Spine

DEFORMITY

Ponte Osteotomies Increase the Risk of Neuromonitoring Alerts in Adolescent Idiopathic Scoliosis Correction Surgery

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Study Design. Observational cohort study of prospective database registry.

Objective. To determine the incidence of neurological complications in AIS patients undergoing surgical treatment with PO.

Summary of Background Data. Despite the widespread use of Ponte Osteotomies (PO) in adolescent idiopathic scoliosis (AIS) correction, outcomes and complications in patients treated with this technique have not been well characterized.

Methods. A multicenter prospective registry of patients undergoing surgical correction of AIS was queried at 2-year follow-up for patient demographics, surgical data, deformity characteristics, and peri-operative complications. A neurological complication was defined as perioperative nerve root or spinal cord injury as identified by the surgeon. Patients were divided into those who underwent peri-apical PO and those without, and further stratified by Lenke curve classification into 3 groups (I-types 1 and 2, II-types 3, 4, 6, and III-type 5). Patients with- and without neurological complications were compared with respect to baseline demographics, surgical variables, curve types, fusion construct types (screws vs. hybrid), curve magnitude (coronal and sagittal Cobb), apical vertebral translation, and coronal-deformity angular ratios (C-DAR).

Results. Of 2210 patients included in the study, 1611 underwent PO. Peri-operative neurological complications occurred in 7 patients, with 6 in the PO group (0.37%) and 1 in non-PO group (0.17%) though this was not a statistically significant risk factor for peri-operative neurological injury ($P = 0.45$). Neuromonitoring alerts were recorded in 168 patients (7.6%: 9.3% PO group; 4.2% no-PO group ($P < 0.001$)). Multivariate logistic regression analysis found PO and curve magnitude to be independent risk factors for intraoperative neuromonitoring alerts ($P < 0.01$).

Conclusion. PO and curve magnitude were independent risk factors for intraoperative neuromonitoring alerts in surgical AIS correction. The effect of Ponte osteotomy on neurological complications remains unknown due to the low incidence of these complications.

Key words: adolescent idiopathic scoliosis, coronal balance, deformity correction, Lenke curve classification, neuromonitoring alerts, patient reported outcome measures, Ponte osteotomy, sagittal balance.

Level of Evidence: 3

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Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the spine involving the coronal, sagittal, and axial planes. While the etiology of AIS remains unknown, it is thought to be multifactorial with hereditary predisposition. Presenting symptoms include physical deformity such as uneven shoulder height, asymmetry of the waistline, or rib prominence, and may include pain or respiratory compromise based on severity.[1] Fortunately, surgical correction is an effective treatment option for patients with significant deformity or one that is likely to progress.[2,3]

The primary goals of surgical management for AIS are arrest of curve progression, correction of deformity with preservation of coronal and sagittal balance, vertebral derotation and achieving fusion with minimal morbidity for the patient.[4] While these goals remain constant, there remains variability in the selection of operative approach and

technique due to a wide spectrum of curve types and surgeon preference.[5] Among these, the Ponte osteotomy (PO) is commonly used to allow larger coronal, sagittal, and axial corrections in AIS.[6] Recent retrospective reviews have highlighted the efficacy of PO in achieving alignment correction for AIS, but there is limited data examining the outcomes and complications associated with use of this technique.[7–9]

Iatrogenic neurologic injury is an uncommon, but feared complication in AIS correction. This becomes readily apparent since surgery is often performed in younger and otherwise healthy individuals with the intention of alleviating deformity and the psychological burden of negative body image. Collaborative, multicenter efforts have taken place to identify and take steps to minimize perioperative complications in the AIS patient population. The Scoliosis Research Society (SRS) morbidity and mortality report published in 2011 reviewed 11,741 cases and found a 0.73% incidence of new neurologic deficits following surgery.[10]

Despite a low rate of neurologic complication, prevention is critical when considering their significantly adverse effects on the patient's quality of life. Intraoperative neurophysiologic monitoring (IONM) allows real-time detection of changes in a patient's neurologic status and through early identification, permits the surgeon to respond appropriately to prevent or reverse injury or physiological insult to the spinal cord. The commonly used forms of IONM include somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs). Due to the risk reduction benefits, multimodal IONM has become standard of care in spinal deformity correction.[11–13] The purpose of this study is to compare the peri-operative and neurological outcomes of AIS patients undergoing surgical treatment with and without Ponte osteotomies.

MATERIALS AND METHODS

A prospectively collected multicenter database was queried to identify patients who underwent surgical management of AIS with a minimum of 2-years follow-up. Institutional review board approval was obtained from each of the contributing institutions involved in this study. Consent was obtained from each patient prior to data collection, which took place from 2006 to 2016. The database was reviewed for patient demographics, surgical data, spinal deformity characteristics, peri-operative complications, and patient reported outcome measures. Patients were divided into two cohorts by those who underwent Ponte osteotomy (PO) and those who did not (non-PO), and further stratified by Lenke curve classification into three groups (I—types 1 + 2, II—types 3, 4, 6, and III—type 5).

A neurological complication was defined as a perioperative nerve root or spinal cord injury as identified by the surgeon. Patients with and without PO were compared with respect to baseline demographics, surgical variables, curve types, fusion construct types (screws *vs.* hybrid), curve magnitude (coronal and sagittal Cobb), apical vertebral translation, and coronal deformity angular ratios (C-DAR).

Propensity score matching (PSM) was completed to control for differences in curve magnitude between PO and noPO and resulted in a cohort of 1196 patients with 598 in each group. Pearson's χ^2 test was used to analyze categorical variables and independent samples t tests and ANOVA for continuous variables. Analysis was also performed comparing patients with and without recorded neuromonitoring alerts and neurological complications. All statistical analysis was performed using SPSS 23.0 (IBM Corp, Armonk, NY). Statistical significance was defined as $P < 0.05$.

A neuromonitoring alert was defined as a reduction in amplitude of 50% or more in SSEPs and/or tcMEPs. Increases in response latency were not included as an alert based on existing literature suggesting that it is not seen as an independent sign of neurologic injury in spine surgery.[14,15] In patients who experienced a neuromonitoring alert, appropriate measures were taken based on each institution's guidelines. The event that triggered the alert and the intervention performed were documented in the surgical index.

RESULTS

Patient Characteristics and Baseline Measurements
A total of 2210 patients were included in the study with the majority being female (80.6%). The mean age at surgery was 14.7 ± 2.1 years old. The mean major Cobb angle was $56.0° \pm 12.3°$ with a mean (T5–T12) kyphosis of $22.8° \pm 13.8°$. Lenke curve distributions were as follows: type 1 (42.6%), type 2 (22.7%), type 3 (8.0%), type 4 (4.3%), type 5 (12.8%), and type 6 (9.5%) (see Table 1).

Comparison of Patients With and Without Ponte Osteotomy at Baseline
Distribution of patient sex ($P = 0.25$) and body mass index (BMI) were found to be comparable between groups ($P = 0.81$). Major coronal Cobb angle was found to be significantly different in patients with and without PO at baseline (PO: $57.3° \pm 13.0°$ *vs.* noPO: $52.4° \pm 9.60°$, $P < 0.001$). T5–T12 kyphosis was similar at baseline (PO: $22.8° \pm 14.3°$ *vs.* noPO: $22.8° \pm 12.5°$, $P = 0.91$) (see Table 2).

TABLE 1. Overall Patient Characteristics

Total # of Patients	2210
Sex	80.6% F
Lenke Type	
1	935 (42.6)
2	499 (22.7)
3	176 (8.0)
4	95 (4.3)
5	281 (12.8)
6	208 (9.5)
Ponte osteotomy	1611 (72.9%)
Major Cobb angle °	56.0 ± 12.3
Kyphosis (T5–T12) °	22.8 ± 13.8

TABLE 2. Comparison of Ponte and No Ponte Patients (n = 2210)			
	Ponte Group	**No Ponte Group**	**_P_ Value**
Patients	1611	599	
Sex	79.9% F	82.1% F	$P = 0.25$
Age	14.6 ± 2.0	14.6 ± 2.2	$P < 0.001$
BMI	21.0 ± 14.7	20.9 ± 4.67	$P = 0.81$
Curve magnitude	57.3 ± 13	52.4 ± 9.6	$P < 0.001$
Kyphosis (T5–T12)	22.8 ± 14.3	22.8 ± 12.5	$P = 0.91$
Neuromonitoring alerts	9.82%	4.01%	$P < 0.001$
Peri-operative deficits	0.37%	0.17%	$P = 0.68$

Intra- and Postoperative Details

Ponte osteotomies were performed in 1611 of 2210 (72.9%) patients. Those who underwent PO had greater number of levels fused than those who did not (11.4 *vs.* 10.2, $P < 0.001$). Estimated blood loss (EBL) was similar between both groups (883 ± 694 mL *vs.* 842 ± 721 mL, $P = 0.23$). However, operative time was higher in cases utilizing PO (294 ± 118 min *vs.* 270 ± 94 min, $P < 0.001$). Overall length of stay was similar between both groups (5.0 ± 1.7 days *vs.* 5.1 ± 2.6 days, $P = 0.17$).

Peri-operative neurological complications occurred in 7 patients, with 6 in the PO group (0.37%) and 1 in non-PO group (0.17%) though this was not a statistically significant risk factor for peri-operative neurological injury ($P = 0.45$). Neuromonitoring alerts were recorded in 168 patients (7.6%: 9.3% PO group; 4.2% no-PO group ($P < 0.001$). Multivariate logistic regression analysis found PO and curve magnitude to be independent risk factors for intra-operative neuromonitoring alerts ($P < 0.01$). Subanalysis after PSM to control for baseline differences in curve magnitude found PO to remain as a risk factor for neuromonitoring alerts ($P < 0.01$).

The percentage change in curve magnitude from baseline to 2-years was higher in those with Ponte osteotomies (64% ± 14% *vs.* NoPO: 60% ± 15%, $P < 0.001$). There was also greater correction of rib prominence in those with PO (57% ± 23% *vs.* NoPO: 49% ± 28%, $P < 0.001$). However, a greater number of patients underwent thoracoplasty in the PO cohort (22.5% *vs.* 7.7%, $P < 0.001$). The addition of a thoracoplasty was not found to be an independent risk factor for neuromonitoring alerts or neurological events ($P < 0.01$).

Triggering Event and Alert Intervention

The triggering event was recorded by the primary surgeon for each neuromonitoring alert, along with the intervention that followed. The most commonly reported triggering events were placement of instrumentation (29.2%) and curve correction maneuvers (22.6%). 2.4% of alerts occurred during osteotomies. 8.3% of patients experienced an alert secondary to cardiovascular causes and 3.0% from an anesthesia-related cause. 5.4% of alerts occurred during patient positioning. 15 of 144 alerts (8.9%) were recorded as "other" and 34 of 144 (20.2%) were from unknown causes or not reported. The majority of neuromonitoring alerts were improved by elevation of blood pressure (30.1%), followed by removal of instrumentation (16.1%). Other interventions included surgical pause (13.5%), release of correction (10.4%), and repositioning of the patient (7.8%). A wake up test was performed on 20 patients (10.4%). Alert interventions were not documented in the database for 26 patients (13.5%) [see Table 3].

Scoliosis Research Society-22 Scores

SRS-22 scores at baseline were different in the PO and noPO group with the exception of SRS Total score (PO: 3.85 ± 0.51 *vs.* NoPO: 3.86 ± 0.49, $P = 0.74$). Patients in the noPO cohort had higher preoperative SRS scores in all subcategories other than SRS General Function ($P < 0.01$).

TABLE 3. Event Triggering Neuromonitoring Alert		
	n = 168	**(%)**
Placement of instrumentation	49	29.2
Curve correction maneuver	38	22.6
Cardiovascular	14	8.3
Patient positioning	9	5.4
Anesthesia-related	5	3.0
Osteotomy	4	2.4
Other	15	8.9
Not reported	34	20.2
Alert intervention	**#**	**(%)**
Elevation of blood pressure	58	30.1
Removal of instrumentation	31	16.1
Surgical pause	26	13.5
Release of correction	20	10.4
Wake up test	20	10.4
Repositioning of patient	15	7.8
Administer Steroid Protocol	1	0.5
Not reported	26	13.5

TABLE 4. Comparison of SRS Scores by Ponte and No Ponte

	Preop			2 Yr		
	Ponte	**No Ponte**	***P* Value**	**Ponte**	**No Ponte**	***P* Value**
Pain	4.00 ± 0.74	4.38 ± 0.65	< 0.01	4.42 ± 0.57	4.38 ± 0.65	0.23
Self-image	3.30 ± 0.71	4.02 ± 0.74	< 0.01	4.44 ± 0.54	4.40 ± 0.59	0.24
General function	4.35 ± 0.62	3.30 ± 0.67	< 0.01	4.60 ± 0.46	4.59 ± 0.51	0.87
Mental health	3.96 ± 0.74	4.42 ± 0.56	< 0.01	4.25 ± 0.66	4.21 ± 0.71	0.27
Satisfaction	3.69 ± 0.93	3.91 ± 0.72	< 0.01	4.60 ± 0.61	4.54 ± 0.74	0.15
Total	3.85 ± 0.51	3.86 ± 0.49	0.74	4.44 ± 0.41	4.41 ± 0.50	0.24

TABLE 5. Comparison of SRS Scores by Alert and No Alert

	Preop			2 Yr		
	Alert	**No Alert**	***P* Value**	**Alert**	**No Alert**	***P* Value**
Pain	3.96 ± 0.75	4.06 ± 0.74	0.11	4.32 ± 0.69	4.41 ± 0.59	0.18
Self-image	3.32 ± 0.76	3.50 ± 0.79	< 0.01	4.39 ± 0.56	4.43 ± 0.55	0.46
General function	4.13 ± 0.70	4.06 ± 0.79	0.22	4.59 ± 0.57	4.60 ± 0.47	0.98
Mental health	3.94 ± 0.71	4.10 ± 0.72	0.01	4.21 ± 0.64	4.24 ± 0.68	0.67
Satisfaction	3.78 ± 0.85	3.75 ± 0.88	0.77	4.62 ± 0.57	4.58 ± 0.66	0.57
Total	3.80 ± 0.51	3.87 ± 0.51	0.16	4.39 ± 0.48	4.43 ± 0.44	0.39

At 2-year follow up however, SRS scores were statistically similar in all domains between patients who underwent PO and those who did not (see Table 4).

SRS-22 scores were also compared for patients who experienced a neuromonitoring alert and those who did not. Preoperatively, patients who experienced alerts scored lower in self-image but higher in mental health domains, but otherwise displayed similar SRS scores to those without alerts. At 2-year follow up, there was no statistical difference identified in any domain (see Table 5).

DISCUSSION

This study examines the risks of intraoperative neural monitoring alerts and postoperative neurological outcomes in the setting of Ponte osteotomies in AIS correction. While the technique is widely used in surgical correction of AIS, the existing evidence surrounding the outcomes associated with its use is limited, with the bulk focused on establishing its efficacy in achieving multiplanar correction.

In a single center review of 87 consecutive AIS patients who underwent Ponte osteotomy, Shah *et al* reported an 8% incidence of neuromonitoring changes with no neurologic complications.[13] In addition to the small sample size, a limitation of their study was reported to be the absence of a non-Ponte control group, which prevented a side-by-side comparison and identification of possible confounding variables. The present study analyzed 2210 surgical AIS patients from a prospectively collected multicenter registry and found a 9.3% incidence of neuromonitoring alerts in patients who underwent Ponte and 4.2% in those who did not. The overall rate was 8.0%, consistent with the earlier findings of Shah *et al*. Our study however found a 0.37% and 0.17% incidence

of neurologic complications in the PO and non-PO groups respectively, likely the result of improved granularity from utilizing a larger patient sample size.

In an earlier study evaluating potential risk factors for neuromonitoring changes in spinal deformity correction, Feng *et al* identified osteotomy procedures as a risk factor. They proposed that this could be due to an increase in the corrective forces and opportunities for injury to the spinal cord involved with performing an osteotomy.[16] The advantage behind Ponte osteotomies however is that they permit increased tri-planar correction of the spine via posterior anatomical releases.[6] Samdani *et al*[8] compared 2-year radiographic data in AIS Lenke type 1 patients with similar baseline parameters who underwent PO and those who did not, and found improved thoracic Cobb angle correction, increased T5-T12 kyphosis, and greater rib prominence correction. Another comparison study by Pizones *et al* incorporated Lenke type 1–4 patients and found better main curve correction with PO at 2 years, but no difference in pre- to postoperative T5–T12 kyphosis. However, a subanalysis after stratifying patients into hypo-, normo-, and hyper-kyphotic groups found that PO was significant in restoring a normal sagittal profile in hypo- and hyper-kyphotic patients.[6]

The peri-operative outcomes surrounding Ponte osteotomies are conflicting in the existing literature. Halanski *et al*[17] compared PO with inferior facetotomy and reported higher blood loss and operative time with no difference in correction of alignment parameters. However, this was a nonrandomized study with a small sample size of 37 patients. A similar study with a larger sample size of 191 patients was performed by Samdani *et al*[8] and did not find an increase in EBL with PO despite also adjusting for patient

weight. In addition, their study found that operative time was not increased with the use of PO. Our study found no difference in EBL between PO and noPO (883 ± 694 mL vs. 842 ± 721 mL, $P = 0.23$), but an increase in operative time with PO (294 ± 118 min vs. 270 ± 94 min, $P < 0.001$). Responses to neuromonitoring alerts, as well as a higher number of fusion levels (11.4 vs 10.2) and thoracoplasty procedures (22.5% vs. 7.7%), may explain the increased operative time in patients with PO.[15]

Based on the existing literature, it is difficult to assess the true rate of neurologic complications in patients treated with Ponte osteotomy. The majority of studies that report this outcome use smaller patient samples, placing the ability to accurately capture an event with an already low incidence in question.[6–9,17,18] This study identified seven patients experiencing new postoperative neurologic deficit, and this was not found to be statistically significantly different between PO and noPO groups (0.37% vs. 0.17%, $P = 0.68$).

One hundred sixty-eight patients (7.6%) experienced a critical reduction of IONM signals, with a statistically significant difference based on PO and noPO (PO 9.3% vs. noPO 7.6%, $P < 0.001$). Despite debate over the precise sensitivity and specificity of IONM modalities in identifying neurologic deficits,[11] multimodal IONM is considered a valuable asset and standard of care in deformity surgery as it allows surgeons to take immediate action and alter the course of a potentially adverse neurological outcome.[13,19] Vitale et al[19] found 8% of patients experienced an electrophysical event in an earlier study of pediatric spinal deformity and reported curve correction and hypotension to be the most common causes of alerts. A more recent study of AIS patients reported a 5.3% alert rate and identified placement of instrumentation and hypotension as major alert triggers.[15] This study however excluded patients requiring intraoperative traction, and the potentially smaller curve magnitudes may explain the lower alert rate. The most common causes of neuromonitoring alerts in the present study were placement of instrumentation and curve correction maneuvers. These findings are consistent with proposed mechanisms of nerve injury in PO, which include stretching or mechanical trauma of the spinal cord and nerve roots, as well as regional cord ischemia from vascular insufficiency.[20]

This study also examined patient reported outcomes at baseline and at 2-year follow-up. SRS scores were different at baseline for patients undergoing PO and noPO with the exception of total SRS score. Patients who did not require PO experienced less pain and higher self-image, mental health and satisfaction, but worse general function. At 2-year follow-up, patients with and without PO reported similar outcomes in all domains. These findings are consistent with those reported by Samdani et al and expand upon their study, which examined only patients with Lenke type 1 curves and the SRS-22 Self-Image and Total domains.[8] The improved correction seen in patients who underwent PO was not reflected in SRS-22 scores. This may reflect the higher baseline scores in patients who did not require PO.

The limitations of this study include nonrandomization of patients undergoing PO and the inability to measure surgeon-specific variables and technique of PO. However, the study was done using a prospectively collected database with extensive clinical and radiographic follow-up. In addition, because this was a multicenter database, we were able to obtain the patient sample necessary to capture low incidence neurologic events.

CONCLUSION

PO is an independent risk factor for neuromonitoring alerts in surgical correction of AIS. However, there was no detectable difference in the incidence of peri-operative neurologic injury. This may be secondary to the low incidence of these complications, and further research is necessary to examine the effect of PO on neurologic outcomes. Operative time was increased with PO but EBL and hospital length of stay were found to be similar to noPO patients. This study found greater correction in radiographic parameters with the use of PO but did not find a difference in clinical outcomes.

➢ **Key Points**

❑ Ponte Osteotomy is an independent risk factor for neuromonitoring alerts in surgical correction of AIS.

❑ Ponte osteotomy is associated with increased operative times but similar EBL and length of stay.

❑ Patients undergoing Ponte osteotomy had greater correction postoperatively, but did not have an increased incidence of peri-operative neurological complications.

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