Year 3 SSC Project

Risk factors for spinal cord monitoring changes in paediatric patients

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Abstract

Study Design.
Retrospective review.

Objective.
To determine clinical factors that increase the risk of intraoperative neurophysiological monitoring (IONM) changes in paediatric patients.

Methods.
All cases involving paediatric patients who underwent scoliosis correction surgery in a single institute between 2017 and 2022 were reviewed. Patients with IONM alerts were identified and their demographic and clinical details were obtained. Operative and radiological factors analysed included estimated blood loss (EBL), operative time, number of levels fused, preoperative major Cobb angle, postoperative major Cobb angle and mean corrective rate.

Results.
A total of 206 cases used IONM, including 11 cases which recorded significant neurophysiological changes. Compared to the non-alert group, the alert group had a significantly greater EBL ($P < .001$), operative time ($P < .001$) and postoperative major Cobb angle ($P = 0.032$). There were no significant differences in preoperative major Cobb angle ($P = 0.266$) and mean corrective rate ($P = 0.199$) between the two groups. IONM alerts were found to be triggered by insertion of screws (36.4%), rod application and curve correction manoeuvres (36.4%), technical issues (18.2%) and corpectomy procedure (9.1%). 1 patient (9.1%) developed postoperative transient neurological deficits and 2 operations (18.2%) were aborted.

Conclusion.
Longer operative time, higher EBL and greater postoperative major Cobb angle are associated with an increased risk of spinal cord injury. IONM alerts commonly occur during and after insertion of instrumentation and curve correction manoeuvres.

Introduction

With every spinal deformity surgery, there is a 0.5-3.2% risk of major neurological complications[1]. In 1992, the Scoliosis Research Society advocated the use of intraoperative neurophysiological monitoring (IONM) or spinal cord monitoring during spinal surgery to detect iatrogenic neurological injury at an earlier rate[2]. Over the past decade, several studies have demonstrated the efficacy and vitality of IONM, and it has now become the standard of care during spinal deformity surgery[3,4,5,6]. Most recent guidelines from the British Society of Clinical Neurophysiology recommended the use of IONM in all spinal deformity surgery and in particular the need for motor evoked potentials (MEPs) in high-risk causes[7].

There are several modalities of IONM that can measure the physiological function of the spinal cord during surgical deformity corrective procedures. The first and most widely employed approach consists of recording somatosensory evoked potentials (SSEPs) in response to electrical stimulation of the dorsal columns of the spinal cord. SSEPs were first introduced in the early 1970s and could reliably monitor the integrity of the somatosensory pathways in the dorsal columns. However, use of SSEPs only is limited as it does not tell real-time information about the motor pathways. This requires monitoring of motor evoked potentials (MEPs), later introduced in 1980, which can detect injuries to the anterior and central portions of the spinal cord. MEPs are very sensitive indicators of corticospinal tract injuries by measuring muscle responses to intermittent stimulation of the motor cortex. The use of both SSEPs and MEPs, also known as multimodal IONM, has demonstrated exceedingly high sensitivity and specificity in detecting early spinal cord dysfunction[8,9].

Aims

Although IONM is widely used in spinal surgery, there is limited literature related to its use in paediatrics when compared to adults. This study aims to identify clinical factors that increase the risk of IONM changes in paediatric patients.

Methods

A database containing all the patients who underwent spinal surgery at our institution was filtered to include patients who had surgery for scoliosis correction, had the operation between 2017-2022 and were ≤ 18 years old at the time of surgery. A total of 232 cases were found, in which 26 cases (11 with adolescent idiopathic scoliosis, 7 with neuromuscular scoliosis, 4 with syndromic scoliosis, 3 with congenital scoliosis and 1 with Scheuermann's disease) were excluded because of inadequate medical records, leaving 206 cases that met all the criteria. Out of the 206 cases, 11 patients underwent 11 operations for spinal deformity and experienced IONM alerts. These patients were categorised as the alert group, whereas the remaining 195 patients were the non-alert group.

Electrophysical Methodology
IONM was used in all the cases which included SSEPs only, MEPs only or both modalities. Electroencephalography (EEG) was monitored in some cases, but an analysis of this modality is not reported in this study due to its inability to detect neurological damage on its own. A reference waveform was obtained before starting surgery and monitoring was continued at least 20 minutes after completing instrumented fixation of the spine. The alert criteria used for SSEPs included a reduction in amplitude of ≥50% or a latency increase of ≥10% in cortical and sub-cortical recording channels. For MEPs, the alert criteria used was a reduction in amplitude of ≥80% or disappearance of waveform.

Lower limb SSEPs were elicited using bilateral stimulation of the posterior tibial nerve. Recording was performed with use of corkscrew-like needle electrodes positioned on the popliteal fossa, posterior neck and scalp. Upper limb SEPs were elicited using stimulation of median or ulnar nerve and recorded using electrodes placed at the posterior neck and scalp. MEPs were stimulated with the use of corkscrew-like needle electrodes and recorded using subdermal needle electrodes positioned over muscles of the lower limbs (usually Tibialis Anterior and Abductor Hallucis) and small muscles of the hands (usually Abductor Pollicis Brevis and Abductor Digiti Minimi). A total intravenous anaesthesia technique (TIVA) was used which consisted of continuous infusion of propofol and remifentanil. Halogenated agents and nitrous oxide were avoided during the operations.

In the event of an IONM alert, the surgical team followed the standard approach to IONM changes (Figure 1). Patients with IONM alerts were checked for neurological deficits immediately upon waking up and 6 weeks postoperatively. The nature of the alerts was defined and categorized (Table 1).

Figure 1. Surgical intervention algorithm in response to IONM alert

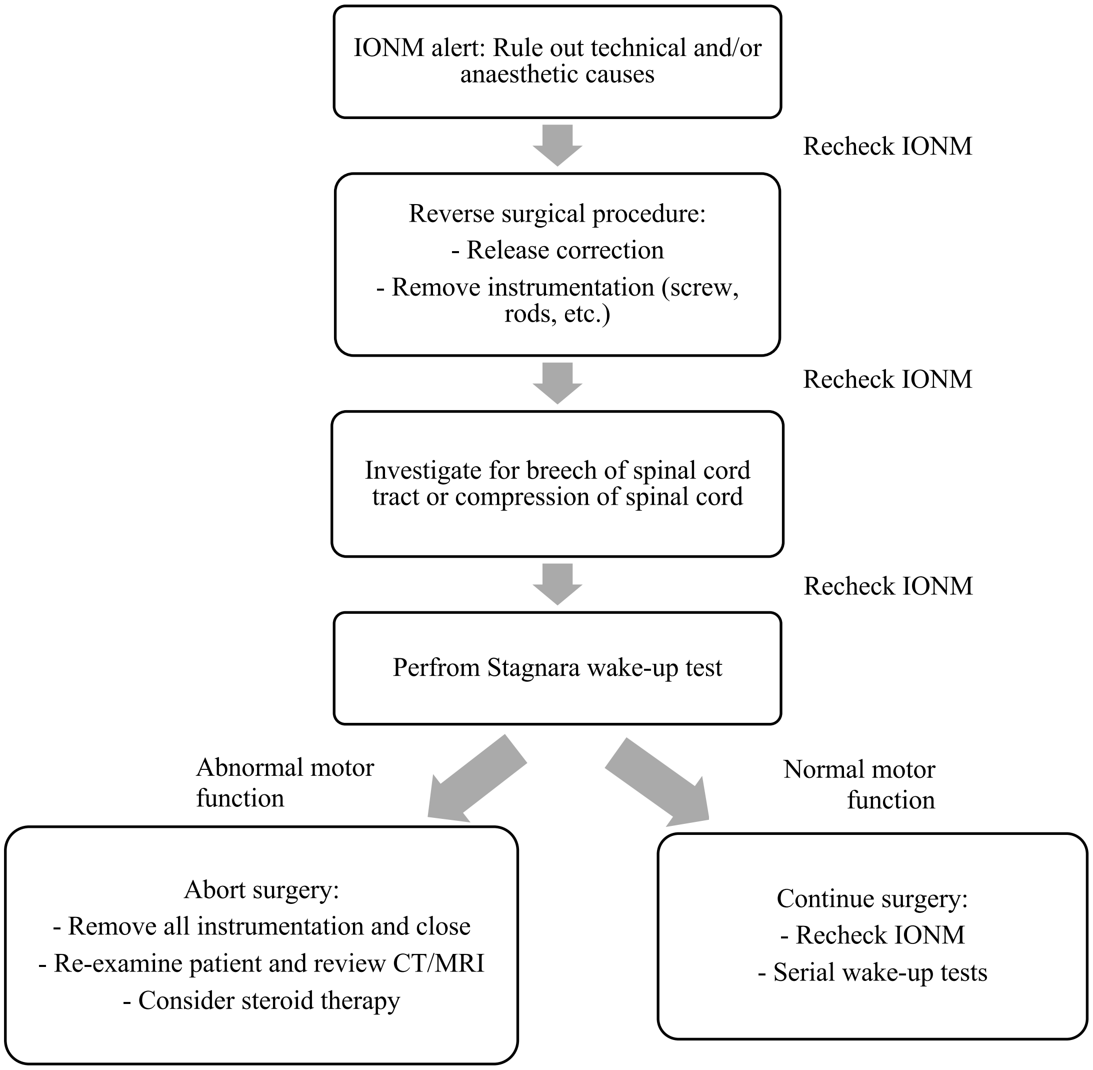

Table 1. Definitions of types of alerts

Type of alert	**Definition**
True positive	(1) An alert with recovery of potentials, after reversal actions (i.e. release of instrumentation, increased blood pressure), without any neurological complications (2) An alert without recovery of potentials despite reversal actions, and with the patient having new postoperative neurological deficits

False positive	An alert without recovery of potentials followed by no post-operative neurological deficits
True negative	No alert and no development of postoperative neurological deficits
False negative	No alert but patient developed postoperative neurological deficits

Variables

Demographic, clinical and intraoperative data including age, sex, diagnosis, estimated blood loss (EBL) and operative time of all 206 cases were recorded. Radiographic measurements of number of levels fused, preoperative major Cobb angle, postoperative major Cobb angle and degree of correction were measured and calculated at the time of the study. In the group with IONM alerts, additional details were recorded, including cell salvage, mean arterial pressure (MAP) at the time of alert, timing of the alert and immediate postoperative neurology of the patients. Trigger events that caused IONM alerts and the interventions performed were also recorded for patients in the alert group.

Statistical analysis

The alert and non-alert groups were compared using Student's T-test and Fischer's Exact Test. Statistical analysis was performed using IBM® SPSS® (version 27) software. Statistical significance was set at $P < 0.05$.

Results

Patient characteristics

A total of 206 operations were included in this study. This consisted of 150 females and 56 males with a mean age of 14.0 ± 2.9 years. Patient characteristics are summarised in Table 2. The majority of the patients were diagnosed with Adolescent idiopathic scoliosis (70.4%) followed by Neuromuscular scoliosis (12.1%), Syndromic scoliosis (10.7%), Congenital scoliosis (2.9%), Scheuermann's kyphosis (2.4%) and Adult deformity (1.5%). The preoperative mean Cobb angle of the major curve was 63.7 ± 18.4°.

Table 2. Patient Characteristics

	Value
Total no. of patients	206
Age*	14.0 ± 2.9
Female/ male ratio (no. [%])	150 (72.8) / 56 (27.2)
Diagnosis (no. [%])	
Adolescent idiopathic scoliosis	145 (70.4)
Neuromuscular scoliosis	25 (12.1)
Syndromic scoliosis	22 (10.7)
Congenital scoliosis	6 (2.9)
Scheuermann's Kyphosis	5 (2.4)
Adult deformity	3 (1.5)
Preop. major Cobb angle (°)*	63.7 ± 18.4

*The values are shown as mean and standard deviation.

Comparison between alert and non-alert groups

11 patients (5.3%) experienced an alert intraoperatively. Among the perioperative factors, operative time and EBL were significantly greater in the alert group compared to the non-

alert group (both P < .001). The postoperative major Cobb angle was found to be larger in the alert group (P = 0.032). However, age, sex, number of levels fused, preoperative major Cobb angle and mean corrective rate did not demonstrate significant differences between the two groups (Table 3). This study did not identify a significant correlation between the rate of IONM alerts and the type of spinal deformity (Table 4).

Table 3. Demographic factors, perioperative factors and postoperative results by group

	Non-alert	N	Alert	N	P value
Age (years)	14 ± 2.9	195	13.7 ± 2.1	11	0.689
Sex (F:M)	150 (72.8%): 56 (27.2%)	195	6 (54.5%): 5 (45.5%)	11	0.174
Levels fused (no.)	12.8 ± 2.9	195	12.7 ± 3.8	11	0.974
Preop. major Cobb angle (º)	63.2 ± 18.0	189	72.2 ± 24.9	11	0.266
Postop. major Cobb angle (º)	33.0 ± 14.5	178	42.9 ± 18.3	11	0.032*
Mean corrective rate (%)	46.4 ± 19.3	175	38.7 ± 20.9	11	0.199
Operative time (min)	160.2 ± 37.0	109	368.2 ± 120.8	11	< .001*
EBL (mL)	768.8 ± 352.1	156	1213.6 ± 514.8	11	< .001*

EBL = estimated blood loss

Age, Levels fused, Preop. major Cobb angle, Postop. major Cobb angle, Mean corrective rate, Operative time, EBL were analysed using Student's T-test.

Sex was analysed using Fischer's Exact Test.

Table 4. Diagnoses by group

Diagnosis	Non-alert	Alert	Incidence of alerts (%)	P value
Adolescent idiopathic scoliosis	140	5	3.4	
Neuromuscular scoliosis	23	2	8.0	
Syndromic scoliosis	20	2	9.1	
Congenital scoliosis	5	1	16.7	
Scheuermann's kyphosis	4	1	20.0	
Adult deformity	3	0	0	
Total	195	11	5.3	0.067

Diagnosis was analysed using Fischer's Exact test.

Cases with IONM alerts

In the group of patients with IONM alerts, 1 (9.1%) had waveform changes in SSEP, 9 (81.8%) in MEP and 1 (9.1%) in both modalities. Only one patient experienced a near disappearance of MEP waveform and had immediate postoperative neurological deficits in which leg weakness occurred, but the symptoms disappeared within 1 week after surgery (Table 5). In the non-alert group, one patient experienced a significant drop in MEP amplitude and developed a right-sided foot drop and reduced sensations from L5-S1 after surgery. Therefore, in SSEP, the sensitivity was 100% and specificity was 100%. In MEP, there was one alert that was deemed falsely negative, so the sensitivity and specificity were 99% and 100% respectively.

Table 5. Patients with IONM alerts

Patient	Sex	Age (years)	Diagnosis	Fusion range	Preop. Cobb angle of major structural curve (°)	Postop. Cobb angle of major structural curve (°)	Curve correction (%)	Surgical time (min)	EBL (mL)	Cell salvage (mL)	MAP during alert (mmHg)	Timing of alert	Immediate post-op neurology	Alert category
1	M	9	Syndromic scoliosis	T4-L2	39	36	7.7	510	1000	500	140/85	Before screw insertion	Normal	TP
2	F	14	Adolescent idiopathic scoliosis	T2-L5	94	36	61.7	540	1000	363	116/79	Before screw insertion	Normal	TP
3	M	14	Congenital scoliosis	T1/2-T8/9	67	55	17.9	300	2600	450	120/50	After right-sided coprectomy	Normal	TP
4	F	12	Kyphoscoliosis	T8-T11	58	28	51.7	360	1000	500	130/90	After correction manoeuvre	Normal	TP
5	F	13	Adolescent idiopathic scoliosis	T2-L4	96	53	44.8	450	1000	634	90/50	After correction manoeuvre	Normal	TP
6	F	13	Neuromuscular scoliosis	T2-L5	110	80	27.3	180	1700	532	80/50	After screw insertion	Normal	TP
7	M	13	Adolescent idiopathic scoliosis	T2-L4	91	55	39.6	360	1000	353	145/80	After screw insertion	Normal	TP
8	F	15	Syndromic scoliosis	T6-L5	53	39	26.4	300	1000	500	118/85	After correction manoeuvre	Normal	TP
9	M	16	Adolescent idiopathic scoliosis	T2-L3	89	50	43.8	180	1250	700	100/52	After screw insertion	Normal	TP
10	F	16	Adolescent idiopathic scoliosis	T3-L5	60	12	80	420	1000	500	87/53	After screw insertion	Right leg weakness	TP
11	M	16	Neuromuscular scoliosis	T3-L4	37	28	24.3	450	800	260	90/50	After correction manoeuvre	Normal	TP

Ten out of the eleven patients with an IONM alert had identifiable causes for the alert which was reported by the surgeons. 4 cases (36.4%) were caused by insertion of screws, 4 (36.4%) were caused by rod application and curve correction manoeuvre, 2 (18.2%) were caused by technical issues and 1 (9.1%) was caused by corpectomy procedure (Table 6).

Table 6. Triggering event

	No. (%)
Insertion of screws	4 (36.4)
Rod application and curve correction manoeuvre	4 (36.4)
Technical issues (detachment of electrodes)	2 (18.2)
Corpectomy procedure	1 (9.1)

When an alert was detected, the surgeons and anaesthesiologist were notified and initiated the standard protocol for investigation and intervention of IONM alerts. The primary intervention in four cases was increasing the MAP but further interventions were taken due to failure of reversal of IONM waveform changes. Instrumentation was removed in 3 patients (27.3%), curve correction was released in 3 patients (27.3%) and the operation was completed without specific measurements in 3 patients (27.3%) (Table 7). The actions taken resulted in the return of waveform to the baseline values in the nine cases. However, the IONM changes could not be reversed in 2 patients (18.2%), so the operation was aborted and staged. No IONM alerts were experienced in the staged operations and both patients did not develop postoperative neurological deficits.

Table 7. Alert intervention

	No. (%)
Removal of instrumentation	3 (27.3)
Release of curve correction	3 (27.3)
Operation abandoned	2 (18.2)
Completion of operation without specific measurements	3 (27.3)

Discussion

In this study, 5.3% (11) of 206 cases experienced IONM alerts during spinal deformity surgery, a rate that is consistent with the literature. A recent study by Lee et al. reported that 2.1% of paediatric patients diagnosed with adolescent idiopathic scoliosis (AIS) demonstrated IONM signal changes[10]. Samdani et al. identified 5.3% of patients with AIS experienced IONM alerts[4]. In 2010, Kamerlink et al. reported 4.6% of paediatric patients had changes in spinal cord monitoring leading to an alert[11]. Both SSEPs and MEPs were highly sensitive and specific. The sensitivity was 100% and 99% respectively and the specificity was 100% for both modalities.

Predictors of IONM alerts were assessed to aid surgeons in managing alert situations. The current study suggests that there is an increased risk of IONM alerts in the group with greater surgical extent. Kamerlink et al. identified an increased risk of IONM alerts in the group with higher BMI, EBL, operative time and postoperative thoracolumbar or lumbar coronal Cobb angle[11]. Our study reports similar results, with the alert group having a higher EBL, longer operative time and greater postoperative major Cobb angle. Increased estimated blood loss and operative time are both associated with higher risk of spinal cord injury. Yang et al. reported that 20% of patients had return of IONM signals after increasing MAP on its own and 60% of patients had return of signals after raising MAP in conjunction with other interventions[12]. Another study by Kobayashi et al. suggested that excessive bleeding causes changes in MEPs due to spinal cord ischaemia, although blood pressure does not always reflect this[13]. Although there is a significant difference between operative durations in the alert and non-alert groups, it is important to note that in most cases, operative time had been extended due to additional time needed for identifying and responding to the IONM alerts.

In the literature, Samdani et al. was the first study to analyse the radiographic and clinical outcomes of patients with IONM alerts[4]. They reported that the group of patients that experienced IONM alerts had a larger preoperative major Cobb angle and a greater number of levels fused. Among the patients who had a completed operation, the postoperative major Cobb angle and percentage of correction were similar between the alert and non-alert groups. Unlike their study, we did not find a correlation between IONM alerts and larger preoperative major Cobb angle, higher percentage of correction or greater number of levels fused. Interestingly, the postoperative major Cobb angle was significantly greater in the alert group compared to the non-alert group. Historically, patients with greater preoperative deformities are at a higher risk of experiencing IONM alerts due to greater changes in spinal cord trajectory during deformity correction[14,15]. Similarly, procedures that involve changing the spinal cord trajectory increases the risk of cord injury. Kobayashi et al. reported 64% of patients had exhibited an IONM alert during rotation manoeuvre followed by 14% during incision, 7% after screw fixation, 7% during placement of second rod and 7% after intervertebral compression[13]. Our study reports 36% of patients had IONM alerts caused by curve correction manoeuvre, 36% caused by screw insertion and 9% caused by corpectomy procedure. The remaining 18% of patients experienced a significant drop in amplitude of waveforms before screw insertion and the cause was found to be due to detachment of electrodes. Although this study identified more IONM alerts during and after correction, it is important to note that spinal cord monitoring should be performed at the same level of attentiveness throughout the operation. Following Kamerlink's study[11], more attention is now paid to monitoring the spinal cord at the beginning of the surgery as several reports have shown IONM alerts occurring before correction or without correction[16,17].

Out of the 11 patients, 1 patient (9.1%) developed a transient postoperative neurological deficit, and 2 operations (18.2%) were aborted and staged. The decision to stage the operation was made after factoring in the risks of increased stress to the spinal cord on both occasions. In the first case, MEP waveform disappeared in the tibialis anterior during right sided corpectomy and did not return despite raising MAP. Halo traction was staged due to increased risk of spinal cord injury. Feng et al. reported that performing osteotomy procedures and intraoperative halo traction can increase the likelihood of IONM alerts due to the greater corrective forces required[14]. In the second case, there was a loss of signal in the left tibialis anterior followed by the right tibialis anterior. MAP was increased and rods were removed to allow the spinal cord to recover. Curve correction was attempted again but resulted in disappearance of MEP waveforms. The operation was repeated two weeks later, and the patient did not develop neurological deficits.

This study has several limitations. First, the data was insufficient in the non-alert group resulting in a discrepancy of total cases reviewed in some perioperative and postoperative variables. This limits the capacity of this study to demonstrate the significance of some risk factors between both groups. Second, there is a potential of measurement error in the calculation of Cobb angles in the non-alert group as this was not measured by an experienced surgeon. Finally, it cannot be ruled out that the retrospective nature of the study may result in inherent bias. A future study may involve multiple centres for external validation and undertake statistical analyses of more predictive factors.

Conclusion

In conclusion, this retrospective study reaffirms some of the risk factors of IONM alerts in paediatric spinal deformity patients as previously described in other literature. Patients with IONM alerts had a greater EBL, operative time and postoperative major Cobb angle. IONM waveform changes commonly occurred during or after insertion of instrumentation and curve correction manoeuvres.

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