular importance in cases of emergency during surgical intervention where the use of Stagnara wake up test is required.

MEPs are sensitive to the action of anaesthetics. The suppressive effect of inhaled halogenated anaesthetics is more pronounced [10]. To overcome this effect, multipulse stimulation of the cerebral cortex is applied, thus summing the action of the excitatory postsynaptic potentials and producing a response of greater amplitude. Application of transcranial stimulation with only two electrical pulses at 0.5 MAC Sevoflurane produced a motor response in only 55% of patients. Propofol also had a suppressive effect on MEP with increasing dose. At an infusion rate of 75–100 mcg/kg/min and with 5-pulse stimulation, motor responses were recorded in 60–88% of patients [11]. Using a larger number of high-frequency pulses allowed motor responses to be obtained.

In the two anaesthesia groups, we compared the stimulation intensity to obtain baseline MEPs with good pulse amplitude and repetitiveness. The results showed that the initial stimulation intensity was greater in the inhalation anaesthesia group. There was also a statistically significant difference in the change of current strength used to produce MEPs during surgery. The combined anaesthesia group required a greater increase in current strength during surgery to obtain MEP (37.3 mA) compared with the TIVA group (22.5 mA). These results are not surprising and are due to the more pronounced suppressive effect of inhalational anaesthetics on MEP.

The use of inhalational anaesthetics should not be overlooked when using IONM. Propofol administration in prolonged infusion and in high doses has its side effects: hypotensive effect, propofol-infusion syndrome, delayed awakening, and suppressive effect on EP.

A study by SLOAN et al. [12] compared two anaesthesia groups, TIVA and combined, and found no statistically significant difference in cortical SSEP and MEP amplitudes; in MEP stimulation voltages; and in amplitude variations between trials.

LUO et al. [13] demonstrated that administration of Propofol together with Sevoflurane reduced the MAC of inhalational anaesthetic in a dose-dependent manner. The use of combined balanced anaesthesia reduced both the doses of both intravenous and inhalational anaesthetic used and their side effects. SSEPs

are usually recorded at $MAC < 1$, MEPs at $MAC < 0.5$.

In a review of the literature, FORBES et al. [14] reported a sensitivity of 100% and specificity of 57.8% for SSEP monitoring. A study by KUNDNANI et al. [15] covering 354 cases of AIS reported a sensitivity of 51% and specificity of 100% on SSEP monitoring; for MEP monitoring, specificity was 96% and sensitivity 100%.

A study of 477 patients with idiopathic scoliosis [16] reported a sensitivity of 95.0% and a specificity of 99.8% for SSEP neuromonitoring.

Another study comprising 1155 paediatric patients with different types of scoliosis reported a sensitivity of 100% and specificity of 99.3% on combined multimodal monitoring [17]. Of note is the difference in sensitivity for the individual modalities: 20% for cortical and cervical SSEPs and 100% for MEP. The specificity for both monitoring components is approximately the same 99.74%/99.91%/99.56%, respectively.

In the present study, for the combined multimodal IONM – SSEP + MEP, we calculated for patients with combined anaesthesia: specificity 90.38% and sensitivity 90.91%. In the TIVA group, the values were 97.5% specificity and 100% sensitivity, respectively. This indicates a high effectiveness of the method in preventing neurological complications in scoliosis surgical corrections. The lower sensitivity in the first group was due to the only patient with a false-negative result, but in whom changes in spontaneous and triggered EMG were recorded. Intraoperative EMG is a very sensitive method and gives rapid feedback to the surgeon when nerves are manipulated or damaged [18]. SSEP and MEP may remain unchanged in root injury. The addition of EMG as a component of the IONM increases the sensitivity of the method to 100% and in the combined anaesthesia group. The difference of about 7% in specificity in the two groups is the result of the greater number of false positives when inhalation anaesthesia is used. This difference is to be expected, but a good knowledge of the action of anaesthetics and of electrophysiological monitoring allows correct interpretation of the results.

Conclusion. IONM is strongly influenced by anaesthetics. Most anaesthetics suppress EP. If the type and dosage of anaesthetics are chosen correctly, both types of anaesthesia – combined (intravenous+inhalation at $MAC \leq 0.5$) and TIVA – can be used when performing IONM. The choice depends on which is good for the patient, individual sensitivity to anaesthetics and concomitant pathology.

Conducting the IONM by the anaesthesia team facilitates interpretation of monitoring data and increases the effectiveness and reliability of the IONM. Training of anaesthesiologists on the nature and specifics of IONM. is necessary.

The development of protocols for anaesthetic management and IONM ensures patient stability during surgery, reduces the risk of complications and facilitates team performance.

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