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DEFORMITY

At What Point Should the Thoracolumbar Region Be Addressed in Patients Undergoing Corrective Cervical Deformity Surgery?

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Study Design. Retrospective cohort study.

Objective. The aim of this study was to investigate the impact of cervical to thoracolumbar ratios on poor outcomes in cervical deformity (CD) corrective surgery.

Summary of Background Data. Consideration of distal regional and global alignment is a critical determinant of outcomes in CD surgery. For operative CD patients, it is unknown whether certain thoracolumbar parameters play a significant role in poor outcomes and whether addressing such parameters is warranted.

Methods. Included: surgical CD patients (C2-C7 Cobb >10°, cervical lordosis [CL] >10°, C2-C7 sagittal vertical axis (cSVA) >4 cm, or chin-brow vertical angle >25°) with baseline and 1-year data. Patients were assessed for ratios of preop cervical and global parameters including: C2 Slope/T1 slope, T1 slope minus C2-C7 lordosis (TS-CL)/mismatch between pelvic incidence and lumbar lordosis (PI-LL), cSVA/sagittal vertical axis (SVA). Deformity classification ratios of cervical (Ames-ISSG) to spinopelvic (SRS-Schwab) were investigated: cSVA modifier/SVA modifier, TS-CL modifier/PI-LL modifier. Cervical to thoracic ratios included C2-C7 lordosis/T4-T12 kyphosis. Correlations assessed the relationship between ratios and poor outcomes (major complication, reoperation, distal junctional kyphosis (DJK), or failure to meet minimal clinically important difference [MCID]). Decision tree analysis through multiple iterations of multivariate regressions assessed cut-offs for ratios for acquiring suboptimal outcomes.

Results. A total of 110 CD patients were included (61.5 years, 66% F, 28.8 kg/m^2). Mean preoperative radiographic ratios calculated: C2 slope/T1 slope of 1.56, TS-CL/PI-LL of 11.1, cSVA/SVA of 5.4, CL/thoracic kyphosis (TK) of 0.26. Ames-ISSG and SRS-Schwab modifier ratios: cSVA/SVA of 0.1 and TS-CL/PI-LL of 0.35. Pearson correlations demonstrated a relationship between major complications and baseline TS-CL/PI-LL, Ames TS-CL/Schwab PI-LL modifiers, and the CL/TK ratios ($P < 0.050$). Reoperation had significant correlation with TS-CL/PI-LL and cSVA/SVA ratios. Postoperative DJK correlated with C2 slope/T1 slope and CL/TK ratios. Not meeting MCID for Neck Disability Index (NDI) correlated with CL/TK ratio and not meeting MCID for EQ5D correlated with Ames TS-CL/Schwab PI-LL.

Conclusion. Consideration of cervical to global alignment is a critical determinant of outcomes in CD corrective surgery. Key ratios of cervical to global alignment correlate with suboptimal clinical outcomes. A larger cervical lordosis to TK predicted postoperative complication, DJK, and not meeting MCID for NDI.

Key words: Ames-ISSG criteria, cervical deformity (CD), clinical outcomes, distal junctional kyphosis (DJK), global

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alignment, minimal clinically important difference (MCID), postoperative complications, radiographic parameters, SRS-Schwab modifiers, surgical correction.
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Cervical deformity (CD) often results in deterioration of horizontal gaze and neurologic compromise, and has been increasingly studied in the literature.[1] Studies explore the effect of CD on cervical radiographic alignment and health-related quality of life (HRQL) measures.[2,3] Cervical malalignment in CD patients has been explored in terms of creating a standard classification system, coinciding with outcomes. Radiographic parameters often surveyed include the T1 slope minus C2-C7 lordosis (TS-CL), C2-C7 sagittal vertical axis (cSVA), and McGregor slope (MGS).[4] The disease process has even been explored based upon neutral and dynamic alignment, where Kim and the International Spine Study Group identified three patterns of CD, flat neck, focal deformity, and cervicothoracic deformity.[5] But, as the spine stands as a chain of correlation, there is a paucity in the literature connecting the thoracolumbar spine to a patient's initial deformity of the cervical spine.

Reciprocal changes in the cervical region have been extensively investigated in patients with primary thoracolumbar deformity (ASD), as well as postoperative adjustments in cervical alignment following ASD surgery. Specifically, up to 53% of thoracolumbar deformity patients have been identified to have concomitant CD at baseline.[6] Cervical changes were also noted to occur from 6 weeks up to 2 years postoperative ASD corrective procedures.[7] This compensatory reciprocal cervical hyperlordosis to maintain horizontal gaze is notable for patients with thoracolumbar deformities. It is necessary to understand the reverse, to consider the distal regional and global alignment for patients who undergo CD surgery.

With recognition of the complex global interactions among these sagittal curves, the pelvis, and compensatory mechanisms that attempt to maintain global sagittal spinopelvic alignment, it is still unknown whether certain thoracolumbar parameters play a large role in the poor outcomes of surgical CD patients. This includes postoperative complications, distal junctional kyphosis (DJK), and reoperations. This study sought to determine the impact of cervical to thoracolumbar ratios on poor postoperative outcomes, to determine whether surgeons should consider thoracolumbar parameters preoperatively.

MATERIALS AND METHODS

Study Design and Data Source

The present study was a retrospective cohort study of a prospectively collected, consecutively enrolled, multicenter CD database, collected by the International Spine Study Group (ISSG) from 2013 to 2018. Thirteen centers participated in patient enrollment across the United States. Institutional Review Board was obtained before patient enrollment. Within the dataset, CD radiographic criteria was defined as baseline cervical kyphosis (C2-C7 sagittal Cobb angle >10°), cervical scoliosis (C2-C7 coronal Cobb angle >10°), C2-C7 sagittal vertical axis (cSVA) >4 cm, or chin-brow vertical angle >25°. Operative CD patients with radiographic and HRQL data available at both baseline and 1-year follow-up were included.

Data Collection

Patient demographic and clinical data collected for this study were age, sex, body mass index (BMI), comorbidity status, comorbidity severity (Charlson Comorbidity Index). Surgical data included surgical approach, operative time (Op time), estimated blood loss, and length of stay, construct length (levels fused), and technique (eg, osteotomy, decompression).

Full-length free-standing lateral spine radiographs (36" cassette) were used to assess patients at baseline, 3-month, 6-month, 1-year, 2-year follow-up intervals. Radiographs were analyzed using SpineView (ENSAM, Laboratory of Biomechanics, Paris, France) software according to validated and standardized techniques previously described in the literature.[8–10] Long-cassette radiographic analysis included the following parameters: sagittal vertical axis (SVA; horizontal distance from C7 plumbline relative to the posterosuperior corner of S1), pelvic tilt (PT), pelvic incidence (PI), T4-T12 thoracic kyphosis (TK), L1-L4 lumbar lordosis (LL), C2-C7 cervical lordosis (CL), cSVA, and T1 slope.[11] Cervical radiographs allowed for assessment of C0-C2 sagittal Cobb angle (C0-C2), C2 slope, and MGS.[12] Mismatches between T1 slope and CL (TS-CL), and PI and LL (PI-LL) were also calculated.

HRQL data were collected and analyzed. This included the Neck Disability Index (NDI) and the Euro-QOL 5 Dimension (EQ5D) questionnaire.

Ratios

Ratios of preoperative cervical and global parameters were calculated, including C2 Slope/T1 slope, TS-CL/PI-LL, and cSVA/SVA. Additionally, deformity classification ratios were calculated. This included cervical classification modifiers (Ames-ISSG) over spinopelvic classification modifiers (SRS-Schwab), involving cSVA modifier/SVA modifier and TS-CL modifier/PI-LL modifier. Lastly, cervical to thoracic ratios calculated included the C2-C7 lordosis/T4-T12 kyphosis.

Poor Outcome

A poor outcome was defined as occurrence of a major postoperative complication, reoperation, decline in HRQLs or failure to meet the minimal clinically important difference (MCID) for NDI or EQ5D. Complications across all institutions are reported to a central committee that evaluates severity to determine major vs. minor status. Complications

TABLE 1. Rates of Poor Outcomes in a Population of 110 Cervical Deformity Patients

Outcome	Percent Occurrence	No. of Patients (n)
Major complication	19.1%	21
Reoperations	15.5%	17
Distal junctional kyphosis	31.8%	35
Not meeting MCID EQ5D	79.1%	87
Not meeting MCID NDI	31.8%	35

EQ5D indicates Euro-QOL 5 Dimension; MCID, minimal clinically important difference; NDI, Neck Disability Index.

are considered ''major'' when they significantly alter treatment course, that is, necessitating additional medical or surgical treatment, reoperation, prolonged hospital stay, or readmission. Complications are also classified by system such as cardiac, pulmonary, infection, renal, gastrointestinal, radiographic, and mechanical, among others.

Statistical Analysis

All statistical tests were performed using SPSS software (v23.0, Armonk, NY). Descriptive analyses assessed means and frequencies of demographic variables, clinical characteristics, surgical variables, and radiographic alignment. Correlations assessed the relationship between each of the ratios and occurrence of a poor outcome. Conditional inference tree analysis through multiple iterations of multivariate regressions assessed cut-offs for ratios for acquiring suboptimal outcomes. The level of significance for all tests was set to $P < 0.05$.

RESULTS

Cohort and Surgical Overview

Overall, 110 patients were included in our analysis. The mean age was 61.5 years' old with 66% of the patients as female. The average BMI was 28.8 kg/m^2. By surgical approach, 18.2% underwent anterior-only procedures, 46.4% posterior-only, and 35.4% combined approaches. The mean levels fused were 7.7.

Mean Radiographic Ratios

The average preoperative radiographic ratios assessed included a C2 slope/T1 slope of 1.56, TS-CL/PI-LL of 11.1, cSVA/SVA of 5.4, and a CL/TK of 0.26. The Ames-ISSG and SRS-Schwab modifier ratios had averages of cSVA/SVA 0.1 and TS-CL/PI-LL of 0.35.

Radiographic Ratio Correlations With Poor Outcomes

Rates of poor outcomes (major complication, reoperation, DJK, and not meeting MCID) are reported in Table 1. A total of 110 patients met criteria for one of the poor outcomes. Poor outcome due to failure to reach either NDI or EQ5D MCID alone was 50 of the patients (45.5%). Poor outcome due to failure to reach MCID and experienced a major complication accounted for 52 of the patients (47.3%). Poor outcome due to major complication alone = 4 patients (3.6%). Pearson correlations demonstrated a relationship between major complications and the baseline TS-CL/PI-LL, Ames TS-CL/Schwab PI-LL modifiers, and the CL/TK ratios. Reoperation had a significant correlation with the TS-CL/PI-LL and the cSVA/SVA ratios. Postoperative DJK had a correlation with the C2 slope/T1 slope and CL/TK ratios. Not meeting MCID for NDI correlated with the CL/TK ratio and not meeting MCID for EQ5D correlated with the Ames TS-CL/Schwab PI-LL. (Pearson correlations are listed in Table 2)

Ratio Cut-offs for Significant Radiographic Ratios

For the radiographic ratios predicting each individual poor outcome, specific cut-offs were determined. For those that predicted a major complication, a TS-CL/PI-LL >12.72 ($P = 0.034$), Ames TS-CL/Schwab PI-LL >0.482 ($P = 0.019$), and CL/TK >0.814 ($P = 0.050$) were most significant. A reoperation was most significantly predicted

TABLE 2. Pearson Correlations Between Radiographic Ratios and Poor Outcomes

	C2 Slope/T1 Slope	TS-CL/ PI-LL	cSVA/ SVA	C2-C7 Lordosis/ T4-T12 Kyphosis	cSVA Modifier/ SVA Modifier	TS-CL Modifier/ PI-LL Modifier
Major complication	0.162	0.216*	0.235*	0.191	−0.012	0.011
Reoperations	−0.017	0.263*	0.255*	−0.009	−0.158	−0.194
DJK	0.241*	0.143	0.134	0.220*	−0.016	−0.031
Not meeting MCID EQ5D	−0.078	−0.077	−0.046	−0.02	0.095	−0.497*
Not meeting MCID NDI	−0.035	−0.087	−0.071	0.256*	−0.016	−0.086

CL indicates cervical lordosis; cSVA, C2-C7 sagittal vertical axis; DJK, distal junctional kyphosis; EQ5D, Euro-QOL 5 Dimension; MCID, minimal clinically important difference; NDI, Neck Disability Index; TS-CL, T1 slope minus C2-C7 lordosis; PI-LL, mismatch between pelvic incidence and lumbar lordosis; SVA, sagittal vertical axis; TK, thoracic kyphosis.

**Indicates statistical significance, $P < 0.050$.*

TABLE 3. Cut-offs of Cervical to Thoracolumbar Ratios Predicting a Poor Outcome

	Cut-off	*P*
Major complication		
TS-CL/PI-LL	>12.72	0.034
Ames TS-CL/Schwab PI-LL	>0.482	0.019
CL/TK	>0.814	0.050
Reoperation		
TS-CL/PI-LL	>5.819	0.009
cSVA/SVA	>3.79	0.002
Distal junctional kyphosis		
C2 slope/T1 slope	>1.59	0.017
CL/TK	>0.692	0.029
Not meeting MCID for NDI		
CL/TK	>1.402	0.016
Not meeting MCID for EQ5D		
Ames TS-CL/Schwab PI-LL	>0.564	0.010

CL indicates cervical lordosis; cSVA, C2-C7 sagittal vertical axis; EQ5D, Euro-QOL 5 Dimension; MCID, minimal clinically important difference; NDI, Neck Disability Index; TS-CL, T1 slope minus C2-C7 lordosis; PI-LL, mismatch between pelvic incidence and lumbar lordosis; SVA, sagittal vertical axis; TK, thoracic kyphosis.

through a TS-CL/PI-LL ratio of >5.819 ($P = 0.009$) and a cSVA/SVA >3.79 ($P = 0.002$). Occurrence of postoperative DJK was most predicted by a C2 Slope/T1 Slope >1.59 ($P = 0.017$) and a CL/TK >0.692 ($P = 0.029$). A CL/TK ratio of >1.401 ($P = 0.016$) predicted not meeting MCID for NDI, whereas an Ames TS-CL/Schwab PI-LL >0.564 ($P = 0.010$) predicted not meeting MCID for EQ5D (Table 3).

DISCUSSION

The spine is a chain of correlation, where one region significantly determines the fate of another. When a patient is affected by CD, physicians and researchers alike must investigate the impact this has on sagittal radiographic alignment globally. The sagittal balance of the physiologic upright spine maintains alignment with a minimum of energy expenditure.[13–15] The cervical region is influenced by the thoracolumbar spine to maintain physiologic balance as represented in the relationship between sacral slope and lumbar lordosis or lumbar lordosis and thoracic kyphosis.[16–18]

The present study determined that specific thresholds of ratios of cervical to thoracic alignment determine the predictability for a poor postoperative outcome, including major medical complications, reoperations, DJK, and HRQL metrics. We determined that having a larger cervical parameter over its thoracolumbar counterpart significantly predicts a poor postoperative outcome.

Cervical sagittal alignment is becoming an increasingly apparent determinant of health related quality of life measures.[1,19,20] This has been explored through the NDI, and more general questionnaires, such as the 36-item short form health survey. But, without considering the spine as a whole, and the reciprocal changes that occur throughout from disease or postoperatively, we cannot understand the influence of the collective spine regions on outcomes. An underlying thoracolumbar sagittal malalignment has been found to cause positive cervical sagittal balance, and many times correction of the thoracolumbar spine can reverse the effects seen in the cervical spine.[1,21]

There is an inherent relationship between TS and CL in patients who have CD, and PI and LL in thoracolumbar patients. Protopsaltis *et al* even termed TS-CL to be the "Cervical Answer" to PI-LL, and an important determinant of finding concomitant cervical and thoracolumbar deformity.[22] Additionally, there has been established a significant positive correlation between C2-C7 SVA and C7-S1 SVA, connecting the global alignment of the spine to malalignment rooted in the cervical region.[23,24] That being said, these essential relationships, that of TS-CL to PI-LL and cSVA to SVA, speak to our results on their key effect on major postoperative complications and reoperations.

Occurrence of DJK was found to be influenced greatly by the radiographic ratios of C2 slope to T1 slope and CL to TK. The C2 slope is a mathematical approximation of TS-CL and has been found to correlate strongly with previously described measures of CD and a strong influencer of outcomes.[25] Likewise, the T1 slope has been determined to be a direct impact upon cervical malalignment, and correction of this, in conjunction with cervical lordosis is key to realignment of the cervical spine.[22,26] Lee *et al* found that T1 slope was key to determining cervical sagittal balance.[16] Likewise, the connection between thoracic kyphosis and cervical lordosis was explored in this study, and similarly, directly influences each other.[27]

Lastly, HRQL outcomes were directly influenced by the Ames-ISSG to SRS-Schwab radiographic modifiers, and the general, CL to TK. The classification system of severity modifiers for thoracolumbar deformity created by Schwab has been directly linked to patient-reported outcomes.[28] This relationship witnessed in our present study may be a reflection of the previous, as the Ames-ISSG CD deformity severity system does not have a strong link to HRQLs.[1,29] Meanwhile, the normative curvature of the spine, CL, and TK can strongly impact patient functionality and pain.[30] Interestingly, we determined that almost 80% did not reach MCID for EQ5D; however, this was not seen in the NDI metric (31.8%). This could be due to the fact that EQ5D is a general measure of health status used among many surgical specialties, whereas NDI may have more sensitivity to a CD-specific population.

We appreciate several limitations to our study. First, the retrospective nature of this study might limit the findings and predispose to several types of bias, including selection, classification, and surveillance bias. The relatively small sample size also represents a limitation to the generalizability of results and to the statistical power of our study. However, this database remains the largest comprehensive CD database to date and represents a heterogeneous population due to enrollment from multiple centers across the

continental United States. There is variability in the baseline inclusion of CD, but all patients are operative and underwent specific correction of their CD. A further limitation that lies in the database, and with this present study, is that it is uncertain whether our conclusions can be externally validated and generalized to a broader CD patient population; due to the multiple comparisons presented here, the small sample size, and the limited statistical power there is a risk of overfitting.

CONCLUSION

Consideration of cervical to global alignment is a critical determinant of outcomes in CD corrective surgery. Key ratios of cervical to global alignment correlate with suboptimal clinical outcomes. A larger CL to TK predicted postoperative complication, DJK, and not meeting MCID for NDI.

➢ Key Points

- ❑ Consideration of distal regional and global alignment is a critical determinant of outcomes in CD surgery.
- ❑ For operative CD patients, it is unknown whether certain thoracolumbar parameters play a significant role in poor outcomes and whether addressing such parameters is warranted.
- ❑ This study demonstrated that key ratios of cervical to global alignment correlate with suboptimal clinical outcomes.
- ❑ A larger CL to TK predicted postoperative complication, DJK, and not meeting MCID for NDI.

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