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CLINICAL ARTICLE

Does baseline thoracolumbar shape influence patterns of cervical decompensation following surgical adult spinal deformity correction?

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OBJECTIVE Adult spinal deformity (ASD) surgery is complex and may lead to postoperative cervical deformity (CD) and/or proximal junctional kyphosis. The Roussouly classification describes four types of baseline thoracolumbar (TL) morphology, which differentially influence surgical outcomes. However, their role in predicting CD remains underexplored. This study aimed to stratify TL-ASD patients by Roussouly types and examine postoperative CD development patterns.

METHODS The authors included operative ASD patients with no prior fusion and complete radiographic data at baseline, 6 weeks, 1 year, and 2 years. Patients were categorized into Roussouly types 1–4 using baseline pelvic incidence and lumbar lordosis apex. CD was assessed using a point system: cervical sagittal vertical axis (cSVA) of 40–80 mm = 1 point, T1 slope minus cervical lordosis (TSCL) of 15°–20° = 1 point, cSVA > 80 mm = 2 points, and TSCL > 20° = 2 points. CD was defined as a score ≥ 2. Statistical comparisons and multivariate logistic regression were used to assess CD risk across Roussouly types.

RESULTS A total of 546 patients (77% female, mean age 60.9 ± 14.3 years, mean BMI 27.3 ± 5.7 kg/m^2, mean Charlson Comorbidity Index score 1.7 ± 1.7) were included. The mean number of fused posterior levels was 10.6 ± 4.5, with a mean estimated blood loss of 1548 ± 1450 mL, mean operative time of 438 ± 180 minutes, and mean length of stay of 7.7 ± 4.2 days. At baseline, 239 (43.8%) patients met CD criteria. The Roussouly distribution was as follows: type 1 (8.4%), type 2 (12.6%), type 3 (47.3%), and type 4 (31.7%). Among 307 patients without baseline CD, 174 (31.9%) developed CD within 2 years: 99 (32.2%) at 6 weeks, 44 (14.3%) at 1 year, and 31 (10.1%) at 2 years. Type 2 patients had higher odds of developing CD at 2 years compared to type 3 patients (OR 2.15, p = 0.019). Type 4 patients had lower odds of developing CD (OR 0.22, p = 0.12).

CONCLUSIONS Roussouly type influences the timing and likelihood of CD following ASD correction. Type 1 patients tended to develop CD earlier, while type 2 patients showed delayed onset. Type 4 morphology may be protective against CD.

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KEYWORDS adult spinal deformity; cervical deformity; Roussouly classification; spinal morphology; proximal junctional kyphosis

ABBREVIATIONS ASD = adult spinal deformity; CCI = Charlson Comorbidity Index; CD = cervical deformity; HRQOL = health-related quality of life; LL = lumbar lordosis; MCID = minimal clinically important difference; ODI = Oswestry Disability Index; PI = pelvic incidence; PJK = proximal junctional kyphosis; PT = pelvic tilt; SRS-22 = Scoliosis Research Society–22 outcomes questionnaire; SVA = sagittal vertical axis; TL = thoracolumbar; TPA = T1 pelvic angle.

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The alignment of the spine is a complex, interdependent system, where alterations in one region inherently influence the biomechanical demands placed on adjacent regions. This interplay becomes particularly evident in patients undergoing corrective surgery for adult spinal deformity (ASD), where the maintenance and restoration of sagittal and coronal balance is a primary goal. Because of global spine alignment changes, cervical deformity (CD), such as cervical malalignment and proximal junctional kyphosis (PJK), is increasingly seen as a complication after thoracolumbar (TL) ASD correction. Studies have estimated the incidence of postoperative CD to range from 30% to 63.3%, and it is associated with worsened health-related quality of life (HRQOL).[1–3] In addition, surgical correction of CD carries a high risk of major complications.[4] While substantial improvements have been made in understanding and correcting ASD, the risk of CD following surgery remains a significant concern.

One particularly challenging aspect of CD is its timing. While some patients experience this decompensation immediately following surgery, others may develop progressive deformity over months to years. A previous study by Passias et al. found that in addition to increased BMI and comorbidities, both higher cervical lordosis and C2–T3 angle positively predicted later-onset CD conversion.[5]

The morphology of the physiological spine is often characterized by the Roussouly classification, which describes sagittal spinal alignment and offers insights into the reciprocity of regional and global alignment.[6] The system is based on the position of the apex of lumbar lordosis (LL) and sacral slope, which may determine zones of increased stress on the spine and areas at greater risk for breakdown. Previous studies have shown that restoration of ideal Roussouly spine shape after deformity correction is associated with significant decreases in PJK and subsequent revision surgery, while Roussouly classification mismatch leads to an increased risk of postoperative deformity and clinical worsening.[7–9] Given the interplay between the cervical and TL spine and findings in the extant literature, baseline TL morphology may influence the risk and timing of CD after ASD correction. However, whether specific Roussouly types are more prone to cervical decompensation or delayed conversion to CD remains unclear.

In this study, we examined a large cohort of patients with TL-ASD undergoing surgical correction. We aimed to stratify patients by morphology using Roussouly types 1–4 and to investigate the patterns of conversion to CD following surgery.

Methods

Study Design and Inclusion and Exclusion Criteria

A retrospective cohort analysis of a prospective multicenter ASD database was conducted. Patients were consecutively enrolled from 13 participating centers with institutional review board approval, and informed consent was obtained from all centers prior to initiation of the study and enrollment. The database was routinely audited, monitored, and updated on a yearly basis by dedicated research coordinators at each institution, ensuring a high standard of quality control for the database. Inclusion criteria for the dataset consisted of patients ≥ 18 years of age undergoing operative treatment for ASD. ASD was defined radiographically as a sagittal vertical axis (SVA) ≥ 5 cm, Cobb angle ≥ 20°, pelvic tilt (PT) ≥ 25°, and/or thoracic kyphosis > 60°. The records of patients with available baseline, 6-week, 1-year, 2-year, and 3-year radiographic data were analyzed.

TABLE 1. Cohort definitions of Roussouly types

Roussouly Type	Parameter
Type 1	PI <45° & apex of LL distal to L4
Type 2	PI <45° & apex of LL at or proximal to L4
Type 3	45° ≤ PI ≤ 60°
Type 4	PI >60°

Data Collection and Radiographic Parameters

Demographic and surgical parameters were collected with standardized forms. Demographic data included age, BMI, sex, and Charlson Comorbidity Index (CCI) score. Surgical data encompassed estimated blood loss, levels fused, surgical approach, operative time, and rates of decompression osteotomies. Patient-reported outcome measures administered at baseline and follow-up intervals included the Oswestry Disability Index (ODI), Scoliosis Research Society–22 outcomes questionnaire (SRS-22), and SF-36 questionnaire. Minimal clinically important difference (MCID) thresholds were applied to evaluate improvement in outcomes using previously published values for the ODI (12.8), SF-36 (4.9), SRS-Pain (0.587), SRS-Appearance (0.8), SRS-Activity (0.375), and SRS-Mental (0.42).

Full-length freestanding lateral spine radiographs (36-inch cassette) were collected and assessed at baseline and follow-up intervals. Radiographic images were analyzed using SpineView (ENSAM, Laboratory of Biomechanics) software according to standardized and validated techniques previously published in the literature. The spinopelvic radiographic parameters measured were PT, pelvic incidence (PI), SVA, T1 pelvic angle (TPA), and mismatch between PI and LL (PI-LL).

Cohort Definitions

Operative ASD patients with complete radiographic data at baseline, 6 weeks, 1 year, and 2 years were included. Patients were grouped by baseline PI and apex of LL into component types of the Roussouly classification system utilizing PI as published by Pizones et al.[10] The stratification of Roussouly types can be found in Table 1. CD was classified based on a point system using the Ames CD criteria.[11] The point scoring system can be found in Table 2.

Statistical Analysis

Patient baseline factors and operative characteristics were compared using descriptive statistics, one-way

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TABLE 2. CD point system using the modifiers of Ames et al.[11]

Modifier	No. of Points
cSVA 40–80 mm	1
TSCL 15°–20°	1
cSVA >80 mm	2
TSCL >20°	2

cSVA = cervical SVA; TSCL = T1 slope minus cervical lordosis.

TABLE 3. Development rates of postoperative CD based on Roussouly type in patients without baseline CD

	Roussouly Type				
Time Point	1 (n = 27)	2 (n = 37)	3 (n = 141)	4 (n = 102)	p Value
6 wks	22.2%	37.8%	30.5%	35.3%	0.493
1 yr	19.0%	21.7%	19.4%	24.2%	0.892
2 yrs	17.6%	27.8%	20.3%	14.0%	0.611
All	48.1%	64.9%	55.3%	57.8%	0.578

ANOVA, and chi-square testing to identify group differences. Multivariate logistic regression was used to assess the risk of development of CD between groups while controlling for appropriate covariates. Regression results were presented using odds ratios and 95% confidence intervals. All analyses were performed using IBM SPSS Statistics software (version 25.0). Statistical tests were 2-tailed with significance set at $p < 0.05$ with odds ratio and 95% confidence interval exclusive of 1.0.

Results

Cohort Overview

In total, 546 operative ASD patients (77% female) were included, with a mean age of 60.9 ± 14.3 years, mean BMI of 27.3 ± 5.7 kg/m^2, and mean CCI score of 1.7 ± 1.7. Operatively, patients had a mean of 10.6 ± 4.5 posterior levels fused, a mean estimated blood loss of 1548 ± 1450 mL, a mean operative time of 438 ± 180 minutes, and a mean length of stay of 7.7 ± 4.2 days. Overall, 60.1% of patients underwent a posterior-only approach and 39.2% a combined anterior-posterior approach, with 65.8% having any osteotomy, 54.9% a decompression, and 68.5% an interbody fusion.

Baseline Radiographic Presentation and HRQOL

At baseline, the mean radiographic parameters included a PT of 23.0° ± 10.4°, PI-LL of 13.0° ± 19.5°, SVA of 52.2 ± 65.1 mm, TPA of 20.8° ± 12.0°, and T1 slope of 28.6° ± 13.2°. A total of 239 (43.8%) patients met criteria for CD at baseline. By Roussouly type, 46 (8.4%) patients had type 1, 69 (12.6%) had type 2, 258 (47.3%) had type 3, and 173 (31.7%) had type 4. For Schwab modifiers, 188 (34.4%) had PI-LL > 20° (++), 118 (21.6%) had SVA > 9.5 cm (++), and 129 (23.6%) had PT > 30° (++). For overall HRQOL at baseline, patients had a mean ODI score of 42.3 ± 16.7, a mean SRS-Activity score of 3.0 ± 0.9, a mean SRS-Pain score of 2.5 ± 0.8, a mean SRS-Appearance score of 2.5 ± 0.7, a mean SRS-Mental score of 3.5 ± 0.9, a mean SRS-Satisfaction score of 2.7 ± 1.0, and a mean SRS-Total score of 2.9 ± 0.6.

Development of CD

In total, 239 (43.8%) patients met criteria for CD at baseline, 264 (48.4%) at 6 weeks, 265 (48.5%) at 1 year, and 292 (53.5%) at 2 years postoperatively. Of the 307 patients without CD at baseline, 174 (31.9%) developed CD within the 2-year study period: 99 (32.2%) developed CD at 6 weeks, 44 (14.3%) at 1 year, and 31 (10.1%) at 2 years postoperatively (Tables 3–5). There were no differences between Roussouly types and the prevalence of CD or the development of new CD.

In multivariate logistic regression controlling for baseline CD, radiographic parameters, and surgical factors, Roussouly type 2 patients had a higher likelihood of having CD at 2 years postoperatively compared with type 3 patients (OR 2.15, 95% CI 1.1–4.1; $p = 0.019$) and, although not significant, were more likely to develop CD within the study period compared to type 3 patients (OR 2.3, 95% CI 0.9–5.4; $p = 0.052$). Additionally, type 4 patients were less likely to have newly developed CD at 2 years compared to type 3 patients (OR 0.22, 95% CI 0.2–0.7; $p = 0.12$).

Discussion

This study provides critical insights into the conversion to postoperative CD in ASD patients undergoing deformity correction. Among the cohort of 546 patients, more than one-quarter underwent postoperative conversion to CD, with the majority experiencing conversion during the early postoperative period. Previous studies have highlighted that malalignment of spinopelvic parameters, including T1 slope, increased PT, and decreased LL, can drive CD as a compensatory response due to its existence in a "chain of correlation."[5,12,13] The observed CD conversion rates in the present study align with previously reported ranges, further substantiating the critical role of spinopelvic alignment in cervical compensatory mechanisms.[1,2]

To our knowledge, this is the first study to examine the timing of conversion to CD after TL-ASD surgery stratified by Roussouly morphological classification. In a study by Passias et al., patients with a more superior LL apex and flatter thoracic and lumbar curvatures, akin to a Roussouly type 2 curvature, at baseline were at a significantly increased risk for early conversion to CD.[5] Similarly, in the present study, we found that type 2 curvatures had early peak rates of conversion. Interestingly, we also found that these patients had a nonsignificant increased rate of CD conversion 1 year after surgery compared to all other curvature types. In addition to increased conversion to CD, Roussouly type 2 morphologies are also more prone to high-grade intervertebral disc degeneration compared to other subtypes.[14] While the exact cause of these increased risks remains unknown, it is possible that decreased sacral slope and LL may cause intervertebral discs to bear additional stressors that may accelerate disc degeneration. As

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TABLE 4. Cervical SVA severity based on Roussouly type in patients without baseline CD

Time Point	Severity	Roussouly Type				p Value
		1 (n = 27)	2 (n = 37)	3 (n = 141)	4 (n = 102)	
6 wks	80° ≥ cSVA ≥ 40°	3.7%	2.7%	9.9%	9.8%	0.392
1 yr		7.4%	0%	12.8%	5.9%	0.053
2 yrs		7.4%	0%	14.9%	8.8%	0.049

the malalignment of the TL spine inherently contributes to global spine alignment, this lumbar disc degeneration could lead to resultant cervical disc degeneration.[15–17] In addition, we found that patients with type 4 curvatures exhibited higher PT and TPA. Our findings of Roussouly type 2 and type 4 patients' increased conversion to CD and risk of PJK, respectively, support prior studies identifying high PT and sagittal malalignment as significant risk factors for CD and proximal junctional pathology.[18,19]

Importantly, no significant differences in patient-reported outcomes (ODI, SF-36 Physical Component Summary, or SRS-22 scores) were observed among Roussouly types after CD conversion. While it has been established that patients with TL deformity have increased pain and disability preoperatively, little is known about the effect of Roussouly classification on postoperative changes. A study by Tu et al. found that disability and pain improved across Roussouly types 6 months after undergoing posterior lumbar interbody fusion, but it did not find significant differences between curvature types.[20] Similarly, a retrospective study by Hiyama et al. did not find significant differences in low back pain between Roussouly types.[21] However, a 2015 study found that cervical lordosis and cervical SVA were correlated with increased disability and worsened health status in patients with TL deformity.[22] Moreover, after undergoing TL-ASD correction, improvements in cervical malalignment were associated with improvements in HRQOL measures. While the lack of significant differences in HRQOL metrics after CD conversion in the present study underscores that radiographic deformities do not uniformly translate to diminished patient-reported outcomes, this divergence warrants further investigation into the influence of Roussouly type on improvements in HRQOL postoperatively.

Future research should explore targeted interventions for high-risk subgroups to mitigate the risk of CD conversion and PJK. Prospective studies incorporating advanced imaging modalities and biomechanical modeling could elucidate the mechanisms underlying these phenomena. Additionally, longitudinal investigations examining the relationship between radiographic alignment, compensatory changes, and long-term HRQOL outcomes are warranted. A more detailed analysis of the role of frailty and demographic factors, as identified through random forest analysis, may also enhance preoperative risk stratification.

This study is not without limitations. The inclusion of only patients with complete radiographic follow-up may exclude those with less favorable outcomes or higher rates of loss to follow-up. Additionally, while Roussouly classification provides a useful framework, it does not capture all nuances of sagittal alignment, potentially oversimplifying complex deformities. In fact, using the categorical Roussouly classification, while clinically intuitive, may reduce the granularity and statistical power compared with continuous variables such as L1 pelvic angle or T4 pelvic angle. Lastly, the reliance on standardized thresholds for MCID may not fully account for individual variability in patient-reported outcomes.

Conclusions

This study highlights the significant risk of postoperative CD in TL-ASD patients stratified by Roussouly curvature classification. In the present study, we found a 31.9% conversion rate, most commonly occurring in the first 6 weeks postoperatively. Roussouly types 2, 3, and 4 were especially prone to this early conversion. Type 4 patients had the highest rate of concurrent PJK. Although no significant differences between HRQOL measures were observed between Roussouly classification types postconversion, these findings emphasize the importance of early monitoring of TL-ASD patients after surgery. Future studies should explore targeted strategies for high-risk subgroups and investigate the biomechanical and longitudinal effects of sagittal alignment to improve surgical outcomes and mitigate complications like CD.

TABLE 5. TSCL severity based on Roussouly type in patients without baseline CD

Time Point	Severity	Roussouly Type				p Value
		1 (n = 27)	2 (n = 37)	3 (n = 141)	4 (n = 102)	
6 wks	20° ≥ TSCL ≥ 15°/TSCL > 20°	22.2%/22.2%	13.5%/37.8%	18.4%/29.8%	16.7%/34.3%	0.855
1 yr		14.8%/18.5%	18.9%/32.4%	19.9%/29.8%	11.8%/36.3%	0.411
2 yrs		25.9%/14.8%	24.3%/48.6%	18.4%/35.5%	19.6%/31.4%	0.098

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