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Reversible intraoperative neurophysiologic monitoring alerts in patients undergoing arthrodesis for adolescent idiopathic scoliosis

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Reversible Intraoperative Neurophysiologic Monitoring Alerts in Patients Undergoing Arthrodesis for Adolescent Idiopathic Scoliosis

What Are the Outcomes of Surgery?

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Background: Confidence in intraoperative neurophysiologic monitoring (IONM) data can allow scoliosis surgeons to proceed with surgery even after a monitoring alert, assuming the recovery of signals. We sought to determine the outcomes of surgical treatment of adolescent idiopathic scoliosis (AIS) after a notable IONM alert.

Methods: We identified 676 patients who underwent arthrodesis with use of IONM for the treatment of AIS. The patients were divided into 2 cohorts: those who experienced a lower-extremity IONM alert and those who did not. An alert was defined as a notable change in IONM data, specifically, a ≥50% drop in somatosensory evoked potentials (SSEPs) and/or in transcranial motor evoked potentials (tcMEPs).

Results: Of the 676 patients, 36 (5.3%) experienced IONM alerts. Those patients had a larger preoperative major Cobb angle (mean of 61° ± 13° compared with 55° ± 12° for the no-alert group; $p < 0.01$), a greater number of levels fused (mean of 12 ± 2 compared with 11 ± 2; $p < 0.01$), a longer operative duration (mean of 357 ± 157 minutes compared with 298 ± 117 minutes; $p < 0.01$), a higher estimated blood loss (1,857 ± 1,323 mL compared with 999 ± 796 mL; $p < 0.01$), and a greater volume of autologous blood transfused (mean of 527 ± 525 mL compared with 268 ± 327 mL; $p < 0.01$). Among patients who experienced an alert and had a completed operation (34 of 36 patients), mean postoperative radiographic measurements were similar to those of the no-alert group in terms of the percentage of correction of the major Cobb angle (alert, 66% ± 13%; no alert, 64% ± 19%; $p = 0.53$) and of rib prominence (alert, 49% ± 36%; no alert, 47% ± 46%; $p = 0.83$) and measurement of thoracic kyphosis (alert, 23° ± 10°; no alert, 22° ± 2°; $p = 0.58$). The Scoliosis Research Society (SRS)-22 outcome scores were also similar between the 2 cohorts.

Conclusions: Notable IONM changes occurred in 5.3% of the patients who underwent arthrodesis for AIS. Those patients had larger preoperative deformity, a longer operative duration, a greater number of levels fused, a higher estimated blood loss, and a greater volume of autologous blood transfused. Return of IONM data guided the surgeon to safely complete the procedure in 34 of 36 patients, with correction similar to that of patients who did not experience an alert.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

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The reported rate of spinal cord injury following scoliosis surgery varies from 0.3% to 1.4%[1-5]. MacEwen et al.[3] first evaluated this complication in a study for the Scoliosis Research Society (SRS) from 1965 to 1971, reporting a 0.72% rate of neurologic complications. Of the 74 patients identified, 55% were noted to have had complete paraplegia

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TABLE I Patient Characteristics

Total no. of patients	676
Female *(no. [%])*	542 (80.2)
Lenke type *(no. [%])*	
1	290 (42.9)
2	158 (23.4)
3	43 (6.4)
4	24 (3.6)
5	92 (13.6)
6	69 (10.2)
Ponte osteotomy *(no. [%])*	519 (76.8)
Major Cobb angle* *(°)*	55 ± 12
Kyphosis (T5-T12)* *(°)*	23 ± 14

*The values are given as the mean and the standard deviation.

and 45%, an incomplete injury. In 2006, the SRS Morbidity and Mortality Committee identified a 0.5% rate of postoperative neurologic deficit in 31 of 6,334 cases treated for adolescent idiopathic scoliosis (AIS), none of which involved complete injuries[6]. Full recovery occurred in 61% of those patients.

In 1977, Nash et al.[7] introduced the technique of intraoperative neurophysiologic monitoring (IONM) to detect spinal cord injury utilizing somatosensory evoked potentials (SSEPs) to monitor posterior column function. Somatosensory data are recorded at baseline and periodically throughout the surgical procedure to monitor for changes in amplitude and latency. A decrease in amplitude of 50% to 80% or an increase in latency of >10% from baseline would be considered notable for spinal cord compromise[8-11]. SSEP monitoring has been used in spinal deformity surgery and has been shown to improve neurologic outcome[12-14]. However, SSEPs may not indicate injuries to the descending anterior motor tracts or the anterior horn of the spinal cord, leading to high false-negative rates[15,16].

In the 1980s, the monitoring of motor evoked potentials (MEPs) with either electrical or magnetic stimulation of the cortex or spinal cord was used to depolarize the pyramidal tract neurons to produce compound muscle action potentials measured by needle electrodes placed in the distal muscle groups[17,18]. Studies have shown that monitoring of transcranial motor evoked potentials (tcMEPs) may provide up to 100% sensitivity but may also result in some false-positive results[19,20].

Hence, multimodality neurophysiologic monitoring of SSEPs in combination with tcMEPs is often used to improve the sensitivity and specificity of neurophysiologic monitoring in scoliosis surgery[10,21-23]. Kundnani et al.[20] reported a sensitivity of 100%, a specificity of 98.5%, and a positive predictive value of 85% when multimodality neuromonitoring was used for the surgical treatment of AIS. Neurophysiologic monitoring changes can occur in 13% of patients undergoing surgery for scoliosis[11], with most recovering with appropriate intervention. Confidence in IONM data may allow surgeons to proceed with surgery even after an alert, assuming the recovery of signals. Although the surgical procedure may be completed, it is unclear how the outcomes compare with those of patients who do not experience an alert. Performing such a comparison was the purpose of this study.

TABLE II Intraoperative Details and Postoperative Results by Group

	Alert	No Alert	P Value
Patients *(no. [%])*	36 (5.3)	640 (94.7)	
Levels fused* *(no.)*	12 ± 2	11 ± 2	<0.01
EBL* *(mL)*	1,857 ± 1,323	999 ± 796	<0.01
Autologous blood transfused* *(mL)*	527 ± 525	268 ± 327	<0.01
Ponte osteotomy†	30 (83.3)	482 (75.3)	0.32
Operative time* *(min)*	357 ± 157	298 ± 117	<0.01
Preop. major Cobb angle* *(°)*	61 ± 13	55 ± 12	<0.01
Preop. kyphosis (T5-T12)* *(°)*	24.6 ± 16.2	22.8 ± 13.7	0.463
2-yr postop. results*			
% correction			
Cobb angle *(%)*	66 ± 13	64 ± 19	0.53
Rib prominence *(%)*	49 ± 36	47 ± 46	0.83
Thoracic kyphosis (T5-T12) *(°)*	23 ± 10	22 ± 2	0.58
SRS total score	4.4 ± 0.5	4.5 ± 0.4	0.43

*The values are given as the mean and the standard deviation. †The values are given as the number of patients, with the percentage of the group in parentheses.

TABLE III Triggering Event or Associated Intraoperative Stage of Alert

	No. (%)
Placement of instrumentation	8 (22.2)
Hypotension	7 (19.4)
Curve-correction maneuver	6 (16.7)
Other	6 (16.7)
Anesthesia-related	2 (5.6)
Not reported	7 (19.4)

Materials and Methods

Institutional review board approval for the study was obtained locally from each of the 9 contributing institutions. For each patient, consent was obtained prior to data collection, which took place from 2006 to 2012. A prospectively collected multicenter database was reviewed to identify patients who underwent surgical treatment of AIS with use of IONM and who had at least 2 years of follow-up.

Allowing for institutional differences, patients were given total intravenous anesthetic agents conducive to IONM, and muscle relaxants were either not used or used only prior to exposure of the spine so as not to compromise neuromonitoring data. Neurophysiologic monitoring of SSEPs and tcMEPs was performed according to each individual institution's protocol by trained surgical neurophysiologists and was achieved successfully in all patients. Serial monitoring was performed in both lower and upper extremities, from the time of positioning the patient to the time the patient was awakened from anesthesia, with stimulus amplitude adjusted as needed for each patient. The upper extremities served as a neurophysiologic control, and upper-extremity monitoring could also be used to identify positional brachial plexopathy. Both cortical and subcortical SSEPs were elicited most commonly using the tibial and ulnar nerves. Cortical potentials were recorded from subdermal needle electrodes attached to standard cranial locations. tcMEPs were recorded bilaterally, most commonly from the first dorsal interosseous muscles in the upper extremity and bilaterally from the tibialis anterior, quadriceps, and gastrocnemius muscles in the lower extremities (specific muscle groups varied by institution). Patients who experienced a notable reduction in signal levels during IONM (≥50% reduction in SSEPs and/or tcMEPs) were identified. We did not utilize a change in SSEP latency as an alert criterion because, in our experience, similar to that of Schwartz et al.[10], we have not seen it in isolation as an indicator of impending spinal cord injury.

In the patients who experienced a critical reduction of signals, a sequence of events was initiated according to each institution's protocol and patient specifics[24]. The triggering event or associated intraoperative stage was prospectively recorded as one of the following: hypotension, placement of instrumentation, curve-correction maneuver, anesthesia-related, or other. The intervention was also recorded as one or more of the following: mean arterial pressure elevation, Stagnara wake-up test[25], removal of instrumentation, release of correction, administration of corticosteroids, or an aborted operation.

Radiographic measurements and clinical characteristics were recorded preoperatively and at 2 years after surgery. Data included age, sex, Lenke curve type[26], major coronal Cobb angle, kyphosis (T5-T12), rib prominence, number of levels fused, Ponte osteotomies performed, operative time, estimated blood loss (EBL), volume of autologous blood transfused, triggering event or associated intraoperative stage for the IONM alert, and intervention performed after an IONM alert was identified.

The patients were divided into 2 cohorts: those who experienced notable IONM changes in the lower extremities (alert) and those who did not (no alert). Patients with an upper-extremity alert or those undergoing intraoperative traction were excluded. The clinical characteristics and radiographic measurements of the 2 cohorts were compared. Statistical analysis was performed using SPSS statistical software (version 12.0.2; SPSS). Results were reported as the mean and the standard deviation (SD), and the level of significance was defined as $p < 0.05$.

Results

Patient Characteristics

A total of 676 patients (80.2% female) were identified. The plurality of the curves (42.9% of the patients) were Lenke type 1, followed by type 2 (23.4%), type 5 (13.6%), type 6 (10.2%), type 3 (6.4%), and type 4 (3.6%). The mean major Cobb angle (and SD) was 55° ± 12°, with a mean kyphosis from T5-T12 of 23° ± 14°. The majority of the patients (76.8%) underwent Ponte osteotomies (Table I).

Group Comparison

Thirty-six (5.3%) of the patients experienced IONM alerts. The alert group had a larger preoperative major Cobb angle (mean of 61° ± 13° compared with 55° ± 12° for the no-alert group; $p < 0.01$), a greater number of levels fused (mean of 12 ± 2 compared with 11 ± 2; $p < 0.01$), a longer operative duration (mean of 357 ± 157 minutes compared with 298 ± 117 minutes; $p < 0.01$), a higher EBL (mean of 1,857 ± 1,323 mL compared with 999 ± 796 mL; $p < 0.01$), and a greater volume of autologous blood transfused (mean of 527 ± 525 mL compared with 268 ± 327 mL; $p < 0.01$) (Table II). The frequency of posterior column osteotomies was similar between the 2 groups (83.3% in the alert group, and 75.3% in the no-alert group; $p = 0.32$), as was the preoperative kyphosis (24.6° ± 16.2° in the alert group, and 22.8° ± 13.7° in the no-alert group; $p = 0.463$). After the intervention in response to an alert, IONM signals improved in 97% (35 of 36) of the patients, with the time until the return of data averaging 20 minutes.

Mean radiographic measurements at 2 years postoperatively were similar between the patients who experienced an alert and had a completed operation (34 of 36 patients) and those with no alert in terms of the percentage of correction of the major Cobb angle (alert, 66% ± 13%; no alert, 64% ± 19%; $p = 0.53$) and correction of rib prominence (alert, 49% ± 36%; no alert, 47% ± 46%; $p = 0.83$) and measurement of thoracic kyphosis (alert, 23° ± 10°; no alert, 22° ± 2°; $p = 0.58$). The 2-year SRS-22 patient-reported outcome scores (see below) were also similar between the 2 cohorts. In addition, the length of hospital stay was similar between the 2 groups (alert, 5.1 ± 3 days; no alert, 5.3 ± 2.3 days; $p = 0.3$).

TABLE IV Alert Intervention

	No. (%)
Elevation of mean arterial pressure	22 (61)
Wake-up test	10 (28)
Removal of instrumentation	7 (19)
Release of correction	3 (8)
Administration of corticosteroids	3 (8)
Operation aborted	2 (6)

TABLE V Comparison of SRS-22 Scores by Group

	Preop.*			2-Yr Postop.*		
	Alert	No Alert	P Value	Alert	No Alert	P Value
Pain	4.00 ± 0.62	4.10 ± 0.69	0.34	4.32 ± 0.73	4.44 ± 0.56	0.37
Self-image	3.44 ± 0.82	3.41 ± 0.67	0.82	4.48 ± 0.49	4.46 ± 0.54	0.84
General function	4.34 ± 0.64	4.46 ± 0.54	0.29	4.61 ± 0.59	4.68 ± 0.43	0.52
Mental health	3.93 ± 0.74	4.04 ± 0.70	0.38	4.13 ± 0.67	4.28 ± 0.68	0.23
Satisfaction	4.10 ± 0.90	3.67 ± 0.94	0.02	4.73 ± 0.44	4.61 ± 0.64	0.14
Total	3.92 ± 0.52	3.96 ± 0.47	0.66	4.41 ± 0.47	4.47 ± 0.42	0.43

*The values are given as the mean and the standard deviation.

Triggering Event or Associated Intraoperative Stage

The surgeon-reported triggering event or associated intraoperative stage was noted as the placement of instrumentation for 8 (22.2%) of the 36 patients who experienced an alert, hypotension for 7 (19.4%), a curve-correction maneuver for 6 (16.7%), an anesthesia-related event for 2 (5.6%), "other" for 6 (16.7%), and unknown or not reported for 7 (19.4%) (Table III).

Alert Intervention

The majority of IONM signals were improved by increasing the mean arterial pressure in 22 (61%) of the patients. Ten (28%) of the patients underwent a Stagnara wake-up test, 7 (19%) of the patients underwent removal of instrumentation, 3 (8%) of the patients had release of the correction, 3 (8%) of the patients were administered corticosteroids, and for 2 (6%) of the patients (1 of whom did not experience a return of IONM signals) the operation was aborted (Table IV). With respect to increasing mean arterial pressure, when a notable reduction in IONM occurred, the mean arterial pressure was increased to at least 80 mmHg.

SRS-22 Scores

Preoperatively, the 2 groups had similar SRS-22 scores in all categories, with the exception of satisfaction, for which the scores were higher in the alert group (4.10 ± 0.90 compared with 3.67 ± 0.94; $p = 0.02$). Postoperatively, the 2 groups had similar SRS-22 scores in all categories, including total score (alert, 4.41 ± 0.47; no alert, 4.47 ± 0.42; $p = 0.43$) (Table V).

Aborted Procedures

For 2 patients, the operation was aborted. For 1 of these patients, motor signals were lost but returned after mean arterial pressure was increased; however, the surgeon decided to abort the procedure and complete it at a later date. In the other case, motor signals were lost and did not return. A wake-up test was performed, and the patient was noted to have right lower-extremity weakness. The operation was aborted, and the patient recovered full power of the right lower extremity within 72 hours. Thus, no patient who had a return of IONM data sustained a permanent neurologic deficit postoperatively.

Discussion

Given the known risk of neurologic compromise during complex spinal surgery, IONM aids the surgeon by providing real-time data regarding the patient's neurologic status. The goal of IONM is to prevent neurologic injury and permit a change in intraoperative strategy to minimize or reverse any deficit. The advent of IONM also potentially allows for more definitive maneuvers than might not otherwise be undertaken, such as maximal deformity correction. Our results suggest that the majority of posterior spinal arthrodesis procedures for the treatment of AIS can be completed safely with the help of IONM and that, even when an alert is detected, the clinical and radiographic results of those patients are similar to the results of the patients who experience no change in IONM data.

In 2002, Noonan et al.[27] attempted to determine the factors related to changes in SSEPs, with or without the monitoring of MEPs, in a retrospective review of patients with AIS undergoing surgery. False-positive readings were found in 4.5% of the patients and were seen more frequently in patients with a labile mean arterial pressure. They recommended using the Stagnara wake-up test when changes occur as indicated by monitoring thresholds because of the possibility that spinal cord injury may exist even when monitored values return to baseline. However, others argue that the wake-up test is not effective at identifying subtle weakness, timing, or location of injury, especially in patients who are unable to follow commands because of intellectual or developmental disabilities or preoperative weakness[28]. In addition, the wake-up test risks self-extubation, loss of intravenous access, loss of positioning, air embolus, and/or event recollection[28]. The surgeon and anesthesiologist must work as a team to ensure that a wake-up test is done safely and efficiently. This includes preoperative communication by the surgeon to the anesthesiologist of the need for a possible wake-up test so that the anesthesiology team can adequately prepare. This may, at times, involve maximizing the number of anesthesiology team members in the room during the wake-up test.

In 2010, Vitale et al.[11] studied the clinical factors associated with IONM changes utilizing multimodality IONM for 162 pediatric patients undergoing arthrodesis for scoliosis and found that 13% of the patients experienced IONM changes.

They identified cardiopulmonary comorbidity as an independent risk factor for sustaining a change and noted that the most common cause of an alert was curve correction followed by hypotension. Our study showed different results, with the placement of instrumentation followed by hypotension being the most common causes of IONM alerts. Their paper included patients with congenital scoliosis, thus tempering direct comparison. In the same year, Kamerlink et al.[29] assessed the risk factors for neuromonitoring changes in consecutive pediatric and adult patients with spinal deformity treated at a single institution. They found that, in patients with scoliosis, neuromonitoring changes increased with greater body mass index, EBL, operative time, and postoperative coronal thoracolumbar curve magnitude. Our study showed similar results, with IONM changes occurring in patients who had a longer operative duration, a higher EBL, and a greater volume of autologous blood transfused. It is important to note that intraoperative alerts may have caused extended operative durations, with surgeons spending time identifying and responding to the IONM alerts, and, in general, proceeding cautiously.

In 2012, Feng et al.[30] evaluated the efficacy of multimodal IONM for predicting iatrogenic neurologic injury during the correction of spinal deformity and evaluated the risks factors for neuromonitoring changes. They found that multimodal IONM can be used to predict events of neurologic injury and, with adjustment of surgical strategy, help prevent irreversible deficits. They found that surgeries involving an osteotomy procedure, kyphosis correction, and a preoperative Cobb angle of >90° were risk factors for possible neuromonitoring changes. Our study showed similar results, where patients with a larger preoperative major Cobb angle and a greater number of levels fused were more likely to experience an IONM alert. Unlike their study, we did not find an association between increased alerts and osteotomies, likely because the highest grade of osteotomy in our cohort was a Ponte, versus the more aggressive pedicle-subtraction osteotomy in the series of Feng et al. Similarly, it is important to note that patients with more severe deformity requiring preoperative or intraoperative traction or a higher-grade osteotomy are likely to experience a higher rate of IONM changes than the 5.3% seen in our cohort[31].

Although many studies have evaluated the efficacy and risk factors of IONM, to our knowledge, ours is the first study to analyze the radiographic and clinical outcomes of patients who experienced IONM alerts. We anticipated that, following the IONM change and appropriate surgical response, surgeons might have been more cautious with respect to correction or that some might have aborted the procedure even after the return of signals. Interestingly, in the patients who experienced an alert, the postoperative percentage of correction of the major Cobb angle and rib prominence and thoracic kyphosis were similar to those of patients who did not experience an IONM alert. In addition, 2-year SRS-22 scores were similar between the 2 cohorts. This suggests that IONM is not only beneficial to the prevention of postoperative neurologic injury but also reassures the surgeon that she or he may often be able to continue the procedure without the need to abort and can generally achieve similar correction in all 3 planes, with similar health-related quality-of-life outcomes, in patients who experience alerts compared with those who do not.

The current study was limited because it was a retrospective review of a prospectively collected, multicenter database. Because of the multicenter nature of the study, some variability in anesthesia protocols existed, and surgeons performed varying interventions when an alert was encountered. However, this may better represent the diverse surgical practices involved with modern scoliosis surgery. The multiple centers were required to include enough patients for a meaningful analysis. Similarly, the time frame of data collection (from 2006 to 2012) also allowed us to include enough patients to perform a meaningful analysis. Radiographic measurements were all performed centrally by 2 reviewers whose findings underwent interrater and intrarater reliability testing. There exists some variability in the protocols utilized for patient positioning (lateral positioning for most patients was with arms "holding ski poles"), and some degree of interuser variability will always be present with the use of the scoliometer. These limitations do not detract from our conclusions.

In summary, notable IONM changes occurred in 5.3% of the patients who underwent posterior spinal arthrodesis without intraoperative traction for AIS. These patients had a larger preoperative major Cobb angle, a longer operative duration, a greater number of levels fused, a higher EBL, and a greater volume of autologous blood transfused. Outcomes for patients who had IONM alerts with a return to normal IONM data resulted in no permanent neurologic deficits, similar correction in all 3 planes, and comparable 2-year SRS-22 scores compared with those who did not experience an alert. ■

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