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Clinical Study

Magnitude of preoperative cervical lordotic compensation and C2–T3 angle are correlated to increased risk of postoperative sagittal spinal pelvic malalignment in adult thoracolumbar deformity patients at 2-year follow-up

Peter G. Passias, MD[a,*], Alexandra Soroceanu, MD[b], Justin Scheer, BS[c], Sun Yang, BA[a], Anthony Boniello, BS[a], Justin S. Smith, MD[d], Themistocles Protopsaltis, MD[a], Han J. Kim, MD[e], Frank Schwab, MD[a], Munish Gupta, MD[f], Eric Klineberg, MD[f], Gregory Mundis, MD[g], Renaud Lafage, MS[a], Robert Hart, MD[h], Christopher Shaffrey[c], Virginie Lafage, PhD[a], Christopher Ames, MD[i], and International Spine Study Group (ISSG)[j]

[a]*Department of Orthopaedic Surgery, New York University Hospital for Joint Diseases, 301 E 17th St #1402, New York, NY 10003, USA*

[b]*Department of Orthopaedic Surgery, University of Calgary, 3330 Hospital Dr NW, Calgary, AB T2N 4N1, Canada*

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* Corresponding author. NY Spine Institute/NYU Medical Center - Hospital for Joint Diseases, Department of Orthopaedic Surgery, 301 East 17th St, New York, NY, 10003, USA. Tel.: (516) 357-8777; fax: (516) 357-0087.

E-mail address: Peter.Passias@nyumc.org (P.G. Passias)

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[c]Department of Neurological Surgery, Northwestern University, Feinberg School of Medicine, 303 E Chicago Ave., Chicago, IL 60611, USA
[d]Department of Neurosurgery, University of Virginia Medical Center, 1215 Lee St, Charlottesville, VA 22903, USA
[e]Department of Orthopaedic Surgery, Hospital for Special Surgery, 535 E 70th St, New York, NY 10021, USA
[f]Department of Orthopaedic Surgery, University of California—Davis, 4860 Y St, Sacramento, CA 95817, USA
[g]San Diego Center for Spinal Disorders, 4130 La Jolla Village Dr, La Jolla, CA 92037, USA
[h]Department of Orthopaedic Surgery, Oregon Health and Science University, 3181 S.W. Sam Jackson Park Rd, Portland, OR 97239, USA
[i]Department of Neurosurgery, University of California—San Francisco, 505 Parnassus Ave., San Francisco, CA 94143, USA
[j]International Spine Study Group Foundation, 4 W. Dry Creek Cir., Littleton, CO 80120, USA

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Abstract

BACKGROUND CONTEXT: Cervical deformity (CD) is prevalent among patients with adult spinal deformity (ASD). The effect of baseline cervical alignment on achieving optimal thoracolumbar alignment in ASD surgery is unclear.

PURPOSE: This study assesses the relationship between preoperative (preop) cervical spinal parameters and global alignment after thoracolumbar ASD surgery at 2-year follow-up.

STUDY DESIGN/SETTING: This study is a retrospective review of a multicenter, prospective database.

PATIENT SAMPLE: Surgical ASD patients with 2-year follow-up and cervical X-rays were included.

OUTCOME MEASURES: The outcome measures were radiographic parameters and self-reported health-related quality-of-life measures (Short-Form 36 [SF-36], Oswestry Disability Index [ODI], and Scoliosis Research Society 22 [SRS-22]).

METHODS: Surgical ASD patients of 18 years and older with scoliosis greater than or equal to 20° and one of the following radiographic parameters were included: sagittal vertical axis (SVA) greater than or equal to 5 cm, pelvic tilt (PT) greater than or equal to 25°, or thoracic kyphosis (TK) greater than 60°. The SRS-Schwab sagittal modifiers (PT, global alignment, and pelvic incidence and lumbar lordosis [PI-LL]) were assessed at 2-year postoperatively as either normal (“0”) or abnormal (“+” or “++”). Patients were classified in the aligned group (AG) or malaligned group (MG) at 2-year follow-up if all three sagittal modifiers were normal or abnormal, respectively. Patients were assessed for CD based on the following criteria: C2–C7 SVA greater than 4 cm, C2–C7 SVA less than 4 cm, cervical kyphosis (CL greater than 0), cervical lordosis (CL less than 0), any deformity (C2–C7 SVA greater than 4 cm or CL greater than 0), and both CD (C2–C7 SVA greater than 4 cm and CL greater than 0). Univariate testing was performed using *t* or chi-square test, looking at the following preop parameters: CD, C2–C7 SVA, C2–T3 SVA, CL, T1 slope (T1S), T1S-CL, C2–T3 angle, LL, TK, PT, C7–S1 SVA, and PI-LL.

RESULTS: One hundred four patients met the initial inclusion criteria with 70 in the AG and 34 in MG. Preoperative, patients in the MG had a higher CL (11.7 vs. 4.9, p=.03), higher C2–T3 angle (13.59 vs 4.9 p=.01), higher PT (p<.0001), higher SVA (p<.0001), and higher PI-LL (p<.0001) compared with the AG. Interestingly, the prevalence of CD at baseline was similar for both groups. There was no statistically significant difference among groups in the amount of improvement more than 2 years on the ODI or the Physical Component Summary of SF-36.

CONCLUSIONS: Patients with sagittal spinal malalignment associated with significant cervical compensatory lordosis are at increased risk of realignment failure at 2-year follow-up. Assessment of the degree of cervical compensation may be helpful in preop evaluation to assist in realignment outcome prediction.

Keywords: Adult spinal deformity; Cervical deformity; Outcome; Radiographic parameter; HRQOL; Alignment

Introduction

Adult spinal deformities (ASDs) most commonly occur in the thoracolumbar spine. As such, previous investigations have focused on this region and placed less emphasis on alignment changes that occur at the cervicothoracic junction and above. More recently, however, several series have shown a high prevalence of cervical deformity (CD) among patients being treated primarily for adult thoracolumbar spinal deformity, which has been attributed to the interconnected relationship between the various portions of the mobile spine and their collective contribution to global sagittal alignment [1,2].

Previous authors have documented that the cervical spine has the capacity to compensate for changes in thoracolumbar alignment because of its flexibility [3–6]. These observed cervical alignment adjustments were found to be dependent on the preoperative (preop) sagittal alignment characteristics of the thoracolumbar spine, but after surgery

EVIDENCE & METHODS

Context

The authors sought to evaluate the relationship between preoperative cervical spinal parameters and global alignment following thoracolumbar adult spinal deformity surgery.

Contribution

This study included a total of 104 patients, with only 34 in the malaligned group. A large number of patients (n=80) were excluded, ie, those not described as frankly aligned or malaligned. The authors conclude that patients with sagittal spinal malalignment associated with significant cervical compensatory lordosis are at increased risk of realignment failure.

Implications

As a retrospective review, this study can only deal with the clinical experiences of the patients treated at the authors' center. The results also hinge on a relatively small sample of patients (n=34) who were considered malaligned. The outcomes for these patients were compared against the ''best-case scenario'' patients who were considered ''aligned.'' The reader should recognize, however, that a plurality of patients (n=80) who existed between the aligned and malaligned groups were actually excluded from this analysis. This fact may limit the generalizability of this study's findings and restricts information to the ''best'' and ''worst'' exemplars of surgical outcome. This could be considered a form of selection, or possibly information, bias and should be acknowledged by readers before they seek to apply the findings of this work to their clinical practice.

—*The Editors*

with instrumentation, this inverse correlation between cervical and thoracic kyphoses was not appreciated presumably because of increased rigidity [1]. The presence of preop CD has also been shown to adversely affect clinical outcomes after surgical correction of adult thoracolumbar spinal deformities at early follow-up [1]. No study to date has clearly assessed the impact on clinical outcomes of CD after thoracolumbar deformity surgery. The reason for this negative clinical impact remains uncertain, as does its persistence with longer follow-up. Specifically, it is unclear whether the baseline cervical alignment plays a role in achieving optimal thoracolumbar alignment after surgical treatment and what the associated clinical impact is at 2 years.

As sagittal malalignment is a major source of pain and disability postoperatively; it is important to investigate this problem with respect to the prevention of secondary cervical spine disorders, particularly because the severity of symptoms has been shown to increase in a linear fashion with progressive sagittal malalignment [6]. Therefore, if certain radiographic parameters of the cervical spine were identified as risk factors for sagittal malalignment after thoracolumbar surgery, surgeons could potentially accommodate for this in surgical planning.

The present study attempts to assess the relationship between preop cervical spinal parameters and postoperative (postop) global alignment. Characteristics of global alignment were assessed using the Scoliosis Research Society (SRS)-Schwab Classification, which correlates radiographic parameters with pain and disability in ASD [7] and has been shown to have the capability to reliably predict patient disability and patient preference for operative versus nonoperative treatment [7]. Therefore, this study used the SRS-Schwab Classification to sort patients into a malaligned group (MG) or aligned group (AG) and to determine risk factors for postop sagittal spinal pelvic malalignment after thoracolumbar ASD surgery at 2-year follow-up.

Materials and methods

Study design and inclusion criteria

This is a multicenter, retrospective review of prospectively acquired data for consecutive patients who underwent surgical correction for sagittal ASD at 11 sites from 2008 to 2011. All participating sites are a part of the International Spine Study Group. Before study initiation, institutional review board approval was obtained. Inclusion criteria were patients of 18 years and older with scoliosis greater than or equal to 20°, sagittal vertical axis (SVA) greater than or equal to 5 cm, pelvic tilt (PT) greater than or equal to 25°, or TK more than 60° who received surgical treatment for a documented spinal deformity. Included subjects also had complete demographic, radiographic, health-related quality-of-life (HRQOL) surveys at baseline and 2-year follow-up, and operative data. Exclusion criteria were patients with a lack of visibility of the cervical spine on their X-rays.

Full-length, freestanding lateral spine radiographs (36″ cassette) at baseline and 6-week, 3-month, 1-year, and 2-year follow-ups were analyzed using a validated software [8,9] (Spineview; ENSAM, Laboratory of Biomechanics, Paris, France). All radiographic measures were performed at a central location based on the standard techniques [10] and included coronal Cobb angles of thoracic and lumbar curves, TK (T4–T12, Cobb angle between superior end plate of T4 and inferior end plate of T12), LL (Cobb angle between superior end plate of L1 and superior end plate of S1), SVA (C7 plumbline relative to S1), PT, and the mismatch between pelvic incidence and lumbar lordosis (PI-LL).

Additional cervical radiographic parameters included cervical lordosis (CL) for C2–C7, C2–T3 angle, cervical

SVA measured from C2 to C7, T1 slope (T1S), and the mismatch between T1S and CL (T1S-CL). Patients were assessed for CD at baseline and at 2-year follow-up based on the following criteria: C2–C7 SVA greater than 4 cm, C2–C7 SVA less than 4 cm, cervical kyphosis (CL greater than 0), CL (less than 0), any deformity (C2–C7 SVA greater than 4 cm or CL greater than 0), and both CD (C2–C7 SVA greater than 4 cm and CL greater than 0).

Based on the previously mentioned radiographic parameters, patients were stratified by the SRS-Schwab ASD classification [11]. The SRS-Schwab sagittal modifiers (PT, global alignment, and PI-LL) were assessed at 2-year postop as either normal (“0”) or abnormal (“+” or “++”). Patients were assigned the AG or MG if all three sagittal modifiers were normal or abnormal, respectively (Fig. 1).

Data that were collected and used for this study included patient demographics and patient-reported health-related quality-of-life scores such as Oswestry Disability Index (ODI) and Short-Form 36 (SF-36) that were analyzed before and after surgery. Data were uploaded into an electronic data capture system and processed through the International Spine Study Group data management center.

Statistical analysis

Statistical analysis was performed using Stata, version 13 (StataCorp, College Station, TX, USA). The two groups (MG vs. AG based on SRS-Schwab sagittal parameters) were compared with regard to patient demographics, surgical data, HRQOL, and cervical and thoracic sagittal radiographic parameters (C2–C7 SVA, C2–T3 SVA, CL, T1S, T1S-CL, and C2–T3 angle) at baseline and 2 years and baseline lumbopelvic radiographic parameters (LL, TK, PT, C7–S1 SVA, and PI-LL) using *t* and chi-square tests as appropriate. The relationship between cervical alignment and SRS-Schwab parameters was assessed using Pearson correlation coefficient. The level of significance was p value of less than .05.

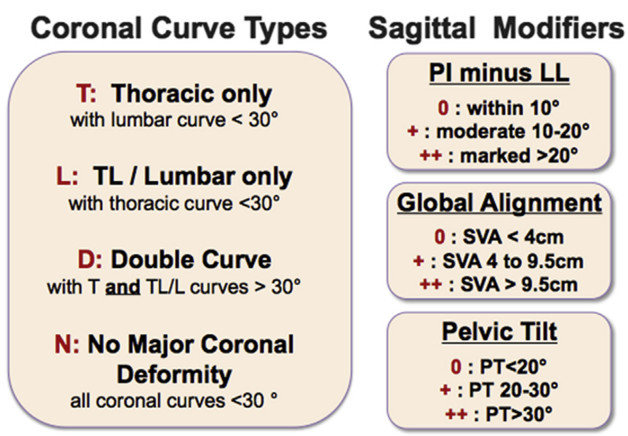

Fig. 1. Scoliosis Research Society-Schwab classification of adult spinal deformity. TL, thoracolumbar; LL, lumbar lordosis; PI, pelvic incidence; SVA, sagittal vertical axis.

Results

One hundred and four patients initially met the inclusion criteria and had completed 2-year follow-up and cervical spine X-rays. Specifically, at the 2-year follow-up, 70 patients had normal alignment on all SRS-Schwab sagittal modifier parameters (AG) and 34 had moderate or severe residual deformity on all Schwab-SRS sagittal parameters (MG). Of the original cohort, 80 patients were not included as they did not fit in either MG or AG, according to the sagittal modifier parameters.

Patient demographics and surgical data for the two groups show that on average, patients who failed to reach alignment on all three SRS-Schwab sagittal modifiers were older (58.9 vs. 48.44 years, p=.0017), had a higher number of comorbidities (Charlson Comorbidity Index, 1.79 vs. 1.07, p=.034), and a higher incidence of diabetes (11.8% vs. 1.4%) than their counterparts who were sagittally aligned at 2 years postoperatively. The two groups were similar with regard to smoking status and incidence of osteoporosis. On average, patients in the MG had less levels fused (8.6 vs. 10.6, p=.0131) and were less likely to have had an osteotomy performed (32.3% vs. 70%, p=.0001). There was no statistically significant difference between the two groups in terms of surgical approach (two-staged vs. posterior only) or the number of patients who underwent three-column osteotomies (Table 1).

Table 2 shows the comparison of preop sagittal alignment between the two groups. Looking at cervical sagittal parameters, patients who were classified as “malaligned” based on the 2-year SRS-Schwab sagittal modifiers had a higher preop CL compared with the AG. This was true when looking at the C2–C7 lordosis (11.66° vs. 4.89°, p=.03) and the C2–T3 lordosis (13.59° vs. 4.93°, p=.015). There was no statistically significant difference between the two groups when looking at the baseline C2–C7 SVA, C2–T3 SVA, T1S, and T1S-CL. The two groups were similar with regard to their baseline TK. Figures 2 and 3 display aligned and malaligned patients according to cervical and thoracolumbar radiographic parameters.

Table 1
Summary of patient population

Baseline and Surgical Variables	2-y AG (n=70)	2-y MG (n=34)	p Value
Age	48.44	58.90	.0017
Charlson Comorbidity Index Score	1.07	1.79	.034
Diabetes	1.4%	11.8%	.021
Osteoporosis	8.6%	14.7%	.34
Smoker	15.9%	9.4%	.384
Levels fused	10.6	8.6	.0131
Interbody	45.7%	64.7%	.07
Osteotomy (all)	32.3%	70%	.0001
Osteotomy (three columns)	13%	17.6%	.533
Approach (two-stage vs. posterior only)	42.8%	52.94%	.333

AG, aligned group; MG, malaligned group.

Table 2
Comparison of preop sagittal alignment between the two groups

Preop sagittal parameters	2-y AG (n=70)	2-y MG (n=34)	p Value
C2–C7 SVA	32.1±1.8	35.4±3.2	.34
C2–T3 SVA	54.3±2.7	61.1±4.6	.17
CL	4.89±1.7	11.66±2.7	.03
T1S	22.3±1.46	25.8±2.17	.18
T1S-CL	17.36± 1.06	14.32±2.1	.15
C2–T3 angle	4.93±1.94	13.59±3.0	.015
LL	45.63±2.5	35.48±4.3	.0315
TK	34.95±2.28	30.3±3.55	.26
PT	15.81±1.08	33.43±1.6	<.0001
C7–S1 SVA	36.7±7.2	124.9±12.5	<.0001
PI-LL	1.68±2.18	27.03±3.88	<.0001

AG, aligned group; CL, cervical lordosis; MG, malaligned group; PI-LL, pelvic incidence and lumbar lordosis; preop, preoperative; PT, pelvic tilt; SVA, sagittal vertical axis; TK, thoracic kyphosis; T1S, T1 slope.

When looking at preop pelvic and global sagittal parameters, the MG had greater baseline deformity, as indicated by their higher PT (33.43 vs. 15.81, p<.0001), lower LL (34.48 vs. 45.63, p=.0315), greater mismatch between PI-LL (27.03 vs. 1.68, p<.0001), and greater C7–S1 SVA (124.9 vs. 36.7, p<.0001).

Cervical and thoracic sagittal alignment comparison between the two groups 2 years postoperatively show that patients who did not reach alignment on the SRS-Schwab sagittal modifiers had, on average, more postop lordosis between C2 and T3 (5.9 vs. –1.41, p=.0182) and less TK (39.59 vs. 46.46, p=.0459) compared with their counterparts who were aligned. There was a trend toward higher postop C2–C7 SVA (39.61 vs. 32.24 mm, p=.051) and higher C2–T3 SVA (68.47 vs. 38.95 mm, p=.068) in the MG (Table 3). The two groups were similar with regard to their postop T1S-CL. As shown in Table 4, the change in HRQOL outcomes between baseline and 2-year postop for the two groups was similar, with both groups experiencing an improvement on ODI (11.09 vs. 12.97, p=.6), SRS (0.80 vs. 0.615, p=.2), and Physical Component Summary of SF-36 (5.11 vs. 6.98, p=.45).

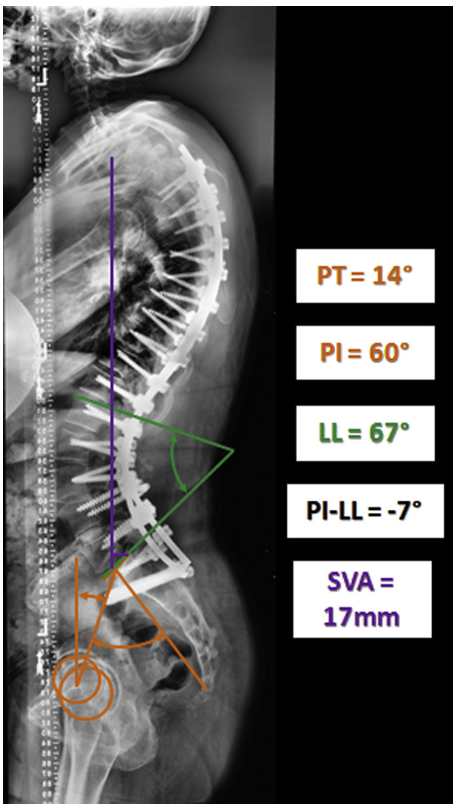

Fig. 2. Preoperative and postoperative changes in radiographic parameters, including the cervical spine, after surgical treatment. LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis.

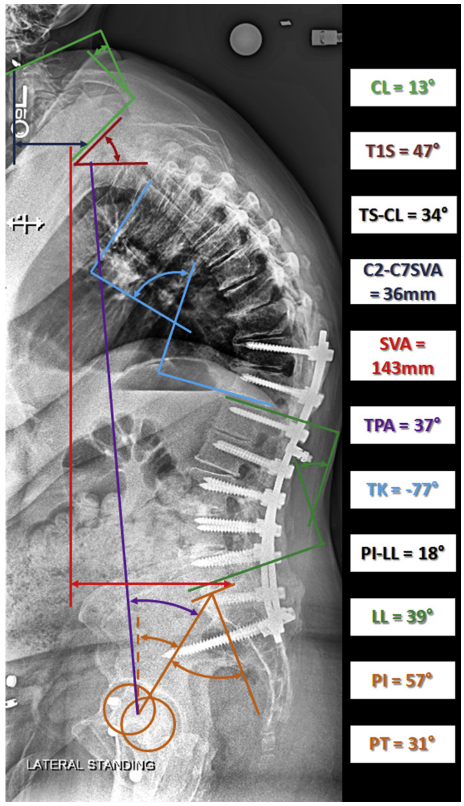

Fig. 3. Clinical preoperative and postoperative changes in radiographic parameters for thoracolumbar and cervical deformities. CL, cervical lordosis; TPA, T1 Pelvic Angle; PI-LL, pelvic incidence and lumbar lordosis; preop, preoperative; PT, pelvic tilt; SVA, sagittal vertical axis; TK, thoracic kyphosis; T1S, T1 slope.

Table 3
Sagittal parameters for the two groups

2-y sagittal parameters	2-y AG (n=70)	2-y MG (n=34)	p Value
C2–C7 SVA	32.24±1.72	39.61±3.9	.051
C2–T3 SVA	58.95±2.6	68.57±5.1	.068
CL	4.3±1.92	8.8±3.01	.196
T1S	26.7±1.49	31.5±2.44	.0821
T1S-CL	22.44±1.2	22.73±2.32	.9
C2–T3 angle	–2.41±1.9	5.9±3.1	.0182
TK (T2–T12)	46.46±1.9	39.59±2.85	.0459

AG, aligned group; CL, cervical lordosis; MG, malaligned group; SVA, sagittal vertical axis; TK, thoracic kyphosis; T1S, T1 slope.

Table 4
Changes in HRQOL outcomes between baseline and 2-year postop for patient population

HRQOL difference baseline to 2 y	2-y AG (n=70)	2-y MG (n=34)	p Value
ODI	−11.09	−12.97	.60
SRS	0.80	0.615	.2
SF-36 (PCS)	6.98	5.11	.45

AG, aligned group; HRQOL, health-related quality of life; MG, maligned group; ODI, Oswestry Disability Index; postop, postoperative; SF-36 (PCS), Physical Component Summary of Short-Form 36; SRS, Scoliosis Research Society.

The Pearson test shows a small, statistically significant positive correlation between baseline CL (as measured by both C2–C7 and C2–T3), postop PT, and C7 SVA (Table 5). Results also show a small positive correlation in two sets of radiographic parameters: between postop C2–T3 lordosis and postop PT/C7 SVA and between postop C2–C7 lordosis and C7 SVA. There was no statistically significant correlation between baseline or postop CL and postop PI-LL.

Discussion

Because of the complex anatomy of the cervical spine and the unequivocal interrelationship between the cervical and thoracolumbar spine, it is important to investigate the compensation that occurs after thoracolumbar surgery. Although the entire spine functions as a single unit, depending on the preop sagittal alignment, history of cervical spine surgery involving fusion and/or instrumentation, and the degree of thoracolumbar correction, patients compensate to different extents. Furthermore, regional changes in spinal alignment after surgery affect the alignment of the cervical region in the early postop period [12–14]. Blondel et al. [13] reported a reciprocal reduction of CL after lumbar pedicle subtraction osteotomies. In this series, we comparatively evaluated two groups, those who obtained and did not obtained ideal SRS-Schwab alignment criteria postoperatively, to look for the difference in the incidence of CD, HRQOL outcome, and the correlation between cervical and thoracolumbar deformities preoperatively and postoperatively.

As ASD often involves various pathologies with a wide range of radiographic and clinical presentations, researchers found importance in developing an ASD classification system that is easy to use, categorized based on clinical impact, and highly reliable [1]. The SRS-Schwab classification system was developed using studies correlating HRQOL and radiographic outcomes and has been shown to have the capability to reliably predict patient disability and patient preference for operative versus nonoperative treatment [7]. It places high import on the role of pelvic alignment in the maintenance of upright posture, and, hence, the development of the concept of spinopelvic alignment [7]. Furthermore, the system provides a unique and invaluable service to surgeons as a guideline for surgical planning with its global alignment and sagittal modifiers (PI-LL, PT, and SVA). Therefore, this study used the SRS-Schwab sagittal modifiers to categorize patients who underwent thoracolumbar surgery into AG and MG at 2 years after corrective surgery. In contrast with adult thoracolumbar deformity, there is a lack of a universally accepted definition of CD. As such, for the purposes of our study, we used a comprehensive group of radiographic parameters, with strict values for inclusion, until these parameters are more clearly established in the literature. This was done for the purposes of being more inclusive of all variations of CD while only including patients with true CD.

This series demonstrated distinct differences between patients who obtained ideal alignment relative to those who did not. In terms of demographics, patients in the MG at 2 years, as determined by the SRS-Schwab classification, were older and had a higher comorbidity burden, representing a higher surgical risk population. Surgically, the MG had less levels fused than patients in the AG. Additionally, the MG was more likely to undergo osteotomies and presented with greater overall thoracolumbar deformities. This is expected as osteotomies are often reserved for patients with significant spinal deformities. However, it is interesting to note that despite the performance of these osteotomies, their overall alignment remained inferior at 2-year follow-up. The same group of patients also had higher overall baseline thoracolumbar deformities, as evidenced by higher PT, PI-LL mismatch, and SVA, all p values of less than .0001.

Table 5
Relationship between baseline and postop spinal parameters

Radiographic Variables	2-y PT r	2-y PT p Value	2-y PI-LL r	2-y PI-LL p Value	2-y C7 SVA r	2-y C7 SVA p Value
Baseline lordosis						
C2–C7	0.2419	.0134	0.1074	.2779	0.2517	.0099
C2–T3	0.2599	.0077	0.1076	.2770	0.3196	.0009
2-y lordosis						
C2–C7	0.1335	.1766	−0.0010	.99	0.2385	.0148
C2–T3	0.2274	.0203	0.0663	.5040	0.3314	.0006

PI-LL, pelvic incidence and lumbar lordosis; postop, postoperative; PT, pelvic tilt; SVA, sagittal vertical axis.

Not surprisingly, at 2 years postoperatively, the MG continued to manifest statistically different thoracolumbar deformities compared with the AG. However, their baseline degree of cervical lordotic compensation improved to the point where the difference in CL between AG and MG was not statistically significant. By our definition and categorization, the MG was malaligned both before and after their thoracolumbar surgery. However, our analysis showed a more significant improvement in CL measurement in the MG than the AG, most likely a result of this cohort starting with larger baseline sagittal deformity. Despite the difference in preop and postop alignments, the HRQOL score differences at 2 years postoperatively between the two groups were not statistically significant. The HRQOL score difference was measured using ODI, SRS-22, and SF-36, which are more specific to the lumbar spine rather than the cervical spine. Therefore, an analysis of the HRQOL score based on the cervical spine, such as the Neck Disability Index, could provide a more representative result on the relative effect of lumbar surgery on cervical spine health, as perceived by the patient. This is particularly relevant in light of our findings of increased baseline cervical and cervicothoracic lordosis.

Perhaps, the most significant finding was that patients who were classified as ‘‘malaligned’’ based on the 2-year SRS-Schwab sagittal modifiers had higher preop cervical and cervicothoracic lordoses compared with the AG, as defined by C2–C7 and C2–T3 lordosis measurements. Postoperatively, the malaligned cohort had persistence of relatively increased C2–T3 lordosis, with a trend toward increased C2–C7 and C2–T3 SVA. These significant findings persisted as being independent predictors of not reaching optimal thoracolumbar alignment even after controlling for confounders. Overall, these findings are novel and can be interpreted as correlative evidence of a relationship between CL and greater thoracolumbar malalignment at 2 years postoperatively. To further define the relationship between cervical compensatory lordosis and postop thoracolumbar malalignment, the present study also analyzed for correlation between all patients, both AG and MG, and radiographic parameters and found a small positive correlation between baseline CL and postop PT and SVA, between postop C2–T3 lordosis and postop PT/SVA, and between postop C2–C7 lordosis and postop SVA. Our results are consistent with the previous studies that have discussed a ‘‘chain of correlation’’ between various regional alignments of the spinal column, including, CL and TK, TK and LL, LL and PI, and PT and CL [15]. However, this is the first series to document a significant correlation between certain baselines and persistent 2-year increased cervicothoracic lordosis and the presence of suboptimal thoracolumbar/pelvic alignment at 2 years after corrective thoracolumbar ADS surgery. Further studies with larger sample sizes are necessary to determine if cervical lordotic compensation is a predictor of 2-year malalignment. In addition, potentially quantifying degree of cervical lordotic compensation as hyperlordosis may be useful in similar future studies and yet requires further investigation as there are no universally established parameters for the definition of the latter.

Although our data and analysis show valuable information, our study is limited in its retrospective design; therefore, a prospective study is warranted. Although representing a large cohort relative to most ADS series, our patient sample remains less than ideal for analyzing variables other than our primary outcomes. Last, spinal alignment is not independent of the entire body alignment, including horizontal gaze and lower extremity posturing, and future studies are required to account for changes in these other regions.

Conclusions

The interdependence between the cervical spine and lumbar spine is not only compelling but also unequivocal. Therefore, for patients undergoing either cervical or lumbar spine surgery, it is imperative that their health-care providers are aware of the impact of the surgery on the region of the spine not undergoing surgery. This study identified preop cervical degree of lordotic compensation and higher C2–T3 angle as risk factors for sagittal malalignment after thoracolumbar surgery. Furthermore, the presence of suboptimal thoracolumbar and pelvic alignment at 2 years after corrective thoracolumbar ADS surgery was identified. Patients who remained malaligned at 2 years postoperatively (MG) also had worse malalignment with higher PT, PI-LL, and SVA despite undergoing more extensive and risky osteotomies. With this information, surgeons could use radiographic parameters of the cervical spine, specifically C2–C7 lordosis, the C2–T3 lordosis, and C2–T3 angle, to identify patients who are at risk for sagittal malalignment after thoracolumbar surgery, to educate patients, and to plan for surgery accordingly, potentially obviating the consideration for osteotomies. Unfortunately, this study is limited because of its retrospective design; therefore, prospective, randomized trials are needed to verify the results of this study.

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