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ORIGINAL ARTICLE

A comparative analysis of the prevalence and characteristics of cervical malalignment in adults presenting with thoracolumbar spine deformity based on variations in treatment approach over 2 years

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Abstract

Purpose Characteristics specific to cervical deformity (CD) concomitant with adult thoracolumbar deformity (TLD) remains uncertain, particularly regarding treatment. This study identifies cervical malalignment prevalence following surgical and conservative TLD treatment through 2 years.

Methods Retrospective analysis of a prospective, multicenter adult spinal deformity (ASD) database. CD was defined in operative and non-operative ASD patients according to the following criteria: T1 Slope minus Cervical Lordosis (T1S-CL) ≥20°, C2–C7 Cervical Sagittal Vertical Axis (cSVA) ≥40 mm, C2–C7 kyphosis >10°. Differences in rates, demographics, health-related quality of life (HRQoL) scores for Oswestry Disability Index (ODI) and Scoliosis Research Society Questionnaire (SRS-22r), and radiographic variables were assessed between treatment groups (Op vs. Non-Op) and follow-up periods (baseline, 1-year, 2-year).

Results Three hundred and nineteen (200 Op, 199 Non-Op) ASD patients were analyzed. Op patients' CD rates at 1 and 2 years were 78.9, and 63.0 %, respectively. Non-Op CD rates were 21.1 and 37.0 % at 1 and 2 years, respectively. T1S-CL mismatch and cSVA malalignment characterized Op CD at 1 and 2 years ($p < 0.05$). Op and Non-Op CD groups had similar cervical/global alignment at 1 year ($p > 0.05$ for all), but at 2 years, Op CD patients had worse thoracic kyphosis (TK), T1S-CL, CL, cSVA, C2–T3 SVA, and global SVA compared to Non-Ops ($p < 0.05$). Op CD patients had worse ODI, and SRS Activity at 1 and 2 years post-operative ($p < 0.05$), but had greater 2-year SRS Satisfaction scores ($p = 0.019$).

Conclusions In the first study to compare cervical malalignment at extended follow-up between ASD treatments, CD rates rose overall through 2 years. TLD surgery, resulting in higher CD rates characterized by T1S-CL and cSVA malalignment, produced poorer HRQoL. This information can aid in treatment method decision-making when cervical deformity is present concomitant with TLD.

Keywords Cervical deformity · Adult spinal deformity · Thoracolumbar deformity · Health-related quality of life · Cervical spine malalignment

Introduction

The pathological overlap between thoracolumbar deformity (TLD) and cervical deformity (CD) among adult patients is one that has been drawing increasing attention from spine surgeons. Significant interactions between

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cervical and thoracolumbar regions have been recently reported to account for reciprocal changes between these adjacent structures [1–4]. Several reports have noted that thoracolumbar sagittal malalignment is associated with compensatory cervical hyperlordosis to help maintain horizontal gaze, and that this reversed post-operatively with global sagittal realignment and correction [4, 5]. Indeed the cervical spine's capacity for self-correction has been well documented in early follow-up periods following thoracolumbar deformity correction. Blondel et al. observed early compensatory loss of cervical lordosis (CL) following osteotomy utilization for posterior global malalignment [6]. Ames et al. also elaborated on a more global perception of alignment in reporting adaptive correlation chains between degree of cervical sagittal alignment (SVA and lordosis) and thoracolumbar and pelvic orientation [7]. While these reports highlight early cervical changes after TLD surgery, few studies have considered the progression of these changes, and how treatment may impact cervical deformity at extended follow-up.

Discrepancies in defining cervical deformity have hindered attempts to describe and quantify the clinical impact. Traditionally, abnormal cervical kyphosis or scoliosis were enough to characterize cervical deformity, but recent reports have suggested that CD on radiographic assessment may also be defined based on other parameters [8]. These include measures that have been found to significantly correlate with disability, including mismatch between T-1 Slope and cervical lordosis (T1S-CL) and C2–C7 sagittal vertical alignment (C2–C7 SVA), for example [8–10]. Recently, Passias et al. used a three-part definition for CD that incorporated all three criteria in surgical ASD patients, resulting in a post-operative cervical deformity rate of 63 % [11]. Whether or not this definition can be applied to all TLD patients, regardless of treatment strategy, remains to be determined. Studying cervical deformity in a non-operative ASD population is essential to determine the natural history of the disease without intervention.

The heterogeneity of CD patients, due to varying definitions and indications, renders evaluations of the deformity's clinical impact difficult. Ties between positive cervical sagittal malalignment and health-related quality of life (HRQoL) scores have been reported, but are in the context of evaluating isolated cervical deformity parameters [12, 13]. Interestingly, post-operative improvement in quality of life scores have been noted in surgical ASD patients even in those that developed new or worsened CD; whether this observation is upheld in all deformity patients regardless of treatment has yet to be considered, and is of interest to surgeons in counseling at-risk patients [11].

A broader analysis of how CD manifests in TLD cases, inclusive of treatment method, has yet to be undertaken. In this report, both operative and non-operative TLD patients were studied and compared with extended follow-up to evaluate the prevalence and type of CD that developed. Considerations with regard to deformity progression and outcome impact associated with CD onset were also objectives of this study.

Methods

Data source and study design

This study was a retrospective analysis of ASD patients from a multi-center database comprised of prospectively collected data from consecutively enrolled patients at 11 US based sites nationwide. Institutional Review Board approval was granted at each enrolling site prior to study initiation and patient enrollment. The inclusion criteria utilized for the database were: age >18years, scoliosis $\geq$20°, sagittal vertical axis (SVA) $\geq$5 cm, pelvic tilt (PT) $\geq$25° and/or thoracic kyphosis (TK) >60°, and with complete demographic, surgical, and radiographic data. Patients whose spinal deformity was of a neuromuscular etiology, or those with active infections or malignancies were excluded.

Patient selection

This study included all ASD patients, both operative and non-operative, with complete demographic and radiographic data at baseline, 1-year and 2-year follow-up. Patients were assessed for cervical deformity (CD) at baseline (CD-BL), 1 year (CD-1Y), and 2 years (CD-2Y) follow-up (Fig. 1 for radiographic examples). Deformity groups were established as meeting $\geq$2 of the following thresholds on radiographic analysis, so as to define the condition more inclusively for multiple types of CD: T1 Slope minus cervical lordosis (T1S-CL) greater than 20°, C2–C7 sagittal vertical axis (C2–C7 SVA) greater than 40 mm, or C2–C7 kyphosis >10°. This radiographic characterization of cervical deformity is based on a previously established definition [11]. CD patients were stratified based on treatment type: operative (Op CD) vs. non-operative (Non-Op CD).

Data collection

Data that were collected and utilized for this study included presenting patient demographics (age, gender, BMI, baseline medical co-morbidities), radiographic measurements for cervical, thoracolumbar, and pelvic parameters, and health-related quality of life (HRQoL) scores at 1 and 2 years follow-up. Standardized health questionnaires were utilized for data collection in this study, including the Oswestry Disability Index (ODI), the 36-Item Short Form

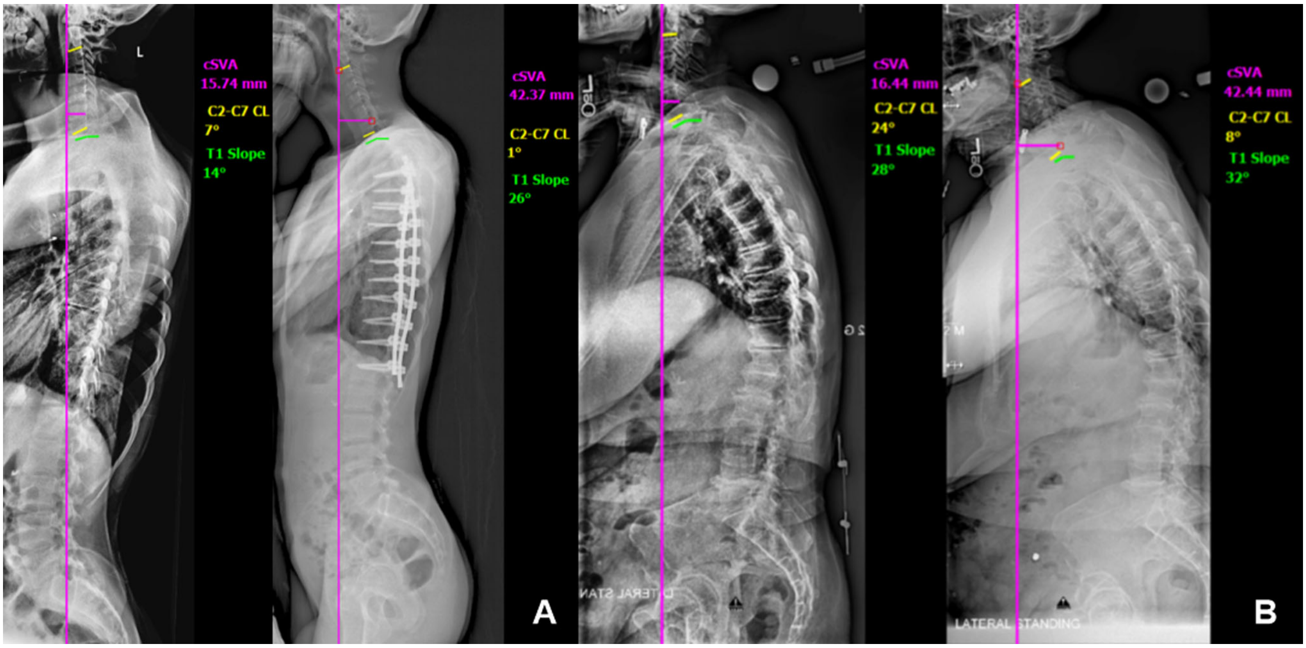

Fig. 1 Examples of cervical deformity onset based on radiographic parameters at 1-year follow-up in Op (**a**) and Non-Op (**b**) patients with TLD

Health Survey (SF-36) with Mental (MCS) and Physical (PCS) component summaries, and the Scoliosis Research Society Patient Questionnaire (SRS-22r) for Activity (AC), Pain (P), Appearance (AP), Satisfaction (S), Mental (M) and Total (T) subsections.

Radiographic analysis

Full-length free-standing lateral spine radiographs (36″ cassette) with visible cervical spine at baseline, 1- and 2-year follow-up were analyzed using a validated software system (Spineview, ENSAM, Paris) at a single site for radiographic sagittal spinopelvic parameters (Fig. 2) [14, 15]. Cervical radiographic parameters included C2–C7 Sagittal Vertical Axis (cSVA: C2 plumb line relative to C7), C2–C7 lordosis (C2–C7 CL: angle between lower endplate of C2 and the lower endplate of C7), C2 Slope (C2-S: angle between a horizontal line and the lower endplate of C2), T1 Slope (T1-S: angle between a horizontal line and the superior endplate of T1), mismatch between T1 Slope and CL (T1S-CL), C2–T3 angle (C2–T3 CL: angle between lower endplate of C2 and lower endplate of T3), and C2–T3 Sagittal Vertical Axis (C2–T3 SVA: C2 plumb line relative to T3). Radiographic measurements of thoracolumbar curves and pelvic parameters were also obtained: sagittal malalignment (SVA: C7 plumb line relative to S1), pelvic tilt (PT), mismatch between pelvic incidence and lumbar lordosis (PI–LL), sacral slope (SS), and pelvic incidence (PI).

Statistical analysis

Op and Non-Op CD groups were compared for demographics, radiographic parameters, and outcomes scores at baseline, 1-year, and 2-year follow-up (Fig. 3). Continuous variables were described by mean and standard deviation, using unpaired Student *t* tests. Categorical variables were described with frequencies using Pearson's Chi square analyses. Paired *t* tests assessed differences in means from baseline to follow-up interview within CD cohorts at each year. Multivariate repeated measures mixed models measured the impact of CD on HRQoL scores at 1- and 2-year follow-up, and outcome scores were correlated with radiographic factors using Pearson's correlations. Statistical analyses were performed using SPSS 20.0 (IBM Corp., Armonk, NY). The level of significance was set at $p < 0.05$.

Results

Patient population

Of eligible patients that met inclusion criteria, 319 were retained for analysis. The included cohort comprised 200 operative (62.7 %) and 119 (37.3 %) non-operative patients. Demographic and radiographic parameters for Op and Non-Op groups, as well as the total cohort, are presented in Table 1. The total cohort had a mean age of 56.3 ± 14.9 years, mean BMI of 26.5 ± 5.8 kg/m^2, and

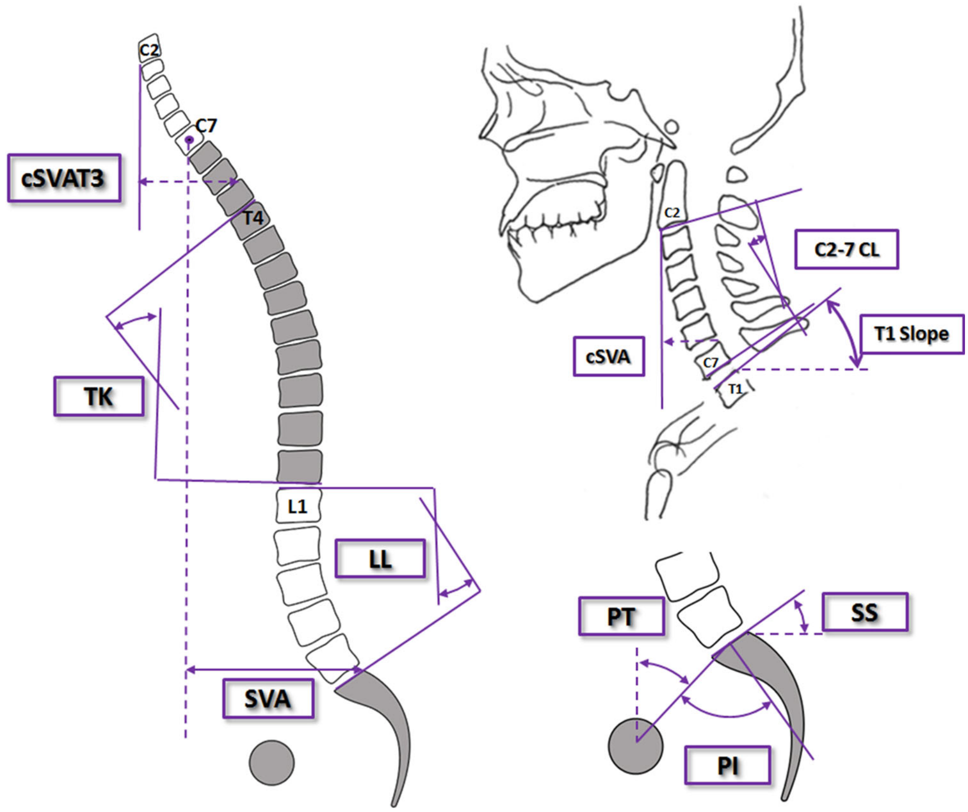

Fig. 2 Sagittal radiographic parameters for cervical, thoracolumbar, and pelvic regions. *SVA* Sagittal Vertical Axis for C2-T3 and C7-S1, *PI* Pelvic Incidence, *PT* Pelvic Tilt, *SS* Sacral Slope, *CL* Cervical Lordosis, *TK* Thoracic Kyphosis, *LL* Lumbar Lordosis

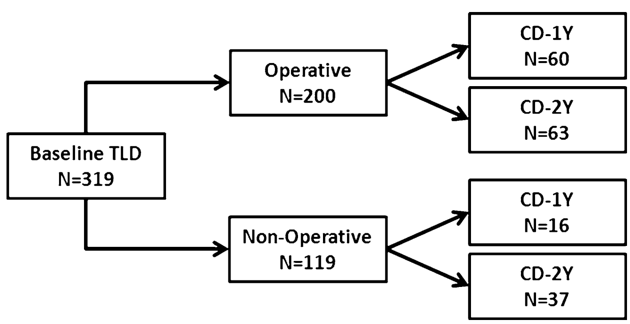

Fig. 3 Flow diagram of TLD patients at baseline with respect to treatment pattern and follow-up CD classification. *TLD* Thoracolumbar deformity, *CD* Cervical deformity

constituted 86.0 % females. Op patients were older (57.7 ± 14.5 vs. 54.2 ± 15.3, $p = 0.027$), and had greater BMI (27.1 ± 5.6 vs. 25.6 ± 6.1, $p = 0.014$). Op and Non-Op patients differed statistically in most baseline radiographic parameters: SS, PT, PI–LL, T1 Slope, C2–C7 CL, cSVA, and C7–S1 SVA ($p < 0.05$). Op patients significantly improved ($p < 0.01$ all cases) in PT (1Y: Δ 7.9°; 2Y: Δ 8.2°) SS (1Y: Δ 8.2°; 2Y: Δ 8.6°), LL (1Y: Δ 18.1°; 2Y: Δ 18.0°), TK (1Y: Δ 15.8°; 2Y: Δ 16.1°), and SVA (1Y: Δ 39.5 mm; 2Y: Δ 31.7 mm) at both 1- and 2-year follow-up.

Cervical deformity prevalence and type

The baseline cervical deformity rate was 15.4 % ($n = 49$ cases), of which 41 were Op, and 8 were Non-Op. At 1- and 2-year follow-up, the overall CD rates (met ≥2 radiographic criteria) were 23.8 % ($n = 76$) and 31.3 % ($n = 100$), respectively. 172 (53.9 %) patients met at least 1 CD criteria at 1 year, and 204 (63.9 %) at 2 years.

There were 48 patients (15.0 %) that maintained radiographic CD from 1- and 2-year follow-up. Of the CD-1Y group, a total of 28 patients (36.8 % out of 76) switched from CD to CA between 1 and 2 years follow-up, mostly due to spontaneous restoration of cSVA within normal range ($n = 16$, 57.1 %). At 2-year follow-up, there were 52 (52.0 %) de novo CD cases that had been aligned at 1-year follow-up. The 52 new CD-2Y cases had mostly T1S-CL deformity; across all follow-up periods, T1S-CL deformity was the most prevalent type of deformity parameter among CD-1Y and CD-2Y groups (Table 2).

T1S-CL deformity also was significantly more prevalent in CD Op patients than in Non-Op (74.4 vs. 25.6 %, $p = 0.001$) at 1-year, but this was not the case for CD-2Y analysis. Of CD-1Y patients, 60 (78.9 %) were Op patients; this rate was 63.0 % ($n = 63$) at 2 years postoperative. Among Non-Op ASD patients, the rates of CD at

Table 1 Demographic and radiographic values for the entire study population, Op cohort, and Non-Op cohort

	Overall ($n = 319$)	Op ($n = 200$)	Non-Op ($n = 119$)	*P* value
Age (years)	56.31 (14.88)	57.72 (14.48)	54.16 (15.28)	**0.027***
BMI (kg/m^2)	26.50 (5.82)	27.14 (5.57)	25.56 (6.06)	**0.014***
Gender (% Female)	86.0 %	86.0 %	86.5 %	0.515
SS	35.26 (11.59)	30.96 (11.96)	35.01 (10.58)	**0.001***
PT	22.60 (10.81)	24.00 (11.20)	20.46 (9.84)	**0.002***
PI	55.15 (12.68)	54.95 (12.76)	55.46 (12.59)	0.714
PI–LL	11.83 (19.87)	15.50 (21.30)	6.20 (15.95)	**<0.001***
T1 Slope	25.69 (12.82)	26.76 (13.80)	24.06 (11.01)	**0.043***
T1S-CL	16.87 (10.57)	16.37 (11.72)	17.76 (8.13)	0.296
C2-C7 CL	8.62 (15.45)	10.01 (16.42)	6.14 (13.28)	**0.046***
C2-C7 SVA	32.99 (17.65)	35.26 (18.13)	28.96 (16.08)	**0.004***
C2 Slope	15.79 (10.57)	15.55 (11.79)	16.23 (7.98)	0.611
C7-S1 SVA	46.69 (70.59)	63.25 (76.22)	21.30 (51.75)	**<0.001***

SS Sacral Slope, *PT* Pelvic Tilt, *PI* Pelvic Incidence, *PI–LL* mismatch between Pelvic Incidence and Lumbar Lordosis, *T1S-CL* mismatch between T1 Slope and Cervical Lordosis, *SVA* Sagittal Vertical Axis

Bold-faced cells are statistically significant to $p < 0.05$

Table 2 Number and percentage of cervical deformity parameters in cervical deformity (CD) groups at baseline visit, and 1-year, and 2-year follow-up

Deformity parameter	Deformity prevalence (%)					
	CD 1-year ($n = 76$)			CD 2-year ($n = 100$)		
	BL	1Y	2Y	BL	1Y	2Y
T1S-CL > 20°	46 (60.5 %)	69 (90.8 %)	60 (78.9 %)	58 (58.0 %)	60 (60.0 %)	80 (80.0 %)
C2–C7 SVA ≥ 40 mm	34 (44.7 %)	63 (82.9 %)	38 (50.0 %)	35 (35.0 %)	52 (52.0 %)	65 (65.0 %)
C2–C7 CK < −10°	23 (30.3 %)	24 (31.6 %)	21 (27.6 %)	18 (18.0 %)	23 (23.0 %)	44 (44.0 %)

T1S-CL mismatch between T1 Slope and Cervical Lordosis, *SVA* Sagittal Vertical Axis, *CK* Cervical Kyphosis

Table 3 Comparisons between cervical deformity (CD) rates and parameter distribution in Op and Non-Op ASD patients

	Non-Op ($n = 119$) (%)	Op ($n = 200$) (%)	*P* value
CD-1Y			
T1S-CL	25.6	74.4	**0.001***
C2–C7 SVA	27.0	73.0	**0.004***
C2–C7 CL	23.3	76.7	0.069
CD-2Y			
T1S-CL	38.9	61.1	0.842
C2–C7 SVA	27.3	72.7	**0.003***
C2–C7 CL	46.8	53.2	0.265

T1S-CL mismatch between T1 Slope and Cervical Lordosis, *SVA* Sagittal Vertical Axis, *CL* Cervical Lordosis

1 and 2 years follow-up were 21.1 % ($n = 16$) and 37.0 % ($n = 37$), respectively (Table 3). Op and Non-Op patients also differed on the prevalence of cervical deformity criteria: Op patients' C2–C7 SVA malalignment contributed more to their CD at 1-year (73.0 vs. 27.0 %, $p = 0.004$) and 2-year (72.7 vs. 27.3 %, $p = 0.003$).

Cervical deformity progression

Op and Non-Op CD patients were compared at follow-up for differences in radiographic alignment (Table 4). At 1-year, Op and Non-Op CD groups were statistically similar for all considered cervical and spino-pelvic parameters ($p > 0.05$ all cases). However, at 2 years, Op CD patients demonstrated significantly greater acquired deformity compared to Non-Op, largely in the cervical spine: T1S-CL, cSVA, C2-T3 SVA were all higher ($p < 0.05$). 2-year Op CD patients also showed greater TK (38.46° vs. 28.41°, $p = 0.005$) and SVA (44.16 mm vs. 18.39 mm, $p = 0.043$) than the Non-Op CD group.

Patients with baseline CD ($n = 34$) that had persistent deformity at 1-year ($n = 28$, 36.8 %) and 2-year ($n = 28$, 28.0 %) follow-up had worsening of cervical sagittal parameters: by 1-year, T1S-CL (BL: 27.06° vs. 1Y: 31.59°, $p = 0.001$) and CL (BL: 2.04° vs. 1Y: −2.92°, $p = 0.003$) increased significantly; the same trend was observed for 2-year T1S-CL (BL: 25.96° vs. 2Y: 30.94°, $p < 0.001$) and CL (BL: 0.84° vs. 2Y: −2.85°,

Table 4 Follow-up radiographic values comparisons for Op vs. Non-Op cervical deformity patients 1 and 2 years follow-up

	1-year follow-up			2-year follow-up		
	Op ($n = 60$)	Non-Op ($n = 16$)	*P* value	Op ($n = 63$)	Non-Op ($n = 37$)	*P* value
SS	35.79 (10.56)	36.83 (8.30)	0.715	33.71 (11.17)	36.06 (8.85)	0.276
PT	22.20 (11.73)	19.40 (8.68)	0.376	23.62 (11.02)	19.87 (10.75)	0.098
PI	57.99 (12.71)	56.24 (10.60)	0.615	57.32 (12.38)	55.91 (11.30)	0.570
PI–LL	4.03 (15.53)	6.03 (12.54)	0.637	6.96 (15.63)	6.95 (15.17)	0.999
LL	53.87 (15.15)	50.21 (11.70)	0.372	50.22 (14.58)	48.95 (13.68)	0.667
TK	39.40 (20.23)	32.43 (13.25)	0.197	38.46 (17.43)	28.41 (15.92)	**0.005***
T1S-CL	30.95 (7.98)	29.17 (5.70)	0.406	32.01 (8.21)	28.84 (6.69)	**0.049***
C2–C7 CL	−0.98 (15.76)	−4.44 (13.47)	0.423	0.81 (15.73)	−7.04 (13.52)	**0.013***
C2–C7 SVA	49.90 (19.38)	45.09 (11.49)	0.348	47.07 (20.81)	37.27 (19.09)	**0.021***
C2–T3 CL	−8.13 (15.37)	−9.99 (10.81)	0.650	−6.51 (14.91)	−11.25 (11.96)	0.103
C2–T3 SVA	78.06 (30.74)	69.53 (25.51)	0.311	76.17 (30.53)	59.39 (27.85)	**0.002***
C2 Slope	31.21 (8.19)	29.41 (6.36)	0.418	30.85 (9.00)	27.84 (7.05)	0.084
C7–S1 SVA	32.21 (61.41)	27.23 (60.10)	0.773	44.16 (63.40)	18.39 (55.80)	**0.043***

NS not significant. *SS* Sacral Slope, *PT* Pelvic Tilt, *PI* Pelvic Incidence, *PI–LL* mismatch between Pelvic Incidence and Lumbar Lordosis, *LL* Lumbar Lordosis, *TK* Thoracic Kyphosis, *T1S-CL* mismatch between T1 Slope and Cervical Lordosis, *SVA* Sagittal Vertical Axis

* Bolded cells are statistically significant to $p < 0.05$

$p = 0.007$). The cSVA among CD-BL patients with deformity at follow-up years did increase, though this trend was statistically insignificant.

Radiographs of CD-1Y and CD-2Y patients of each treatment group were assessed for changes in sagittal spine alignment from baseline to follow-up (Table 5). Differences in groups were more pronounced in CD-1Y Op and Non-Op groups than at 2 years. As anticipated, Op CD-1Y and Op CD-2Y patients demonstrated significant improvement in global balance (LL, TK, SVA, PT) when compared to baseline. Though, OP CD-1Y group showed worsening in cervical sagittal alignment: cSVA increased significantly, as did C2 Slope, and T1S-CL ($p < 0.05$ all cases). From baseline to 2 years, there were no significant differences in cervical parameters among Op CD-2Y patients. Non-Op CD-1Y patients were similar regarding spino-pelvic parameters, but showed more severe cervical sagittal malalignment for all considered parameters (T1S-CL, CL, cSVA, C2–T3 SVA, T1 Slope, C2 Slope, and C2–T3 SVA). At 2-year follow-up, Op CD-2Y patients only had significant improvement in thoracolumbar parameters, Non-Op CD-2Y did not change in alignment measures from baseline to 2-year follow-up ($p > 0.05$, all cases).

Patient-reported outcomes

Operative and non-operative patients with cervical deformity at 1 and 2 years differed from each other in HRQoL results at each follow-up year (Table 6). The Op CD group showed worse ODI and SRS Activity scores at both 1- and 2-year follow-up ($p < 0.05$ both cases); though, at 2 years Op CD patients additionally had a greater SRS Satisfaction score compared to Non-Op patients (4.20 vs. 3.69, $p = 0.019$).

Results from the correlation analysis between cervical deformity radiographic parameters and outcome scores are presented in Table 7. Among operative CD patients, cSVA showed the moderate correlations with 1-year outcomes (ODI: 0.251; PCS: −0.304), while TS-CL mismatch correlated significantly with 2-year scores (SRS Total: 0.252; PCS: 0.260).

Discussion

Links between the loss of cervical alignment concomitant with adult spinal deformity remain unclear. Difficulties in informed recommendations for the management of ASD persist especially with an acknowledgement for the potential for degenerative structural changes in the cervical spine regions [11, 16]. Cervical deformity considerations thus have important value when assessing thoracolumbar malalignment treatment. With this in mind, this study provides an inclusive assessment of CD in ASD patients, treated both operatively and conservatively, which has not been previously undertaken.

The impact of thoracolumbar surgery on cervical deformity development is unclear in recent literature,

Table 5 Baseline and 1- and 2-year follow-up radiographic alignment parameters for cervical and thoracolumbar regions for operative and non-operative cervical deformity (CD) patients at each follow-up year

	Cervical deformity group							
	CD-1Y				CD-2Y			
	Op		Non-Op		Op		Non-Op	
	BL	1Y	BL	1Y	BL	2Y	BL	2Y
PT°	25.14 (11.80)	22.20 (11.73)	20.34 (10.13)	19.40 (8.68)	25.92 (12.03)	23.56 (11.35)	20.12 (9.55)	20.00 (9.92)
	0.003*		0.410		**0.022***		0.844	
PI°	57.14 (12.57)	57.99 (12.71)	56.21 (10.77)	56.24 (10.60)	56.32 (12.26)	56.88 (12.80)	55.62 (11.22)	55.67 (10.89)
	0.095		0.958		0.250		0.833	
PI–LL°	17.87 (20.08)	4.03 (15.53)	6.51 (11.05)	6.03 (12.54)	18.87 (20.23)	6.15 (15.61)	6.60 (12.63)	7.30 (14.46)
	<0.001*		0.688		**<0.001***		0.443	
LL°	39.27 (21.28)	53.87 (15.15)	49.70 (10.72)	50.21 (11.70)	37.45 (20.41)	50.68 (14.42)	49.02 (11.50)	48.37 (13.33)
	<0.001*		0.703		**<0.001***		0.488	
TK°	31.66 (20.85)	39.40 (20.23)	31.77 (12.38)	32.43 (13.25)	30.72 (21.44)	38.23 (18.01)	30.00 (13.26)	28.74 (13.70)
	0.001*		0.792		**0.003***		0.331	
SVA	76.59 (81.90)	32.21 (61.41)	28.19 (57.09)	27.23 (60.10)	73.34 (75.37)	29.30 (63.73)	16.42 (61.88)	21.54 (64.32)
	<0.001*		0.903		**<0.001***		0.387	
T1°	29.55 (16.07)	29.98 (16.17)	24.67 (14.29)	24.73 (15.07)	28.00 (13.76)	28.84 (17.82)	22.25 (13.63)	21.42 (13.44)
	0.784		0.982		0.597		0.512	
T1S-CL°	24.35 (9.38)	31.41 (8.08)	22.94 (8.61)	27.72 (4.26)	24.05 (8.85)	26.43 (10.28)	22.17 (7.84)	22.47 (8.11)
	<0.001*		**0.030***		0.138		0.850	
CL°	3.85 (14.22)	−1.80 (15.53)	−0.64 (12.56)	−6.57 (12.32)	3.28 (13.56)	1.44 (16.22)	0.52 (14.78)	−2.04 (13.68)
	<0.001*		**0.042***		0.253		0.244	
cSVA	44.70 (19.14)	49.60 (18.96)	32.30 (10.17)	43.01 (8.02)	43.25 (18.82)	45.71 (20.26)	32.83 (15.18)	36.70 (12.92)
	0.030*		**0.002***		0.285		0.126	
C2-T3 SVA	72.28 (27.97)	77.30 (30.48)	55.63 (13.05)	63.96 (18.58)	71.05 (26.87)	72.55 (31.24)	56.13 (19.61)	57.63 (20.86)
	0.096		**0.030***		0.624		0.566	
C2°	24.39 (9.06)	31.51 (8.05)	22.02 (8.91)	27.92 (5.03)	23.40 (8.51)	26.29 (10.75)	21.05 (7.48)	22.33 (8.90)
	<0.001*		**0.009***		0.067		0.401	

SS Sacral Slope, *PT* Pelvic Tilt, *PI* Pelvic Incidence, *PI–LL* mismatch between Pelvic Incidence and Lumbar Lordosis, *LL* Lumbar Lordosis, *TK* Thoracic Kyphosis, *T1S-CL* mismatch between T1 Slope and Cervical Lordosis, *SVA* Sagittal Vertical Axis

* Bolded cells are significant to $p < 0.05$

Smith et al. observed spontaneous relaxation of cervical hyperlordosis following lumbar PSO, thereby presenting cervical deformity as a compensatory mechanism tied with thoracolumbar malalignment [4]. Post-operative reductions in global, upper, and lower cervical lordosis were also observed in a study on 39 PSO patients with sagittal malalignment by Cecchinato et al. [5]. Oh et al. similarly evaluated CD in PSO adults, and noted persistence of pre-operative cervical sagittal malalignment (cSVA) at 3 months and 2 years following surgical ASD correction

Table 6 Comparative HRQoL analysis between CD operative and Non-operative patients at each follow-up

	1-year follow-up			2-year follow-up		
	Op ($n = 60$)	Non-Op ($n = 16$)	*P* value	Op ($n = 63$)	Non-Op ($n = 37$)	*P* value
ODI	31.90 (19.64)	20.60 (13.85)	**0.035***	31.78 (22.24)	22.70 (13.79)	**0.027***
PCS	38.15 (10.81)	42.91 (11.07)	0.145	38.03 (11.61)	42.41 (10.92)	0.082
MCS	50.49 (13.18)	53.24 (14.16)	0.482	49.65 (12.52)	52.08 (11.96)	0.371
SRS AC	3.34 (0.99)	3.94 (0.75)	**0.027***	3.44 (1.06)	3.92 (0.54)	**0.014***
SRS P	3.27 (1.00)	3.60 (0.66)	0.225	3.28 (1.15)	3.47 (0.84)	0.379
SRS AP	3.54 (0.93)	3.18 (0.78)	0.157	3.49 (1.01)	3.36 (0.67)	0.477
SRS M	3.81 (0.91)	4.20 (0.80)	0.124	3.73 (0.94)	3.97 (0.70)	0.194
SRS S	4.20 (0.98)	3.66 (1.12)	0.062	4.20 (1.10)	3.69 (0.88)	**0.019***
SRS T	3.55 (0.81)	3.72 (0.58)	0.440	3.55 (0.91)	3.68 (0.50)	0.409

ODI Oswestry Disability Index, *PCS* Short Form 36 Physical Component Summary, *MCS* Short Form 36 Mental Component Summary, *SRS* Scoliosis Research Society, *AC* Activity, *P* Pain, *AP* Appearance, *M* Mental, *S* Satisfaction, *T* Total

* Bolded cells are statistically significant to $p < 0.05$

Table 7 Correlations between cervical deformity (CD) parameters (cSVA, T1S-CL, CL) and HRQoL scores for patients with CD at each follow-up year, based on treatment (operative vs. non-operative)

CD Group	HRQoL	CSVA (mm)	T1S-CL (°)	CL (°)
CD1Y-Op	ODI	**0.251***	0.040	0.154
	SRS total	−0.032	0.131	−0.192
	PCS	**−0.304***	−0.067	**−0.298***
CD1Y-NonOp	ODI	−0.139	−0.001	0.212
	SRS total	0.062	−0.065	−0.142
	PCS	0.146	0.211	−0.330
CD2Y-Op	ODI	0.102	−0.197	0.098
	SRS total	−0.083	**0.252***	−0.238
	PCS	−0.130	**0.260***	**−0.348***
CD2Y-NonOp	ODI	**0.339***	−0.079	0.312
	SRS total	−0.209	−0.049	−0.212
	PCS	−0.165	0.248	−0.264

HRQoL scores for CD-1Y Op and Non-Op groups were considered at 1-year follow-up; HRQoL scores for CD-2Y Op and Non-Op groups were considered at 2-years

* Bolded cells are statistically significant to $p < 0.05$

cSVA Cervical Sagittal Vertical Axis, *T1S-CL* mismatch between T1 Slope and Cervical Lordosis, *CL* Cervical Lordosis, *ODI* Oswestry Disability Index, *SRS* Scoliosis Research Society, *PCS* Short Form 36 Physical Component Score

[3]. This worsening of cSVA highlights that CD onset may be a more isolated pathology than once believed, developing independent of thoracolumbar changes. The present study seeks to respond to discrepancies in CD onset, through comparing operative and non-operative ASD patients' cervical profiles at multiple follow-up intervals. Among 319 ASD Op and Non-Op patients, CD prevalence was 23.8 % at 1-year, and rose to 31.3 % at 2-year follow-up. These patients represented those with more significant CD compared to previous reports, as these cases must have met at minimum two radiographic deformity criteria (cSVA, T1S-CL and/or CK). Specific deformity parameter rates in CD patients have proposed by Smith et al., but not as extensively in this report [16]. CD presentation was greatest at 1-year follow-up and among Op patients.

Overall, mismatch between T1 Slope and CL predominantly characterized the cervical deformity in this patient population. This is a relatively different finding compared to previous reports, which typically highlight abnormal cervical kyphosis as the deformity driver [17–19]. Though, T1S-CL mismatch may be more representative of CD on a patient-specific basis; the parameter provides a better gauge of balance of head over neck, and retains importance in the additive context of thoracolumbar deformity [20]. Op CD-1Y patients also showed greater T1S-CL deformity compared to the Non-Op group (74.4 %), and there was a worsening of T1S-CL mismatch from baseline to 1-year post-operative among Op CD-1Y patients (24.35°–31.41°). As PI–LL mismatch has been previously reported to influence post-operative residual symptoms, it is possible that abnormal T1S-CL could represent a similar degenerative process in the cervicothoracic junction and marker for overall deformity and imbalance [21]. T1S-CL mismatch has also been correlated with inferior patient-reported outcomes by Lee et al., an observation which is sustained in this report [9].

Cervical deformity patients in this series significantly changed in cervical and spino-pelvic sagittal measures from baseline to follow-up. Expectedly, Op patients showed improved global alignment correction at 1 and 2 years, but this was in the context of significant worsening of cervical alignment, particularly at 1-year follow-up. This provides further evidence for the cervical spine's potential for decompensation following ASD surgery, which chiefly occurred in a more acute post-operative window than at 2-year follow-up. The mechanism by which this occurs still has yet to be identified. These results reflect growing controversy concerning how the cervical spine responds to thoracolumbar sagittal plane correction. Furthermore, Op and Non-Op CD patients only differed in cervical and thoracolumbar (TK, and SVA) radiographic parameters at 2-year follow-up, suggesting that though CD peaked at 1-year follow-up, alignment differences based on treatment are more protracted as the deformity develops. This study also provides insight into how cervical deformity develops concomitant to ASD in the absence of surgical correction, which has not yet been previously reported on: Non-Op CD patients did not exhibit any significant improvements in global deformity at 1- or 2-year follow-up, though cervical alignment parameters did worsen. Specifically, Non-Op CD1Y patients had greater T1S-CL mismatch, CL, C2 Slope, and C2–T3 SVA. Direct comparisons of cervical deformity between treatment groups revealed that cSVA malalignment was more often characteristic of CD in Op patients at both years. This supports the view of CD as a reciprocal change following ASD correction: as Oh et al. indicated, persistent cSVA may be a result of incomplete TK correction, prompting the present suggestion that TK over-correction should be more of a consideration at-risk CD patients [3]. Across treatment groups, however, it appears that CD (and cervical sagittal malalignment worsening) was consistent in both patient sets, even though thoracolumbar alignment improvements were not always seen. Taken together, these results suggest that CD may act as an independent entity, not necessarily strictly tied to compensatory post-operative mechanisms as previously thought.

The clinical impact of cervical deformity has been studied chiefly in operative settings [12, 22]. In this study, differences in HRQoL scores, ODI and SRS Activity scores in particular, for the Op CD group were significantly worse than Non-Op counterparts. That these findings were consistent at both 1- and 2-year follow-up indicates a sustained clinical impact with the onset of CD. It is important to note though that these clinical discrepancies, between Op and Non-Op CD groups, may also be reflective of baseline TLD disability differences. Further, several CD criteria correlated with inferior outcomes among treatment groups for CD-1Y and CD-2Y patients. Notably, cSVA correlated moderately well with increased ODI scores at 1 and 2 years, and with inferior 1-year PCS. This is sustained by several reports demonstrating associations between cervical deformity and poorer outcomes: Tang et al. observed that cervical positive sagittal malalignment ≥40 mm (CPSM) achieved significant correlations with poorer disability and physical ability, which is mirrored in this study [12]. Scheer et al. also found that pre-operative CPSM patients were less likely to achieve MCID for multiple disability and pain outcome components (ODI, PCS, SRS Activity, SRS Pain), despite overall HRQoL improvements in all study cohorts [22]. While the specific mechanism of CD's impact remains to be fully explained, this study's results provide evidence for the longitudinal clinical effect of deformity concomitant with ASD.

Limitations

This study is predominantly limited in its retrospective nature—mainly differences in surgical approach, and non-operative management among centers and surgeons. The utilized database was one developed for ASD patients, and thus patient-reported outcome tests are skewed to a population experiencing changes principally in thoracolumbar deformities—outcomes specific to cervical spine changes are also relevant. Further, differences in radiographic imaging methods (such as patient positioning) may exist between sites, which have the potential to alter methods of determining deformity.

Conclusions

This study is the first to quantify and compare trends in the development of cervical deformity (CD) concomitant with thoracolumbar deformity (TLD) in patients treated both operatively and non-operatively over a 2-year follow-up. CD rates were 23.8 and 31.3 % at 1- and 2-year follow-up, respectively, and were significantly higher in Op patients (78.9 and 63.0 %) compared to non-Op patients. T1S-CL mismatch and positive cervical sagittal malalignment were consistent markers of CD in both treatment groups over time. Op CD patients persisted in cervical alignment deterioration at 1 and 2 years, and consequently displayed inferior HRQoL scores at both time intervals. These results can aid surgeons in educating at-risk patients on an optimal treatment method when cervical deformity is present with thoracolumbar deformity. This study moreover builds on indications for defining cervical malalignment both pre- and post-operatively, and may provide a basis for cervical alignment consideration following lower deformity correction.

Compliance with ethical standards

Conflict of interest None.

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