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REPORTS OF ORIGINAL INVESTIGATIONS

Intraoperative neurophysiologic monitoring in idiopathic scoliosis surgery: a retrospective observational study of new neurologic deficits

Monitorage neurophysiologique peropératoire en chirurgie de scoliose idiopathique : une étude observationnelle rétrospective sur l'apparition des déficits neurologiques

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Abstract

Purpose *Patients with adolescent idiopathic scoliosis undergoing corrective surgery are at risk for iatrogenic spinal cord injury and subsequent new neurologic deficits (NNDs). Intraoperative neurophysiologic monitoring (IONM) has been used to identify spinal cord injury; however, available data showing that IONM leads to improved clinical outcomes are inconclusive. This exploratory study aimed to examine the incidence of NNDs after idiopathic scoliosis surgery in two pediatric institutions in Canada with a focus on IONM use.*

Methods *Charts of pediatric patients (10–18 yr) with adolescent idiopathic scoliosis who underwent scoliosis correction surgery were retrospectively identified from the operating room database. Data regarding incidence and severity (mild [isolated sensory deficit] vs severe [any motor deficit]) of NNDs as well as demographic and clinical characteristics were extracted.*

Results *Of 547 patients reviewed, 359 (66%) underwent IONM and 186 (34%) underwent wake-up test. Neuromonitoring data were missing in two patients. Total incidence of NNDs was 4.9% (95% confidence interval [CI], 3.1 to 6.8). Compared with the wake-up test, patients undergoing IONM were less likely to develop NNDs (unadjusted odds ratio, 0.39; 95% CI, 0.18 to 0.86; P = 0.02). Nevertheless, subgroup analysis did not reveal a statistical difference in severity of those deficits (mild vs severe) with IONM vs wake-up test. Combined anterior and posterior approach was also significantly associated with increased risk of such deficits.*

Conclusion *This exploratory study revealed that IONM was associated with a reduced overall incidence of NNDs in idiopathic scoliosis correction; however, its impact on the severity of those deficits is questionable. As we were unable to adjust for confounding variables, further research is needed to determine the impact of IONM on NNDs.*

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Résumé

Objectif *Les patients adolescents atteints de scoliose idiopathique subissant une chirurgie corrective sont à risque de lésions médullaires iatrogéniques et de nouveaux déficits neurologiques (NDN) subséquents. Le monitorage neurophysiologique peropératoire (MNP) a été employé pour identifier les lésions médullaires; cependant, les*

données disponibles montrant que le MNP entraîne de meilleurs pronostics cliniques ne sont pas concluantes. Cette étude exploratoire visait à examiner l'incidence des NDN après une chirurgie de scoliose idiopathique dans deux établissements pédiatriques au Canada en se concentrant sur l'utilisation du MNP.

Méthode *Les dossiers des patients pédiatriques (10-18 ans) atteints de scoliose idiopathique ayant subi une chirurgie de correction de scoliose ont été rétrospectivement identifiés dans la base de données de salle d'opération. Les données concernant l'incidence et la gravité (légers [déficit sensoriel isolé] vs graves [tout déficit moteur]) des NDN ainsi que les caractéristiques démographiques et cliniques ont été extraites.*

Résultats *Parmi les 547 patients passés en revue, 359 (66 %) ont eu un MNP et 186 (34 %) ont eu un test d'éveil ('wake-up test'). Les données de monitorage neurologique manquaient pour deux patients. L'incidence totale des NDN était de 4,9 % (intervalle de confiance [IC] de 95 %, 3,1 à 6,8). Par rapport au test d'éveil, les patients subissant un MNP étaient moins susceptibles de présenter des NDN (rapport de cotes non ajusté, 0,39; IC 95 %, 0,18 à 0,86; P = 0,02). Néanmoins, l'analyse des sous-groupes n'a pas révélé de différence statistique dans la gravité de ces déficits (légers vs graves) en comparant un MNP à un test d'éveil. Une association significative a également été relevée entre une approche combinée chirurgicale antérieure et postérieure et un risque accru de tels déficits.*

Conclusion *Cette étude exploratoire a indiqué que le MNP était associé à une incidence globale réduite de NDN lors d'une chirurgie de correction de scoliose idiopathique; toutefois, son impact sur la gravité de ces déficits est discutable. Comme nous n'avons pas été en mesure d'ajuster les données aux variables confondantes, d'autres recherches sont nécessaires pour déterminer l'impact du MNP sur les NDN.*

Keywords Scoliosis · Idiopathic · Neuromonitoring · Neurological complications

Adolescent idiopathic scoliosis (AIS) is defined as scoliosis that develops after 10 years of age and whose cause is essentially unknown.[1] It is a relatively common condition with a prevalence of 0.47–5.2% in the pediatric population.[2] Those who require corrective surgeries are at risk of potential complications inherent to this major undertaking, the most concerning of which are new neurologic deficits (NNDs).

To decrease the incidence and severity of postoperative NNDs, various methods have been used to identify spinal cord injury. The well-established Stagnara wake-up test, developed in the 1970s, uses partial temporary awakening of the patient during surgery to assess voluntary motor power.[3] Once the patient's neurologic condition is known, the surgeon is informed of the results; if the test is negative for paraplegia, the patient is re-anesthetized and surgery is resumed. If the test result is positive for a neurologic deficit, interventional strategies are initiated. The Stagnara wake-up test, when properly administered, allows detection of gross motor movements; however, the patient must be adequately awake to follow the commands.[4] The major limitations of the procedure are the difficulty in waking the patients and the problems associated with its repeated application, and that the test provides information regarding the motor function only.[4] More recently, intraoperative neurophysiologic monitoring (IONM) by means of somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs), has largely replaced the Stagnara wake-up test. Multimodal IONM offers the advantage of timely detection of spinal cord compromise during manipulation and instrumentation of the vertebral column,[5,6] with sensitivity of 91% and specificity of 96% in pediatric populations.[7] This feedback may prevent or mitigate neurologic injury.[8] Hamilton *et al*. indicate that there are limited published data showing that this monitoring actually leads to improved patient outcomes[9]; however, this study has been criticized for methodological flaws. Moreover, the use of IONM dictates modifying the anesthetic technique to total intravenous anesthesia as opposed to volatile anesthetics. Total intravenous anesthesia has its own risk-benefit concerns, including potential risk of awareness, longer recovery time, and increased cost.[10,11]

The routine use of IONM in spine surgeries varies across Canadian institutions, and its clinical usefulness for procedures associated with relatively low incidence of spinal cord injury such as AIS, compared with any other form of scoliosis, is not yet supported by strong evidence-based research.

Our primary objective was to determine the incidence and severity of NNDs in pediatric patients with AIS undergoing surgical correction before and after the use of IONM technology. A NND is defined as any sensory or motor deficit that was not present before the surgery. A mild NND is defined as an isolated sensory deficit, while a severe NND is defined as one with motor deficits. The secondary objective was to explore clinical risk factors of such neurologic injuries.

Methods

This retrospective chart review was conducted at McMaster Children's Hospital (Hamilton, Ontario), a large tertiary-care teaching hospital serving south-central Ontario, and Children's Hospital of Eastern Ontario (CHEO; Ottawa, ON), a large university teaching hospital serving Eastern Ontario and western Quebec. Ethics approval was received from the Hamilton Integrated Research Ethics Board (project number 0944-C, approval date 7 March 2016) and CHEO Research Ethics Board (REB protocol number 16/151X, annual renewal date 29 October 2019) and the need for informed consent was waived. Together, these hospitals perform approximately 80 scoliosis corrections annually.

Study population

Data from 1 January 2007 to 31 December 2014 were retrospectively collected from the operating room database at each institution to identify pediatric patients who underwent scoliosis correction surgery. The anesthesia residents conducting the study reviewed the identified patient records and extracted pre-defined data into the Research Electronic Data Capture (REDCap, Nashville, TN, USA) database at each institution.

Intraoperative neurophysiologic monitoring

Intraoperative neurophysiologic monitoring was conducted by evaluating SSEPs and MEPs using a 32-channel IONM machine (Cadwell Elite; Cadwell Laboratories, Inc, Kennewick, WA, USA). At both institutions, all surgeons had at least five years' experience at the beginning of the data collection time, and the decision to perform wake-up test *vs* IONM was according to the availability of the IONM technology at the time of the surgery. At CHEO, surgeons began using IONM in 2007, and at McMaster Children's Hospital, surgeons switched to IONM in 2009–2010. Use and technique of IONM were similar between institutions. The complete methodology has been previously published.[12] We defined an alert as a persistent loss of $\geq$ 65% amplitude of MEP or $\geq$ 50% amplitude of SSEP or 10% increase in the latency of the SSEP relative to a stable baseline. We defined recovery as return of the signal to within 25% of baseline after intervention.

Wake-up test

The wake-up test was conducted by pausing the surgical intervention, waking the patient while still in surgical prone position, and asking the patient to move their limbs while a surgical team member observed the limbs for movement.

Inclusion criteria

Pediatric patients aged 10 to 18 yr, presenting with AIS requiring surgical correction by a pediatric spine surgeon.

Exclusion criteria

Scoliosis etiology other than AIS and patients with preoperative neurologic deficits.

Outcomes

The primary outcomes were the incidence and severity of NNDs in the immediate postoperative period and its association with the neuromonitoring technique. Secondary outcomes included total operating room time (patient in–patient out), estimated blood loss, and postoperative ventilation.

Statistical analysis

Demographic characteristics are presented using means and standard deviations for normally distributed continuous variables; medians and interquartile ranges for skewed continuous variables; and counts and percentages for categorical variables. *T* tests, Mann-Whitney U tests, and Chi square tests were conducted for normally distributed continuous, skewed continuous, and categorical demographic characteristics, respectively, to determine whether significant differences existed in individuals who did and did not receive IONM. Logistic regression analyses were conducted for several potential factors (type of monitoring, age, sex, Cobb angle, surgical approach [posterior, anterior, combined], type of surgery [primary *vs* revision], kyphosis, number of levels corrected, and estimated blood loss) to explore if there was an association between each factor and occurrence of NNDs. Results are reported using odds ratios (OR), 95% confidence intervals (CIs), and values. A multivariable logistic regression analysis was not conducted because of the low number of NND events. A subgroup analysis using a Fisher's exact test was conducted to determine whether there was an association between NND severity level (mild *vs* severe) and IONM use among patients who had a NND. Analyses were performed in SAS software Version 9.4 (Cary, NC, USA).

Results

In total, 547 patients were included in the study (309 [56%] from CHEO and 238 [44%] from McMaster); of these, 359 (66%) patients were monitored with IONM, and 186 (34%) were monitored with wake-up test (Figure). Approximately one-third of the cases were performed before IONM technology was implemented in our institutions. The neural integrity of those patients was tested with the wake-up test after the correction was completed. The remaining two-thirds were monitored with SSEPs and MEPs by certified neurophysiologists. Monitoring of two patients was aborted because of technical difficulties, and information on the monitoring methods was missing in two patients. Individuals whose monitoring process was aborted were grouped with those who had a wake-up test. Demographic and clinical data of the patient sample, distributed by type of neuromonitoring, are reported in Table 1. There was no difference in mean age, weight, or height between the two groups; however, there were significantly more female patients in the wake-up test group ($P < 0.001$). The crude incidence of NND occurrence in the IONM patients group was significantly lower than in the wake-up test group (3.3% *vs* 8.1%, respectively, $P < 0.02$). In addition, the total operating room time and the estimated blood loss were significantly lower in the IONM group than in the wake-up test group ($P = 0.003$, $P = 0.007$, $P < 0.001$, respectively). The overall incidence of NNDs in our study was 4.9% (95% CI, 3.12 to 6.75); of these, a severe NND was found in 1.7% of patients (95% CI, 0.58 to 2.71) and a mild NND was found in 3.3% of patients (95% CI, 1.80 to 4.79).

Unadjusted logistic regression analyses were conducted for the above-listed factors to explore whether there was an association between each factor and NND status (Table 2). A multivariable logistic regression analysis could not be conducted because of the low number of NND events. Compared with the wake-up test, individuals receiving IONM were significantly less likely to develop NND (OR, 0.39; 95% CI, 0.18 to 0.86; $P = 0.02$). Patients who had anterior release and posterior instrumentation done separately were less likely to have NND (OR, 0.11; 95% CI, 0.01 to 1.08; $P = 0.06$; and OR, 0.23; 95% CI, 0.08 to 0.81; $P = 0.02$, respectively), than patients who underwent a combined anterior and posterior surgical approach were.

Among individuals who experienced a NND, there was no significant association between the method of intraoperative monitoring and NND severity ($P = 0.13$; Table 3). Clinical data of the nine patients who had severe NNDs are summarized in Table 4.

TABLE 1 Distribution of patient's demographics and clinical data by type of neuromonitoring

	Wake-up test (n=186)	Intraoperative neuromonitoring (n=359)	P
Demographics			
Age; mean (SD)	14.5 (1.7)	14.6 (2.0)	0.33*
Missing	0	0	
Weight (kg); mean (SD)	53.1 (13.8)	53.1 (15.7)	0.98*
Missing	3	11	
Height (cm); mean (SD)	160.9 (10.4)	160.1 (11.3)	0.48*
Missing	15	64	
Female; n (%)	151 (83)	243 (68)	<0.001
Missing	3	0	
Clinical characteristics			
Total operating room time (min); mean (SD)	546.9 (109.8)	518.6 (97.6)	0.003*
Missing	4	0	
Estimated blood loss ($mL \cdot kg^{-1}$); median [IQR]	25.4 [14.7–40.7]	21.1 [12.6–34.1]	0.007†
Missing	11	6	
Postoperative ventilation in OR‡; n (%)	68 (37)	140 (39)	0.66
Missing	4	3	

P values were determined using Chi square tests for categorical variables, t tests for normal continuous variables (*), and Mann Whitney U tests for skewed continuous variables (†). ‡Patient was not extubated in the OR, and was transferred to the intensive care unit still intubated.

IQR = interquartile range; OR = operating room; SD = standard deviation.

TABLE 2 Determining factors associated with new neurologic deficits

Variables	Unadjusted analysis OR (95% CI)	*P* value
Type of monitoring		
Wake-up test	REF	
IONM	0.39 (0.18 to 0.86)	0.02
Age		
10–15 yr	REF	0.35
> 15–18 yr	0.19 (0.20 to 0.86)	
Female	1.33 (0.53 to 3.36)	0.55
Cobb angle		
< 60°	REF	
60°–90°	0.99 (0.45 to 2.19)	0.42
> 90°	0.38 (0.05 to 2.97)	0.35
Surgical approach		
Combined	REF	0.02
Posterior	0.23 (0.08 to 0.81)	
Anterior	0.11 (0.01 to 1.08)	0.06
Type of surgery		
Primary	REF	
Revision	0.66 (0.15 to 2.87)	0.58
Kyphosis	1.78 (0.51 to 6.22)	0.36
Number of levels corrected		
< 10	REF	
≥ 10	1.54 (0.61 to 3.89)	0.36
Estimated blood loss		
<10 mL·kg^{-1}	REF	
10–20 mL·kg^{-1}	1.29 (0.33 to 4.97)	0.95
>20 mL·kg^{-1}	1.56 (0.44 to 5.48)	0.46

CI = confidence interval; IONM = intraoperative neuromonitoring; OR = odds ratio; REF = reference.

TABLE 3 Subgroup analysis of type of spinal cord function monitoring and severity of new neurologic deficit

NND	Wake-up test (*n*=15)	IONM (*n*=12)	*P*
Mild	12 (80)	6 (50)	0.13*
Severe	3 (20)	6 (50)	

Data presented as *n* (%). **P* value was determined from a Fisher's exact test.

IONM = intraoperative neuromonitoring; NND = new neurologic deficit.

Discussion

This exploratory study revealed that IONM was associated with a reduced overall incidence of NNDs after correction of idiopathic scoliosis, although NND severity was not different between the two groups. The overall incidence of severe NND after AIS correction was 1.6%, which is slightly higher than in previous reports.[9,13] A potential explanation of this finding is that we considered any motor deficit as severe (whether it was related to spinal cord, nerve root, or cauda equina injury) and regardless of recovery (temporary or permanent). Sensory deficits and those related to positioning were considered mild, as they are usually transient and self-limiting. Six patients (out of 359 in the IONM group) and three patients (out of 186 in the wake-up test group) woke up with motor deficits. Among those nine patients, five almost completely recovered while the other four only partially recovered from their deficits at three months. Qiu *et al.* reported eight cases of NNDs in a cohort of 756 patients with AIS with an incidence of 1.06%.[13] In the study by Qiu *et al.*, all cases were monitored by SSEP, and patients who had abnormal SSEP signals underwent the Stagnara wake-up test. A review of the Scoliosis Research Society Morbidity and Mortality Committee on 11,741 AIS patients revealed 89 cases of NNDs with an incidence of 0.73%.[9]

Among the potential predictors of neurologic complications, we found that a combined anterior and posterior approach was significantly more associated with NNDs than single-stage procedures were. This is in agreement with Coe *et al.*,[14] who also reported a significantly higher overall postoperative complication rate of 10% compared with 5% when the anterior and the posterior instrumentation were done separately. Therefore, most surgeons have changed their practice, and the anterior release and the posterior instrumentation are now done separately. Other patient-related risk factors of NNDs include type of scoliosis (highest in congenital scoliosis), hyperkyphosis, and Cobb angle > 90°.[13] We were not able to show statistical significance with other clinical risk factors; however, this could be attributed to the low number of patients included.

In our study, NND severity (mild *vs* severe) was not different between the two groups (IONM *vs* Stagnara wake-up test). Nevertheless, our study was not powered to detect a statistically significant association between IONM use and the severity level of NNDs given the low number of individuals who experienced an NND event (n = 27). Moreover, confounders (such as the institution in which the procedure took place) and lack of randomization adds to our limitation in making such a conclusion. Nevertheless, the role of IONM in reducing the risk of neural complications has been a matter of debate. The Scoliosis Research Society Morbidity and Mortality Committee published one of the largest reports on neurologic complications of spine surgery in more than 100,000 cases.[9] In this report, neuromonitoring was performed in 238 of 293 patients, 407 of 662 patients, and 43 of 74

TABLE 4 Clinical data of patients with severe new neurologic deficit after surgery for adolescent idiopathic scoliosis

Patient	Age	Sex	Cobb angle	Surgical approach	Surgery type	Number of levels	EBL, $mL \cdot kg^{-1}$	MEP	SSEP	Monitoring modality	ASA	Kyphosis	NND	NND recovery at 3 months (*vs* baseline)
1	18	Female	–	Posterior	Revision	5	21.1	Yes	Yes	IONM	.	No	Yes	Partial
2	17	Male	–	Posterior	Primary	8	18.2	Yes	Yes	IONM	2	No	Yes	Complete
3	11	Female	90°	Anterior	Primary	6	4.7	Yes	Yes	IONM	2	No	Yes	Complete
4	12	Female	70°	Posterior	Primary	13	49.8	Yes	Yes	IONM	2	No	Yes	Complete
5	13	Female	65.2°	Posterior	Primary	13	28.6	Yes	Yes	IONM	1	No	Yes	Partial
6	13	Female	73°	Posterior	Primary	.	.	Yes	Yes	IONM	2	No	Yes	Partial
7	17	Female	60.1°	Posterior	Primary	12	25.4	.	.	Wake-up test	.	No	Yes	Complete
8	15	Male	69.6°	Posterior	Primary	11	53.8	.	.	Wake-up test	.	No	Yes	Not available
9	13	Female	78°	Combined	Revision	14	47	.	.	Wake-up test	1	No	Yes	Partial

ASA = American Society of Anesthesiologists score; EBL = estimated blood loss; MEP = motor evoked potentials; NND = new neurologic deficit; SSEP = somatosensory evoked potentials.

patients who had new spinal cord, nerve root, and cauda equina deficits, respectively. Nevertheless, these data are difficult to interpret because of different patient populations, variable indications for surgery, variable monitoring modalities, and its reliance on self-reporting. In a national database search of IONM in the United States, there was a trend toward reduced NND but this was not statistically significant.[15] Nevertheless, the authors suggested that IONM use was underreported in this database, which was a significant limitation. Thuet *et al.*[16] reported 1,618 AIS cases monitored with SSEPs and MEPs. Twelve patients (0.7%) had true positive alerts, but only one patient sustained a permanent neurologic deficit. In a prospective multicentre series, Diab *et al.*[17] reported neural complications in 1,301 patients with AIS who underwent monitored spinal fusion with instrumentation. Four cases (0.3%) woke up with neurologic deficits, but all resolved completely in eight to 12 weeks. Schwartz *et al.*[18] analyzed 26 cases with IONM alerts in a series of 1,121 consecutive AIS patients. Seven cases woke up with motor or combined sensorimotor deficit and two cases woke up with pure sensory deficits. In those nine cases, the sensitivity and specificity of MEPs and SSEPs to detect motor or sensory deficits (respectively) was 100%. The 17 remaining cases of this study had signal improvement to within 25% of the baseline amplitude following intervention, and none of them woke up with an NND. In a similar work by Kundnani *et al.*[19] conducted on a series of 354 AIS patients, 13 patients had IONM alerts, four of which had persistent IONM alerts (two patients woke up with an NND and the other two woke up with no NND [false positives]). Combined MEPs and SSEPs were shown to provide the highest sensitivity and specificity in both previously mentioned studies.

Nevertheless, IONM is not a foolproof tool. False negative results were reported in 0.3–2.6% of cases in some articles.[12,16] Moreover, there is wide variability in defining criteria for an IONM alert (and recovery thereof), which makes it challenging to differentiate between true and false positive results.[20–23] In other words, it is unknown how many patients with an alert will recover without an NND if no intervention took place in response to this alert. Nevertheless, this question is very hard to answer because it is unethical to design a study in which IONM alerts will be intentionally ignored in one group. IONM signals are also affected by other factors unrelated to iatrogenic compromise of the spinal cord. Volatile anesthetics, muscle relaxants, and excessive anesthetic depth can impair IONM signals.[10] Moreover, etiology of scoliosis may alter the accuracy of IONM signals, especially in patients with neuromuscular scoliosis.[24]

Despite those limitations, IONM has become the "standard of practice" in modern scoliosis correction surgery and its routine use is supported by the Scoliosis Research Society with only level C evidence.[25] The Stagnara wake-up test, once the gold standard approach, has multiple potential problems including observation at a single point in time, increased operative time, patient movement, accidental extubation, and vascular lines dislodgement, pain, and recall.[12]

New innovative surgical techniques have been recently developed with promising results. Novel surgical technologies such as the fusionless scoliosis surgery may provide a less invasive and safer approach in selected

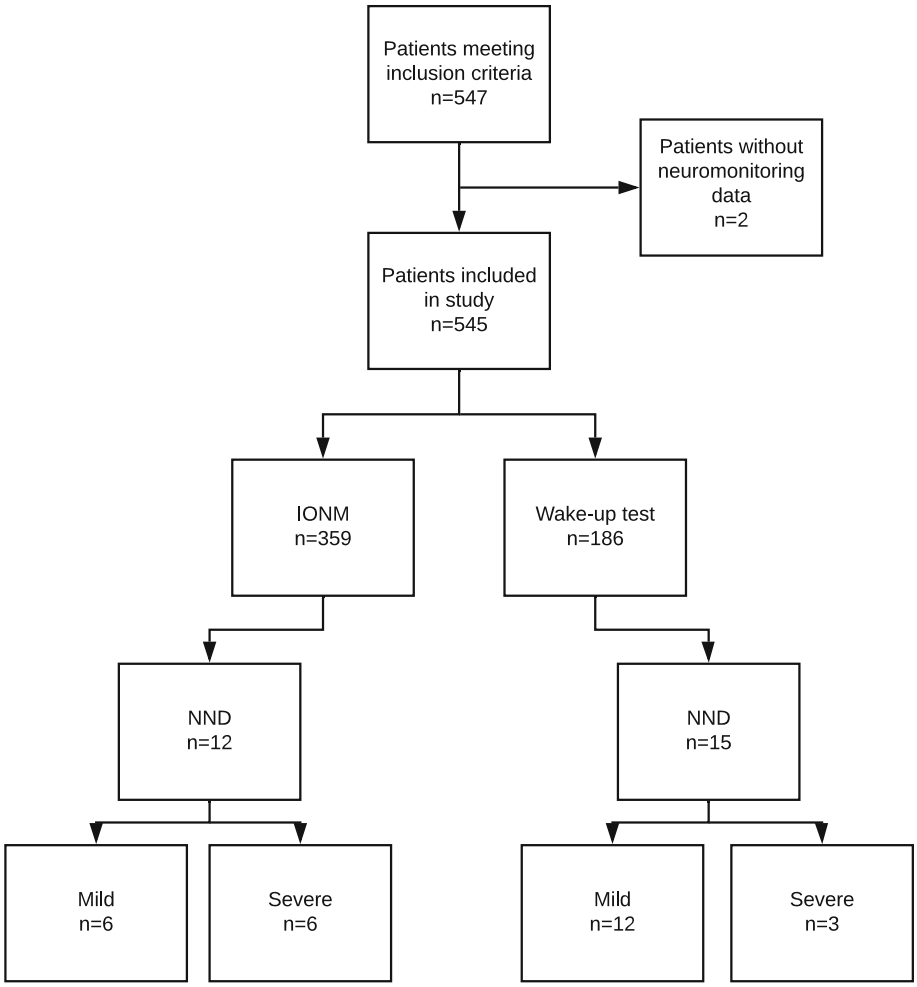

FIGURE Flowchart of patients

scoliosis patients; one example is the posterior dynamic deformity correction device (ApiFix Ltd, Misgav, Israel), which allows less spinal instrumentation without fusion.[26] Floman *et al*. reported an operative time of less than 1 hr, minimal blood loss, and no neurologic complications using this technology.[27] Nevertheless, larger studies are still needed to confirm these results.

Limitations

Our study has some limitations. First, it is a retrospective review with the potential of inaccurate or missing data (*information bias).* We attempted to minimize this by carefully designing the study to ensure appropriate data extraction and analysis. Second, our sample size is not powered to identify the impact of IONM on the primary outcome (NND). Third, there was a disproportionate distribution of IONM cases between the two institutions making it a possible confounder for outcomes such as blood loss, transfusion requirements, and operative time. Fourth, as this is a before and after study, there is potential for historical confounding, and changes in anesthetic and surgical techniques over time potentially affects outcomes like NNDs and blood loss.

Conclusion

Severe NNDs continue to be a potential devastating complication of idiopathic scoliosis surgery and its incidence ($\sim$1%) has not changed significantly over the years despite advancements in neuromonitoring technology and surgical techniques. Our study suggests that multimodal IONM (SSEPs and MEPs) is associated with reduced overall incidence of NND. Nevertheless, as we were unable to adjust for confounding variables, further research is needed to determine the impact of IONM on NNDs. Our data also confirm that a combined anterior/posterior approach has been associated with significant increased risk of NNDs.

Author contributions *James Paul*, *William Splinter*, and *Mohamed Nassef* contributed to study conception and design, acquisition of data, and drafting and critically revising the article. *Abdelaziz Al-Kalbani*, *Natalie Lidster*, *Andrew Nashed*, and *Suzin Ilton* contributed to data collection. *Thuya Vanniyasingam* contributed to data analysis/statistics and manuscript revisions.

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