Original Article

Examining autocorrection of concurrent cervical malalignment following thoracolumbar deformity surgery

ABSTRACT

Aims: The aim of the study was to assess preoperative radiographic parameters predictive of cervical deformity (CD) autocorrection in patients undergoing thoracolumbar deformity (ASD) surgery.

Study Design/Setting: This was a retrospective cohort study.

Methods: Inclusion criteria were operative ASD patients with complete baseline (BL) and 2-year radiographic data. Patients with cervical fusion during index surgery, revision involving cervical fusion, and those who developed proximal junctional kyphosis by 2-year postoperative were excluded from the study. If patients met CD criteria at BL but not at 6 weeks or 2 years postoperatively, they were considered autocorrected (AC).

Statistical Analysis Used: Descriptive and univariate analysis, binominal logistic regression, and multivariable backward stepwise regression.

Results: Two hundred and twenty ASD patients were included. 51.4% of patients had preoperative CD. By 6-week postoperative, 32.7% achieved AC. At 2 years, 24.8% of preoperative CD patients obtained AC. 2-year AC patients had lower BL sacral slope, lumbar lordosis (LL), T1 slope, cervical lordosis (CL), and C2-T3, and T2-T12 kyphosis (all $P < 0.05$). Patients with BL-unmatched Roussouly types are corrected postoperatively and are more likely to experience autocorrection at 1 year (45.2% vs. 19.0%; $P = 0.042$) and at 2 years (31% vs. 4.8%; $P = 0.018$). Multivariable analysis revealed that patients with BL-mismatched Roussouly types were corrected postoperatively and showed a significant increase in likelihood of AC at 1 year (odds ratio [OR]: 18.72; $P = 0.029$) and 2 years (OR: 8.5; $P = 0.047$). Similarly, BL LL (OR: 0.772; $P = 0.003$) and CL (OR: 0.829; $P = 0.005$) exhibited significant predictive value for autocorrection at 1 year and 2 years (OR: 0.927; $P = 0.004$ | OR: 0.942; $P = 0.039$; respectively).

Conclusions: Autocorrection is more likely in patients with postoperatively corrected Roussouly types, those with lower BL cervical, and LL. Given these findings, it may not be necessary to routinely extend reconstruction into the cervical spine for ASD patients with similar characteristics to those in this study.

Keywords: Adult spinal deformity, autocorrection, cervical deformity, surgical correction

INTRODUCTION

Approximately 53% of adults with thoracolumbar deformity also present with concurrent cervical deformity (CD), as reported in the literature.[1] This association may be attributed to reciprocal compensatory changes in the cervical spine that occur in response to thoracolumbar deformities, as well as postoperative alterations following the correction of thoracolumbar misalignment.[2-5] Despite this, there remains a significant gap in the literature regarding the phenomenon of CD autocorrection subsequent to adult thoracolumbar deformity corrective surgery.[2] This study aims to assess for

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perioperative parameters predictive of autocorrection of cervical malalignment in patients undergoing thoracolumbar deformity surgery.

METHODS

Data source and study design

This retrospective analysis utilized a prospectively collected, single-center database comprising adult spinal deformity (ASD) patients enrolled from 2012 to 2024. Institutional review board's approval was secured before enrollment, and all participants provided informed consent. Enrolled patients were adults over 18 years of age and scheduled for surgical correction of ASD, which was radiographically defined by one or more of the following criteria: a coronal Cobb angle of at least 20°, a sagittal vertical axis (SVA) of at least 50 mm, a pelvic tilt (PT) of at least 25°, or thoracic kyphosis exceeding 60°. The inclusion criteria for this study specified operative ASD patients who had complete radiographic data both preoperatively and at 2 years postoperatively. Patients who had undergone cervical fusion during the index surgery (upper instrumented vertebra above T1), those who required revision involving cervical spine fusion after the index surgery, and those who developed proximal junctional kyphosis, as defined by Lovecchio *et al*.,[6] within 2 years postoperatively, were excluded from the study.

Data collection and radiographic assessment

Standardized data collection forms were used to capture patient demographics, surgical parameters, and comorbidities at the initial presentation. Lateral spine radiographs were utilized to evaluate radiographic parameters at baseline (BL) and during follow-up periods. All images were analyzed using SpineView® (ENSAM, Laboratory of Biomechanics, Paris, France). The spinopelvic radiographic parameters assessed included PT, defined as the angle between the vertical and the line from the sacral midpoint to the center of the two femoral heads; the mismatch between pelvic incidence and lumbar lordosis (PI-LL); and the SVA, which measures the C7 plumb line in relation to the posterosuperior corner of S1.[7]

Measures of radiographic alignment

Thoracolumbar deformity severity was assessed using the SRS-Schwab ASD classification system, which involves three established modifiers of PT, PI-LL, and SVA, each stratified into three tiers of severity: 0 (nonpathologic), + (moderate deformity), and ++ (marked deformity).[8] Age-adjusted alignment targets for sagittal correction were assessed using previously published formulas established by Lafage *et al*.[9] Patients were grouped by SAAS score: matched (M) if between −1 and 1, under (U) if <−1, and overcorrected (O) if >1. The score was adjusted by one point for each 20-year deviation from the target. Drawing on the work of Pizones *et al*.,[10,11] we classified patients according to both "theoretical" and "current" Roussouly types. The "theoretical" classification utilizes PI to categorize patients into four types: Types 1 and 2 are characterized by a PI of <45°, Type 3 by a PI between 45° and 60°, and Type 4 by a PI >60°.[10] This scheme outlines the ideal sagittal profile for each type, including the ideal sacral slope (SS), lumbar apex, inflexion point, and the number of vertebrae in lordosis (NVL). Conversely, the "current" types were determined using criteria previously proposed, where Types 1 and 2 have an SS <35°, Type 3 has an SS between 35° and 45°, and Type 4 has an SS >45°.[12] Additional parameters such as the lumbar apex, inflexion point, NVL, and overall sagittal shape were also documented, aiding in distinguishing between Types 1 and 2, which share similar PI and SS values.[12,13] Patients were classified as "matched" if their postoperative "current" shape aligned with their "theoretical" type, and as "mismatched" otherwise.

Defining postoperative autocorrection of cervical malalignment

In our cohort of ASD patients, the concurrent CD was determined by meeting one or more of the following radiographic criteria: C2-C7 sagittal kyphosis >15°, T1 slope minus cervical lordosis (T1S-CL) >35°, C2–C7 SVA (cSVA) >40 mm, chin-brow vertical angle (CBVA) >25°, McGregor's slope >20°, or segmental cervical kyphosis >15° across any three adjacent vertebrae from C2 to T1. Patients were classified as autocorrected (AC) if they met these criteria preoperatively but not at 6 weeks or 2 years postoperatively. In addition, patients were considered improved if the total number of CD criteria they met decreased from BL to 6 weeks or 2 years postoperatively.

Statistical analysis

Frequency distributions and summary statistics were computed for all demographic, clinical, surgical, and radiographic variables. Univariate analyses compared AC and non-AC patients across these variables. Categorical variables were assessed using cross-tabulations with Pearson Chi-square tests, while independent sample *t*-tests evaluated differences in continuous variables. Binary logistic regressions were conducted to identify perioperative factors independently predicting autocorrection at 6 weeks, 1 year, and 2 years postoperatively. These predictors were then analyzed using multivariate regression, controlling simultaneously for BL age, Charlson comorbidity index (CCI), body mass index (BMI), osteoporosis, and age-adjusted SVA. All statistical analyses were performed using SPSS software (IBM Corp., IBM SPSS Statistics for Windows, Version 29.0, Armonk, NY, USA), and tests were two-tailed with a significance threshold set at $P < 0.05$.

RESULTS

Cohort overview

The mean age in this cohort was 58.0 ± 16.0 years, 77% were female, the mean BMI was 26.8 ± 5.7 kg/m², and the mean CCI was 1.7 ± 1.8 [Table 1]. Mean preoperative radiographic parameters were as follows: SS: 32.5° ±11.7°, PT: 22.0° ± 11.2°, PI-LL: 12.3° ±21.2°, SVA: 56.9 ± 70.3 mm, TS-CL: 19.8° ± 10.8°, cSVA: 30.3 ± 14.1 mm, CBVA: 7.8° ± 7.3°, C2-T3: 8.6° ± 17.5°, and C2-C7 lordosis 9.1° ±15.8° [Table 2].

Surgical descriptors

In terms of surgical characteristics, the mean levels fused was 9.9 ± 4.9, the mean LOS was 7.0 ± 3.9, the mean estimated blood loss was 1434.7 ± 1516.9 mL, and the mean operative time was 350.7 min. By surgical approach, 0.5% of patients (n = 1) underwent anterior only, 66.4% (n = 146) underwent posterior only, and 32.7% (n = 72) underwent combined approach. Overall, 132 patients (60%) underwent osteotomy as part of their index procedure [Table 1].

Occurrence and timing of autocorrection

Overall, 51.4% of patients (n = 113) had preoperative cervical malalignment. By 6-week postoperative, 49 patients (43.4%) with preoperative cervical malalignment showed improvement and 37 patients (32.7%) with preoperative cervical malalignment no longer met radiographic CD criteria (AC). At 2 years, 37.2% (n = 42) of patients with preoperative cervical malalignment show improvement, and 24.8% (n = 28) of preoperative CD patients were AC at 2 years. The remaining 71 patients (62.8%) with BL CD were not improved or AC at the 2-year time point.

Characterizing patients with autocorrection

2-year AC patients had lower BL SS (27.2° vs. 32.9°; P = 0.016), LL (33.3° vs. 44.2°; P = 0.018), T1S (8.9° vs. 19.0°; P = 0.013), CL (7.0° vs. 16.9°; P = 0.011), and C2-T3 (6.4° vs. 15.3°; P = 0.016), and less pronounced T2-T12 kyphosis (33.6° vs. 48.5°; P = 0.003) [Table 3]. Patients whose mismatched Roussouly types corrected from BL to 6 weeks postoperatively, are more likely to experience autocorrection at 1 year (45.2% vs. 19.0%; P = 0.042) and at 2 years (31% vs. 4.8%; P = 0.018). Patients without BL CD who are undercorrected SAAS at 6 weeks are postoperatively are more likely to develop new CD at 1 year (51.6% vs. 26.1%; P = 0.013) in comparison to SAAS – matched and SAAS – overcorrected but at 2 years (38.7% vs. 36.2%; P = 0.812).

Characterizing patients with new cervical deformity development

Among patients without BL cervical malalignment (48.6% of the cohort, n = 107), 36.4% (n = 39) developed CD within

Table 1: Demographic and surgical details of the cohort

	Mean±SD
Demographic (n=220)	
Age (year)	58.0±16.0
BMI (kg/m²)	26.8±5.7
CCI	1.7±1.8
Female (%)	77
Surgical details	
Operative time (min)	350.7±132.1
EBL (mL)	1434.7±1516.9
Length of stay (days)	7.0±3.9
Approach, n (%)	
Anterior	1 (0.5)
Posterior	146 (66.4)
Combined	72 (32.7)
Osteotomy, n (%)	132 (60.0)
Levels fused	9.9±4.9

SD - Standard deviation; EBL - Estimated blood loss; BMI - Body mass index; CCI - Charlson comorbidity index

Table 2: Baseline preoperative alignment of the cohort

n=220	Mean±SD
Cervical alignment	
T1 slope (°)	11.0±16.3
C2-C7 (°)	9.1±15.8
TS-CL (°)	19.8±10.8
cSVA (mm)	30.3±14.1
CBVA (°)	7.8±7.3
C2-T3 (°)	8.6±17.5
Thoracolumbar alignment	
SS (°)	32.5±11.7
PT (°)	22.0±11.2
PI-LL (°)	12.3±21.2
SVA (mm)	56.9±70.3

SVA - Sagittal vertical axis; PI-LL - Pelvic incidence and lumbar lordosis; PT - Pelvic tilt; CBVA - Chin-brow vertical angle; cSVA - C2-C7 sagittal vertical axis; TS-CL - T1 slope minus cervical lordosis; SS - Sacral slope; SD - Standard deviation

Table 3: Baseline radiographic parameter of 2-year autocorrected cohort

	2-year AC (n=28)	No 2-year AC (n=85)	P
T1 slope (°)	8.9±16.9	19.0±18.6	0.013$^{\alpha}$
C2-C7 (°)	7.0±15.5	16.9±18.2	0.011$^{\alpha}$
TS-CL (°)	20.4±10.1	19.8±13.2	0.803
cSVA (mm)	31.0±13.8	34.7±16.9	0.296
C2-T3 (°)	6.4±18.3	15.3±20.3	0.016$^{\alpha}$
SS (°)	27.2±10.7	32.9±10.6	0.016$^{\alpha}$
PT (°)	22.6±11.5	22.8±11.2	0.910
PI-LL (°)	16.4±24.1	11.5±20.7	0.299
SVA (mm)	63.7±67.2	72.2±63.5	0.296
LL (°)	33.3±20.8	44.2±20.6	0.018$^{\alpha}$
T2-T12 kyphosis (°)	33.6±21.3	48.5±22.5	0.003$^{\alpha}$

$^{\alpha}$ < 0.05 AC - Autocorrected; SVA - Sagittal vertical axis; PI-LL - Pelvic incidence and lumbar lordosis; PT - Pelvic tilt; cSVA - C2-C7 sagittal vertical axis; TS-CL - T1 slope minus cervical lordosis; SS - Sacral slope

2 years. Patients without BL CD who developed new CD postoperatively had a higher BL SVA (71.6 mm vs. 26.6 mm; $P = 0.007$) compared to those who did not develop new CD [Table 4]. No other significant differences were found in BL radiographic, demographic, or surgical details. Binomial logistic regression demonstrated that a higher BL SVA increases the risk of developing new CD (odds ratio [OR]: 1.009; confidence interval [CI] 95%: 1.003–1.015; $P = 0.005$). In multivariable backward stepwise logistic regression, controlling for age, gender, BL deformity severity, BMI, CCI, BL comorbidities, surgical details, and BL radiographic parameters, an increase in BL SVA significantly increased the risk of developing new CD (OR: 1.011; CI 95%: 1.001–1.021; $P = 0.041$).

Predictors of autocorrection

Binomial logistic regression demonstrated that patients in whom mismatched Roussouly types were corrected from BL to 6 weeks postoperatively had an increased likelihood of experiencing autocorrection at 1 year (OR: 3.5; CI 95%: 1.01–12.2; $P = 0.048$) and at 2 years (OR: 9.0; CI 95%: 1.1–74.1; $P = 0.042$). In multivariable backward stepwise logistic regression, controlling for age, gender, BL deformity severity, BMI, CCI, comorbidities, surgical details, and BL radiographic parameters, patients in whom mismatched Roussouly types were corrected from BL to 6 weeks postoperatively showed a significant increase in the likelihood of autocorrection at all stages: 1 year (OR: 18.72; CI 95%: 1.35–259.7; $P = 0.029$) and 2 years (OR: 8.5; CI 95%: 1.03–70.6; $P = 0.047$). In terms of radiographic parameters, multivariable backward stepwise regression revealed that BL LL (OR: 0.772; CI 95%: 0.653–0.914; $P = 0.003$), CL (OR: 0.829; CI 95%: 0.728–0.944; $P = 0.005$), and T2-T12 kyphosis (OR: 0.879; CI 95%: 0.783–0.985; $P = 0.027$) exhibited significant predictive value for autocorrection at 1 year. Similarly, BL LL (OR: 0.927; CI 95%: 0.880–0.977; $P = 0.004$) and CL (OR: 0.942; CI 95%: 0.891–0.997; $P = 0.039$) exhibited significant predictive value for autocorrection at 2 years. Conversely, SAAS – undercorrection did not exhibit significant predictive value for autocorrection at any stage: 1 year (OR: 1.692; CI 95%: 0.694–4.125; $P = 0.247$) and 2 years (OR: 1.0; CI 95%: 0.37–2.7; $P = 0.098$).

Table 4: Baseline radiographic outcome of new-onset cervical deformity cohort

	New-onset CD cohort (n=39)	No new-onset CD cohort (n=68)	P
T1 slope (°)	4.8±7.8	3.0±7.5	0.306
C2-C7 (°)	3.6±8.0	1.0±7.3	0.155
TS-CL (°)	18.7±8.9	20.1±7.7	0.464
cSVA (mm)	27.1±10.6	24.9±7.4	0.293
C2-T3 (°)	4.0±10.6	1.7±10.2	0.341
SS (°)	32.1±11.9	34.6±12.7	0.318
PT (°)	22.5±12.6	20.6±10.5	0.385
PI-LL (°)	15.8±22.0	9.4±19.9	0.126
SVA (mm)	71.6±89.5	26.6±57.9	0.007$^{\alpha}$
LL (°)	38.8±20.6	45.7±21.6	0.107
T2-T12 kyphosis (°)	35.1±18.2	32.5±14.1	0.412

$^{\alpha}$ < 0.05. SVA - Sagittal vertical axis; LL - Lumbar lordosis; PI-LL - Pelvic incidence and lumbar lordosis; PT - Pelvic tilt; cSVA - C2-C7 sagittal vertical axis; TS-CL - T1 slope minus cervical lordosis; SS - Sacral slope; CD - Cervical deformity

DISCUSSION

This study explored the incidence and characteristics of CD autocorrection following ASD surgery, with the goal of understanding how varying degrees of radiographic parameters and alignment schemes impact postoperative outcomes. Our objective was to delineate the relationship between preoperative radiographic parameters, alignment schemas, and the autocorrection of CD, to refine surgical strategies. We discovered that a patient with corrected Roussouly type at 6 weeks postoperatively significantly increases the likelihood of achieving CD autocorrection at 1 and 2 years. Furthermore, BL LL and CL also show significant predictive value for autocorrection at these intervals. These findings underscore the critical importance of alignment schemes in enhancing the likelihood of CD autocorrection.

In our study, nearly 43.4% of patients with preoperative cervical malalignment showed improvement by 6 weeks postoperatively, and 32.7% no longer met the criteria for CD. The cervical deformities identified in this study likely represent a combination of primary cervical pathology and compensatory measures of the cervical spine in response to the TL deformity, which indicates a significant potential for spontaneous correction of cervical alignment without direct surgical intervention in the cervical region. Supporting literature suggests that spinal regions are interlinked, where malalignment in one can lead to compensatory changes elsewhere in the spine or lower extremities.[3-5] Smith *et al*. studied 75 ASD patients who underwent lumbar pedicle subtraction osteotomy and found that surgical correction of sagittal malalignment often leads to improvements in CD through reciprocal changes.[14] The findings suggest that the cervical spine possesses a significant capacity for spontaneous realignment when the underlying thoracolumbar deformity is effectively corrected. This could potentially decrease the need for additional cervical surgeries, which are associated with their own risks and complications.[15] Moreover, a recent cost–utility analysis revealed that the average cost per CD surgery exceeds $55,000.[16] This information is vital for surgeons in preoperative planning and risk assessment, particularly when managing co-occurring CD and ASD, as it could lead to substantial cost reductions for patients.

Interestingly, patients in whom Roussouly types were corrected from BL to 6 weeks postoperatively exhibited significantly higher rates of cervical autocorrection at both 1 and 2 years postoperatively. Roussouly *et al*.[17] proposed that normative sagittal plane alignment parameters for the axial and subaxial cervical spine and cervicothoracic junction are determined based on variations in thoracolumbar sagittal alignment. Supporting studies have shown that cervical alignment correlates with global spine and pelvic curves.[18,19] This insight is crucial for preoperative planning, highlighting the potential importance of achieving an optimal sagittal profile according to Roussouly's classification to facilitate favorable cervical spine outcomes. Moreover, surgical ASD patients matching their Roussouly sagittal spinal type reported superior patient-reported outcomes.[20] This offers additional advantages for patients with concomitant thoracolumbar and cervical/cervicothoracic deformities, where preoperative and persistent postoperative cervical deformities have been shown to jeopardize clinical outcomes after thoracolumbar deformity correction.[21-23] Overall, while the findings from this study are not sufficient on their own to make formal surgical recommendations for patients with concurrent CD and ASD, they should be further investigated and integrated into a broader understanding of regional alignment at the cervicothoracic junction as well as global spinal alignment.

In our investigation, approximately one-third of patients without BL cervical malalignment developed new-onset CD within 2 years following thoracolumbar deformity surgery, aligning with the current literature. In a multicenter study, Passias *et al*. evaluated new-onset CD after surgical correction of ASD, reporting a rate of 47.7%.[24] This rate is comparable to another multicenter study that examined the onset of CD in nonoperative ASD patients, which found a rate of 41.7%.[25] These findings suggest that the natural history of CD development in ASD patients is not significantly altered by surgical intervention. The observed increase in new-onset CD prevalence at 2 years may reflect the phenomenon that the progression of CD can develop independently in postoperative ASD patients and is not necessarily attributable to surgical overcorrection or postoperative disease progression.[14] Furthermore, a multicenter study found that patients with thoracolumbar deformity and no preoperative CD are likely to experience greater improvements in health-related quality of life (HRQOL) after surgery compared to those with concomitant preoperative CD.[22] Cervical-positive sagittal alignment in adult patients with thoracolumbar deformity is strongly associated with poorer outcomes and failure to achieve the minimal clinically important difference at the 2-year follow-up, despite having similar BL HRQOL to patients without CD.[22] Therefore, although more than one-third of patients developed new-onset CD, surgeons should not hesitate to proceed with surgical planning. However, it is important for surgeons to educate and consult with patients regarding the potential risks and future development of CD.

Limitation

One notable limitation of this study is its retrospective design, which inherently carries the risk of selection bias and limits the ability to establish causality. The inclusion criteria, while comprehensive, may not account for all confounding variables that could influence the autocorrection of CD following thoracolumbar deformity surgery. In addition, the study's reliance on radiographic parameters to define and measure CD and its autocorrection might not fully capture the clinical significance and patient-reported outcomes associated with these changes. Future studies should aim to incorporate clinical outcome measures and patient-reported outcomes to provide a more comprehensive view of the impact of these radiographic changes. Moreover, a prospective study design would help confirm these findings and potentially allow for the development of a predictive model of cervical autocorrection, which could be immensely valuable in preoperative planning and patient counseling. In conclusion, this study provides valuable insights into the autocorrection of CD following thoracolumbar deformity correction, emphasizing the potential for conservative management strategies in certain patient subsets. It also underscores the need for a tailored approach to surgical planning, one that carefully considers the preoperative sagittal alignment to maximize the likelihood of favorable postoperative outcomes in the cervical spine.

CONCLUSIONS

Nearly one-third of patients undergoing thoracolumbar deformity surgery, who had preoperative cervical malalignment, no longer met the criteria for CD by 6 weeks postoperatively. This indicates a significant potential for spontaneous cervical alignment correction without direct surgical intervention in the cervical region. Autocorrection of CD is more likely in patients in whom Roussouly types were corrected postoperatively and in those with lower BL cervical and LL. These findings suggest that extending reconstructive procedures into the cervical spine may not be necessary for ASD patients with similar characteristics to those in this study.

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Conflicts of interest

There are no conflicts of interest.

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