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Development of New-Onset Cervical Deformity in Nonoperative Adult Spinal Deformity Patients With 2-Year Follow-Up

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ABSTRACT

Purpose: Evaluate the presence of new-onset cervical deformity (CD) in nonoperative adult spinal deformity (ASD) patients with extended follow-up, with consideration for predictors, prevalence, and impact on patient-reported outcomes.

Methods: Retrospective review of a prospective nonoperative ASD cohort. New onset CD patients at 1- (CD-1Y) and 2-year (CD-2Y) follow-up were defined as displaying baseline cervical alignment. Univariate analyses determined differences in radiographic parameters and outcome scores of CD and maintained-cervical-alignment patients. Multivariate binary logistic regression models determined new-onset CD predictors.

Results: A total of 143 patients were included (mean age 54 years, mean body mass index 25.6 kg/m^2, 86% female). Cervical deformity rate was 38.5% at baseline. New-onset CD incidence at 1- and 2-year follow-up was 30.0% and 41.7%, respectively. Global sagittal profile comparison of CD-1Y/CD-2Y versus maintained cervical alignment cases revealed no differences ($P > .05$) at any interval. Baseline C2-C7 sagittal vertical axis (SVA) was associated with increased new-onset CD risk at 1 (odds ratio [OR] 1.14, $P = .025$) and 2 years (OR 1.04, $P = .032$); prior spine surgical history was associated with CD risk at 1-year follow-up (OR 6.75, $P = .047$); baseline C2 slope was associated with increased CD risk at 2-year follow-up (OR 1.12, $P = .041$). CD development did not significantly impact health-related quality of life ($P > .05$).

Conclusions: Cervical deformity can manifest in nonoperative ASD patients: 30.0% at 1-year follow-up, and 41.7% at 2-year follow-up. Progressive CD manifested independently of thoracolumbar profile changes. Increased baseline C2-C7 SVA, C2 slope, and prior surgical history increased new-onset CD odds at 1 and 2 years.

Lumbar Spine

Keywords: cervical deformity, adult spinal deformity, new-onset cervical deformity, nonoperative

INTRODUCTION

Successful efforts in addressing adult spinal deformity (ASD) regarding the sagittal plane have been recently undertaken, and have also begun to incorporate analyses of upper spinal regions for the maintenance of global alignment.[1,2] While surgical intervention for ASD has demonstrated effectiveness and is regarded as the more viable treatment approach in select patients, conservative management remains the mainstay initial treatment form[3]; however, the lack of corrective alignment with the potential for subsequent degeneration during nonoperative care may portend to clinically important compensatory changes in the cervical spine. Cervical changes in ASD patients recommended for conservative treatment have not been investigated, and this gap in knowledge informs the present study.

Radiographic analyses of cervical alignment (CA) are marked by variations in defining "cervical deformity" (CD) in contrast to CA. Past efforts have highlighted a primary marker of CD as a large C2-C7 sagittal vertical axis (SVA, usually $\geq$ 4 cm), which has been correlated with poor clinical outcomes.[4] Building on this, Scheer et al in 2013 utilized the chin-brow vertical angle and C2-SVA to characterize CD, citing horizontal gaze maintenance and neck pain reduction as primary deformity drivers.[5,6] As the literature has evolved, a more comprehensive definition of CD has been postulated by Passias et al to incorporate 3 cervical parameters: T1 slope minus cervical lordosis $>$ 20°, C2-C7 kyphosis $\geq$ 10°, and C2-C7 SVA $\geq$ 4 cm.[7] Conversely, few efforts however have been directed toward determining radiographic ranges of "normative" CA. Nonetheless, the relation between cervical and thoracolumbar deformities is increasingly investigated, though chiefly following surgical deformity correction. Oh et al recently reported baseline cervical hyperlordosis deformity ($>$ 15°) rates in 48.9% of ASD patients, which persisted at 3 months and 2 years after thoracolumbar surgical correction.[8] These authors also observed that C2-C7 SVA increased following thoracolumbar surgery (41.7° to 47.0°).[8] Postoperative CD after ASD surgery as reported by Passias et al was similarly high at 47.7%.[7]

As the cervical spine is the most mobile segment of the spinal column, it is susceptible to developing changes in alignment in order to maintain the head over the pelvis, thereby facilitating horizontal gaze. Moreover, CA pathology warrants specific consideration, with increasing reports of correlations between health-related quality of life (HRQoL), adverse health and function effects on patients, and sagittal spinal alignment parameters.[9–12] Thoracolumbar deformities thus have important ramifications on upper and lower segmental alignment. However, reciprocal changes in neighboring spine segments have not been thoroughly quantified in nonoperative patients. Effectively, present understanding of the mechanisms by which such changes occur in both operative and nonoperative populations, and whether they are inherent to the disease itself or the intervention, remains thus incomplete. As such, this analysis endeavored to report on new-onset CD among patients with preexisting and maintained thoracolumbar spinal deformities treated nonoperatively.

METHODS

Data Source

This study is a retrospective analysis of a prospectively collected multi-center database for consecutively enrolled operative and nonoperative ASD patients at 11 participating centers around the United States from 2008 to 2014. Prior to study initiation, each participating site received Institutional Review Board approval. Inclusion criteria for the database was patient age $>$ 18 years with a diagnosis of ASD, defined as the presence of: scoliosis $\geq$ 20° (measured by major coronal Cobb angle), SVA (distance between the C7 plumb line and posterior superior margin of the sacrum) $\geq$ 5cm, pelvic tilt $\geq$ 25°, or thoracic kyphosis $>$ 60°. The decision to pursue operative or nonoperative treatment for each patient was arrived at during consultation between the patient and surgeon, and was ultimately guided by patient choice. There was no attempt to randomize patients in this study. This study included only ASD patients treated nonoperatively with complete demographic, radiographic, and HRQoL data at baseline and 1- and 2-year follow-up examinations.

Assessment of CD

CD has been previously radiographically defined as T1 slope minus cervical lordosis (T1S – CL) $>$ 20°, C2-C7 SVA $\geq$ 40mm, or C2-C7 kyphosis (C2-C7 CK) $<$ –10°.[7,11] Patients included within our CD cohort met $\geq$ 2 of the aforementioned criteria on baseline or yearly follow-up radiographs. Cervical alignment was defined as $\geq$ 2 of the following parameters on baseline and yearly follow-up radiographs: T1S – CL $<$ 20°, C2-C7 SVA $\leq$ 40mm, or C2-C7 CK $\leq$ 0°. Nonoperative ASD patients were classified as displaying "new-onset CD" at each follow-up time point and used for analysis only if they were categorized as displaying CA on their baseline radiographs.

Data Collection and Analysis

Collected data included patient demographics (age, gender, body mass index, medical comorbidities) and HRQoL outcome scores at each follow-up interval, including the following: Oswestry Disability Index (ODI), Short-Form (SF-36) Health Survey Mental and Physical component summaries, Scoliosis Research Society (SRS) patient questionnaire

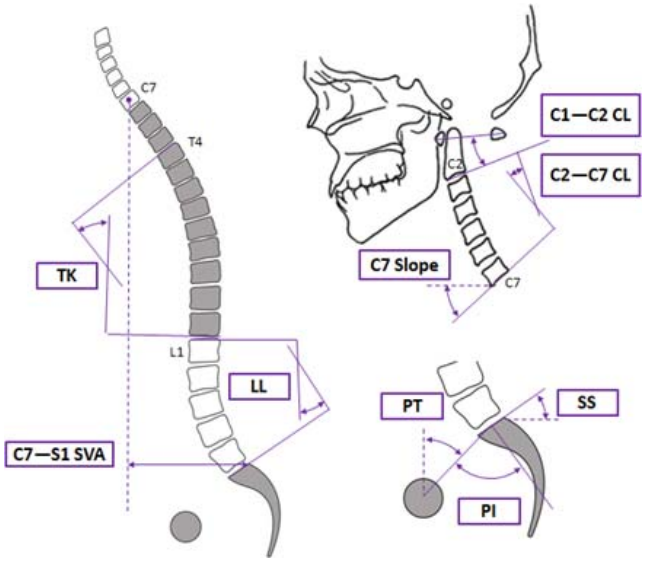

Figure 1. Spinopelvic parameters: LL indicates lumbar lordosis; TK, thoracic kyphosis; PI, pelvic incidence; SS, sacral slope; PT, pelvic tilt; SVA, C7-S1 sagittal vertical axis; and CL, C1-C2 and C2-C7 cervical lordosis. The parameter of C7 slope is also depicted.

(SRS-22r) activity), pain, appearance, satisfaction, mental, and total.

Regional and global radiographic parameters (Figure 1) were analyzed and measured from full-length free-standing lateral spine radiographs (91-4 cm [36-inch] cassette) with visible cervical spine at baseline, 1-year follow-up, and 2-year follow-up with a validated software system (SpineView, ENSAM PariTech, Paris, France) at a single center with high accuracy and reliability.[13–15] Cervical spine measurements included the following: C2-C7 cervical lordosis (angle between lower endplates of C2 and C7); C2 and C7 slopes (angle between horizontal and lower vertebral endplate); SVA (distance between the C7 plumb line and posterior superior margin of the sacrum) for C2-C7 and C2-T3; mismatch between T1-slope and cervical lordosis (T1S – CL), the cervical analog of pelvic incidence minus lumbar lordosis (PI – LL). The following pelvic parameters were obtained: pelvic tilt, pelvic incidence, and sacral slope. Collected thoracolumbar measurements included coronal Cobb angles of thoracic and lumbar curves, T (T4-T12; Cobb angle between superior T4 endplate and inferior T12 endplate), lumbar lordosis (Cobb angle between superior endplates of L1 and S1), SVA (C7 plumb line relative to S1), global angulation (C2-S1), and T1 pelvic angle (angle between femoral head axis to T1 center, and line from femoral head axis to middle of S1 endplate).

Statistical Analysis

Analyses were performed using Statistical Package for the Social Sciences version 20.0 (SPSS Inc, Chicago, Illinois) and R Statistical Package.[16] Variables were assessed for normality utilizing the Shapiro-Wilks test. Independent t tests, Mann-Whitney U, and χ^2comparisons were used to compare continuous (patient demographics, radiographic measurements, and HRQoL data) and categorical variables (gender, comorbidities) between "new-onset CD" versus "Jmaintained CA" patient groups at each follow-up time interval. Variables with P values of $< .1$ on univariate analyses were considered potential predictors of new-onset CD. These were evaluated in multivariable binary logistic regression models built with backward elimination to determine independent predictors of developing new-onset CD at each follow-up interval. Paired t tests and Wilcoxon signed-rank tests were utilized to compare changes in cervical and thoracolumbar sagittal alignment from baseline to subsequent yearly follow-up intervals. Multivariate repeated-measures mixed models measured the impact of new-onset CD on HRQoL scores at 1- and 2-year follow-up visits. The models were adjusted for known confounders of HRQoL, including age and baseline comorbidity status (Charlson Comorbidity Index score). A P value of $< .05$ was used for statistical significance, and odds ratios are reported as (OR [95% CI], P value). Parametric and nonparametric tests were utilized appropriately.

RESULTS

Patient Population and Cervical Radiographic Profile

A total of 143 patients met inclusion criteria, amongst which 123 were female (86.0%). The overall cohort had a mean age of 54.0 ± 15.3 years (range: 18-81 years), and an average body mass index of 25.6 ± 6.1 kg/m^2 (range: 17.0-48.3 kg/m^2). At baseline, 88 (61.5%) patients were classified as showing CA while 55 (38.5%) had CD based on the respective specified criteria for each group. Regarding deformity thresholds, 51.7% of patients met the CK threshold ($> 10°$), 58.7% met T1S – CL threshold ($> 20°$), and 42.0% met SVA threshold (> 40mm). Table 1 presents baseline demographic and radiographic profiles of the CA groups compared to the remaining patients. The CA group at

Table 1. Univariate (independent *t* test and χ^2) results for comparison of baseline patient demographic characteristics and radiographic measurements between cervically aligned patients at baseline and the remaining study cohort.

Baseline Variables	Cervical Alignment (n = 88)	Remaining Cohort (n = 82)	*P*
Patient Demographics			
Age, y	52.68 ± 15.11	54.94 ± 15.38	.384
Weight, kg	66.49 ± 13.71	71.66 ± 21.49	.085
BMI, kg/m^2	24.56 ± 4.47	26.40 ± 6.94	.059
% Female	85.0%	86.7%	.475
Comorbidities			
Prior spine surgery, %	15.3%	19.8%	.324
Arthritis, %	18.3%	22.9%	.328
Depression, %	16.7%	9.8%	.160
Diabetes, %	3.3%	3.6%	.650
Hypertension, %	10.0%	25.3%	**.016***
Neurologic, %	3.3%	1.2%	.380
Osteoporosis, %	8.3%	10.8%	.421
Smoking history, %	11.7%	8.5%	.366
Radiographic parameters			
Baseline PT	18.35 ± 9.28	22.08 ± 10.08	**.025***
Baseline PI	52.84 ± 11.46	57.52 ± 13.08	**.028***
Baseline SS	34.49 ± 10.41	35.46 ± 10.63	.589
Baseline PI − LL	3.32 ± 14.48	8.48 ± 16.81	.059
Baseline T1S − CL	12.43 ± 5.36	25.24 ± 5.02	< **.001***
Baseline C2-C7 CL	13.33 ± 12.14	−3.54 ± 11.84	< **.001***
Baseline C2-C7 SVA	28.42 ± 17.20	29.59 ± 14.07	.719
Baseline C2-T3	9.97 ± 13.07	−3.54 ± 11.84	< **.001***
Baseline C2 slope	11.34 ± 5.54	23.10 ± 5.39	< **.001***

Abbreviations: BMI indicates body mass index; PT, pelvic tilt; PI, pelvic incidence; SS, sacral slope; PI − LL, mismatch between pelvic incidence and lumbar lordosis; T1S − CL, mismatch between T1 slope and cervical lordosis; CL, cervical lordosis; and SVA, sagittal vertical axis.
*Bolded cells are statistically significant to $P < .05$.

baseline had mean age of 52.7 ± 15.1 years, mean body mass index of 24.6 ± 4.5 kg/m^2, and comprised 85.0% females. Cervical alignment patients, as demonstrated by their radiographic profile categorization, displayed smaller T1S − CL (12.4 versus 5.4, $P < .001$) and larger C2-C7 lordosis (13.3 versus –3.4, $P = .002$).

New-Onset CD

The prevalence of new-onset CD from baseline CA patients was 30.0% and 41.7% at 1- and 2-year follow-up examinations, respectively (Figure 2). In all, 18 patients with CD at the 1-year follow-up were de novo cases. Out of these, 11 patients (18.3%) maintained this new-onset CD from 1 to 2 years, whereas 7 patients (11.7%) improved their CA at the 2-year follow-up, mainly due to spontaneous restoration of normal C2-C7 SVA (n = 6). At the 2-year follow-up, 14 (23.3%) new patients developed CD. Following initial CA evaluation within the total cohort, the trend for C2-C7 CK as the most common presentation of CD persisted among new-onset CD patients at each follow-up time point (Table 2): C2-C7 cervical lordosis rates at 1- and 2-year follow-up visits were 56.7% and 55.0%.

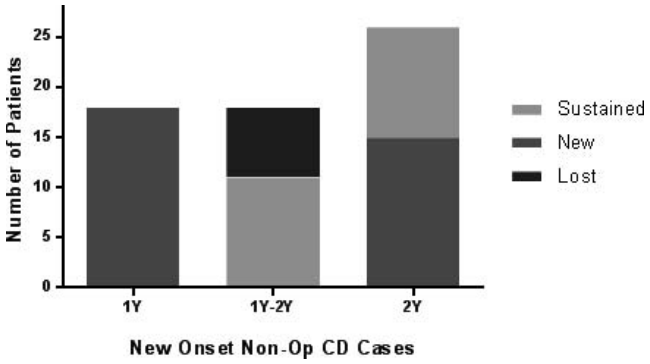

Figure 2. Distribution of new onset nonoperative cervical deformity cases at baseline and at 1 and 2 years. CD indicates cervical deformity; new, unique patients displaying new onset CD at 1 year (n = 18); sustained, patients with new-onset CD that persisted from 1 year to 2 years (n = 11); lost, patients whose new-onset CD corrected from 1-year to 2-year follow-up (n = 7).

Table 2. Comparison of thoracolumbar sagittal profiles changes (gauged by pelvic tilt, thoracic kyphosis, and global angulation) at each follow-up interval for adult spinal deformity patients that were cervically aligned and deformed at baseline.

Sagittal Parameter (Difference From Baseline to X Year)	Cervical Alignment	Cervical Deformity	*P*
1-year follow-up			
S1 PT (PT)	0.39 (4.10)	−0.76 (3.16)	.410
T4-T12 (TK)	2.96 (6.60)	2.80 (5.72)	.945
C2-S1 (GA)	1.11 (7.90)	−3.82 (5.34)	.090
2-year follow-up			
S1 PT (PT)	0.212 (2.80)	1.78 (5.43)	.277
T4-T12 (TK)	−0.83 (5.62)	−1.48 (8.80)	.801
C2-S1 (GA)	−1.40 (6.43)	−8.11 (13.46)	.069

Abbreviations: PT indicates pelvic tilt; TK, thoracic kyphosis; and GA, global angulation.

Table 3. Univariate (independent *t* tests, and Mann-Whitney *U* and χ^2 analyses) results for the comparison of baseline sagittal parameters of new-onset cervical deformity patients to those with maintained cervical alignment at 1- and 2-year follow-up examinations. All included variables with $P < .1$ were assessed in multivariate models.

	Maintained CA	New-Onset CD	*P*
1 year postenrollment			
Baseline weight	64.17 ± 12.67	71.77 ± 14.88	**.049***
Diabetes	0.0%	11.1%	.086
Prior history of spine surgery	7.3%	33.3%	**.018***
Baseline T1 slope	22.76 ± 8.57	29.39 ± 12.84	**.022***
Baseline C2-C7 CL	10.41 ± 10.26	16.80 ± 15.03	.061
Baseline C2-C7 SVA	23.48 ± 14.75	39.93 ± 17.38	**< .001***
Baseline C2-T3 SVA	51.00 ± 13.73	66.96 ± 30.93	**.007***
Baseline C2-S1 SVA	29.14 ± 41.42	51.23 ± 46.56	.073
2 years postenrollment			
Baseline C2-C7 SVA	23.22 ± 14.23	35.70 ± 18.60	**.005***
Baseline C2 slope	10.05 ± 5.83	13.14 ± 4.64	**.032***

Abbreviations: CA indicates cervical alignment; CD, cervical deformity; CL, cervical lordosis; and SVA, sagittal vertical axis.
*Bolded cells are statistically significant to $P < .05$.

Significant differences in baseline demographic and radiographic parameters in new-onset CD and maintained CA groups are reported in Table 3. Patients with 1-year new-onset CD included fewer females (CD: 66.7% versus CA: 92.9%; $P = .016$) and had greater weight (CD: 71.8 versus CA: 64.2 kg; $P = .049$) compared to maintained CA patients. The 2 groups differed predominantly on the basis of baseline radiographic parameters at each follow-up interval: baseline C2-C7 SVA was significantly larger in new-onset CD nonoperative patients at 1 year (CD: 39.9 versus CA: 23.5 mm; $P < .001$), and 2 years (CD: 34.8 versus CA: 23.5 mm; $P = .010$); baseline C2-T3 SVA was significantly larger in new-onset CD patients at 1 year (CD: 67.0 versus CA: 51.0 mm; $P < .001$); new-onset CD patients displayed larger T1 slope at 1-year follow-up (CD: 29.4° versus CA: 22.8°; $P = .022$), and greater C2 slope at 2 years (CD: 13.3° versus CA: 9.8°; $P = .016$). Additionally, patients that developed de novo CD at 2 years displayed significant deterioration of alignment incorporating the cervicothoracic junction: T1 slope, C2-T3 angle, and C2-T3 positive translation all significantly increased during nonoperative treatment ($P < .023$ all cases) (Table 4).

Table 4. Paired *t* tests and Wilcoxon signed-rank tests for cervical and spino-pelvic parameter changes from baseline to 1- and 2-year follow-up, for CD-1Y and CD-2Y deformity groups, respectively. Numbers in parentheses are standard deviations.

	New-Onset Cervical Deformity Group					
	CD-1Y			CD-2Y		
Parameters	**Baseline**		**1 Year**	**Baseline**		**2 Years**
cSVA, mm	45.00 ± 15.88	0.341	48.04 ± 9.53	35.10 ± 19.98	0.674	36.58 ± 17.69
CL, °	19.25 ± 13.90	0.115	22.17 ± 11.99	5.70 ± 18.73	0.081	10.33 ± 13.73
C2-T3 SVA, mm	78.22 ± 21.85	0.117	84.74 ± 17.03	59.76 ± 31.88	**0.014***	66.34 ± 27.93
C2-T3, °	10.25 ± 15.37	**0.013***	16.95 ± 14.11	−0.26 ± 16.25	**0.004***	7.51 ± 14.25
T1 Slope, °	29.39 ± 12.84	0.368	30.74 ± 13.48	25.06 ± 12.57	**0.023***	28.58 ± 13.44
SS, °	32.98 ± 8.45	0.129	34.31 ± 9.58	34.64 ± 7.34	0.286	35.56 ± 8.93
PT, °	19.11 ± 8.44	0.177	17.72 ± 7.20	19.27 ± 8.59	0.701	19.59 ± 9.86
PI − LL, °	4.88 ± 12.74	0.829	5.18 ± 14.07	3.88 ± 12.54	0.331	5.24 ± 14.96
SVA, mm	24.16 ± 44.68	0.159	33.52 ± 43.43	14.66 ± 50.03	0.314	21.15 ± 38.75
TK, °	36.06 ± 19.67	0.383	34.74 ± 18.66	34.48 ± 16.53	0.964	34.56 ± 16.72
LL, °	47.23 ± 11.06	0.768	46.86 ± 13.02	50.03 ± 11.11	0.728	49.54 ± 14.36
C2-S1, °	22.05 ± 10.94	0.078	17.99 ± 12.88	14.35 ± 10.61	**0.001***	22.50 ± 8.06

Table 5. Binary logistic regression modeling for potential independent predictors of new-onset nonoperative cervical deformity at each follow-up year based on significant factors derived from previous univariate analysis.

	Odds Ratio	95% CI (Lower-Upper)	*P*
1-year follow-up			
Baseline weight, per 1-kg increase	1.04	0.99-1.09	.137
Prior history of spine surgery	6.75	1.03-44.2	**.047***
Baseline T1 slope, per 1-degree increase	1.05	0.93-1.18	.436
Baseline C2-C7 SVA, per 1-mm increase	1.41	1.02-1.40	**.025***
Baseline C2-T3 SVA, per 1-mm increase	0.99	0.91-1.07	.726
2-year follow-up			
Baseline C2 slope, per 1-degree increase	1.12	1.00-1.24	**.041***
Baseline C2-C7 SVA, per 1-mm increase	1.04	1.00-1.08	**.032***

Abbreviations: CI indicates confidence interval; SVA, sagittal vertical axis.

Predicting New-Onset CD

Positive predictors (those associated with higher odds of developing new onset CD) identified through multivariate analysis are reported in Table 5. Baseline C2-C7 SVA was significantly associated with increased risk of new-onset CD at 1-year (1.14 [1.02-1.40]; $P = .025$) and 2-year (1.04 [1.00-1.08]; $P = .032$) follow-up. A prior history of spine surgery at baseline was associated with new-onset CD risk at 1 year (6.75 [1.029-44.23]; $P = .047$). Baseline C2 slope was also associated with increased risk of CD at 2-year follow-up (1.12 [1.00-1.24]; $P = .041$).

Sagittal Profile Comparison

Patients displaying new-onset CD at 1- and 2-year follow-up were evaluated for changes in their global sagittal spino-pelvic profiles (measured with thoracic kyphosis, global angulation, SVA, T1 pelvic angle) in comparison to patients that maintained CA. Both groups were consistently statistically similar from baseline to each follow-up period ($P > .05$ for all cases each year; Table 6).

Table 6. Comparison of thoracolumbar sagittal profiles changes at each follow-up interval (1 and 2 years) for adult spinal deformity patients that were cervically aligned and developed new-onset deformity at 1- and 2-year follow-up.

Sagittal Parameter (Difference From Baseline to X year)	New-Onset Cervical Deformity	Maintained Cervical Alignment	*P*
1-year follow-up			
C7-S1 SVA, mm	9.38 ± 26.98	4.32 ± 22.79	.459
T4-T12 TK, °	1.32 ± 6.24	2.14 ± 7.68	.691
TPA, °	0.91 ± 2.63	0.31 ± 2.16	.359
C2-S1 GA, °	−4.06 ± 7.92	−0.10 ± 7.40	.095
2-year follow-up			
C7-S1 SVA, mm	6.48 ± 31.59	3.48 ± 20.33	.658
T4-T12 TK, °	−0.80 ± 8.80	−0.16 ± 7.96	.970
TPA, °	0.34 ± 3.19	0.24 ± 2.08	.882
C2-S1 GA, °	−8.15 ± 9.75	−1.68 ± 6.74	.200

Abbreviations: SVA indicates sagittal vertical axis; TK, thoracic kyphosis; TPA, T1 pelvic angle; GA, global angulation.

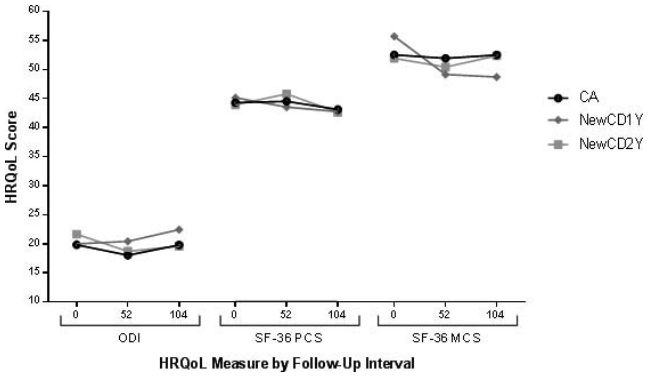

Figure 3. Patient-reported health-related quality of life at baseline, 1-year follow-up, and 2-year follow-up for Oswestry Disability Index (ODI), and Short Form 36 (SF-36) physical and mental component scores for cervically aligned patients at baseline and those that developed new-onset cervical deformity at each year. Abbreviations: HRQoL, health-related quality of life; PCS, physical component score; MCS, mental component score; CA, cervically aligned; NewCD1Y, new-onset cervical deformity at 1 year; NewCD2Y, new-onset cervical deformity at 2 years.

Patient-Reported Outcomes

Patient-reported outcomes are displayed in Figure 3. For nonoperative patients that developed new-onset CD at 1-year follow-up, there were no differences in HRQoL scores compared to CA patients in all categories ($P > .05$). By 2-year follow-up, only the SRS mental score difference from baseline to 2 years was significantly greater in new-onset CD patients (new-onset CD: 4.34 versus CA: 0.11; $P = .018$). Multivariate measures mixed models revealed that at 1- and 2-year follow-up for nonoperative patients, development of CD did not significantly impact patient-reported outcomes, including SRS satisfaction, in all considered categories ($P > .05$).

DISCUSSION

In contrast to thoracolumbar malalignment, there is a relative paucity of literature characterizing CDs, thereby leading to wide variations in surgical planning and management of these conditions among spine surgeons. The cervical spine's structural complexity and functional associations with lower spinal regions make it a critical area for alignment studies however, and many patients may exhibit simultaneous ASD and CD (CD). The optimal treatment algorithm, whether conservative or operative, and clinical importance of these pathologies, however, is not yet known, especially for cases in which CD develops secondary to ASD. This study is one of the first to consider this, by implementing a comprehensive, 3-part definition for

CA and CD based on recently published literature to evaluate de novo CD for ASD patients treated nonoperatively at an extended follow-up.[7]

The baseline rate of CA was 61.5%, with subsequent development of CD observed in 30.0% of patients at 1-year and 41.7% at 2-year follow-up, for an average rate of 35.9%. Patients were classified with CD based on criteria suggested by Passias et al: C2-C7 SVA $>$ 4cm, T1S $-$ CL $>$ 20°, and C2-C7 Cobb angle $>$ 10°.[7] While not otherwise investigated in a nonoperative setting, Passias et al implemented this radiographic definition to evaluate new-onset CD following ASD surgical correction, reporting a rate of 47.7%. This rate is similar to the present study's, signifying that the natural history of CD development in ASD patients remains unaltered by surgical intervention. The increase in new-onset CD prevalence from 1-2 years observed in this study may reflect well-known reciprocal changes and mechanisms in operative ASD patients with cervical pathology as a means of restoring and maintaining horizontal gaze.[12] Our results reflect how compensation occurs initially with ASD onset, but that CD progression may develop independently and in a nonoperative ASD population, CD is not solely attributable to surgical overcorrection and postoperative disease progression. We also observed that C2-C7 CK $<$ $-$10° was the most prevalence driver of CD at each follow-up year. This is consistent with prior reports, such as that of Yu et al, noting that CK characterized cervical malalignment in 40% of cases.[17] The high concurrence of ASD with CD in nonoperative and operative settings reveals that the cervical spine's self-corrective capacity is more limited in ASD cases as anticipated, and that ASD itself is partially responsible for the CA changes that are occurring; the importance of future study lies then in the efficacy and type of treatment for these cases.

New-onset CD has not been clinically evaluated in nonoperative patients. Despite elevated deformity rates, de novo CD occurrence at each follow-up year largely did not impact patient outcomes, determined by the Oswestry Disability Index, SF-36, and SRS-22r questionnaires. The rates of change and overall change were also similar for the yearly new-onset CD groups compared to CA patients, with the exception of SRS mental baseline-to-2-year difference, which was higher CD cases, indicating less improvement. These results may point to progressive neurological deficits linked with CD, and it is possible that our observation of progressive CD in nonoperative patients may result in neurological impairment, consistent with the natural history of several cervical pathologies left untreated.[18,19] Effectively, Grosso et al found a significant relationship between modified Japanese Orthopaedic Association (mJOA) improvement, achievement of postoperative cervical lordosis, and greater degree of focal kyphosis correction in the setting of CD corrective surgery.[20] Nonetheless, our results pertain to the uncertain position CD retains, when present in conjunction with ASD, on patient outcomes which was also initially highlighted recently by Passias et al.[7]

First-visit identification of those ASD patients at risk for new CD is crucial and can consequently alter a surgeon's plan of treatment. Increased baseline C2-C7 SVA and C2 slope were preoperative radiographic markers associated with increased odds of developing new onset CD after conservative ASD treatment at both 1 and 2 years. These measures likely reflect overall balance of the head over the spine. Particularly with respect to C2-C7 SVA, it is not surprising that greater baseline deformity links patients to subsequent upper spinal malalignment: Passias et al observed, for instance, that surgical ASD patients that remained malaligned 2 years postoperatively had larger preoperative C2-C7 SVAs[11]; similarly, Oh et al noted significant deteriorative changes in C2-C7 SVA at 3 months and 2 years following thoracic deformity correction among 57 ASD patients.[8] These authors also observed that among 22 ASD patients with preoperative C2-C7 SVA $>$ 4cm, cervical malalignment persisted in 74% of cases, and was only corrected in 26%.[8] Similarly, in an analysis of 470 adults with thoracolumbar deformities, Smith et al saw significantly greater cervical sagittal malalignment ($>$ 4 cm) in patients with higher C7-S1 SVA and pelvic tilt.[6] These identified factors predisposing ASD patients to CD should be taken into consideration by health-care providers in planning and identifying at-risk patients.

Recent findings suggest that the ability of cervical spine to compensate for global sagittal malalignment can be reversible or permanent. For example, Smith et al demonstrated spontaneous improvement of cervical hyperlordosis following correction of thoracolumbar deformities.[12] Conversely, Oh et al noted that the cervical malalignment corrected in only 26% of patients operated for thoracic defor-

mity.[8] In our study, we noted a progressive trend for increase in the rate of CD development with subsequent follow-up, despite no significant changes in global deformity parameters compared to maintained CA cases. The observation here that CD progression may develop independently in patients with ASD suggests that it cannot be solely attributable to compensatory mechanisms or surgical overcorrection.[11,21,22] ASD treated conservatively may result in a reduced capacity for self-correction.[11] New CD may then be a marker of potential disease progression, or more severe pathology despite similar global measurements. The finding that a prior history of spine surgery increased the risk of new-onset CD at 1-year follow-up in this study also underscores this, and retains clinical value in considering the protracted risk inherent in treating ASD. These identified factors predisposing ASD patients to CD are useful in guiding surgeons in treatment course planning and identifying at-risk patients.

Our results hinge on effectively defining CD and alignment, which remains difficult. The criteria in this report retain validity across other studies quantifying CD. Cervical sagittal spine plane translation is most commonly measured with C2-C7 SVA, which is particularly relevant as it has been directly correlated with poorer SF-36 Physical Component Score and neck disability index outcomes.[23] Multiple studies have defined a 4-cm C2-C7 SVA threshold for deformity.[7,23] Recent presented data from Protopsaltis et al. proposed $T1S - CL > 20°$ as effective in quantifying CD,[24] and this cutoff has since been implemented in numerous CD studies, such as those by Passias et al and Lee et al.[7,9] Clinical evaluations for CK remain to be fully proposed, but we built on use of C2-C7 CK $> 0°$ by Smith et al as a measure of CD in our study.[6] The most recent, and most widely accepted definitions for CD, utilizing previously discussed sagittal radiographic regional and global parameters, are described in the Ames–International Spine Study Group CD classification.[25] In applying the 3 measures of C2-C7 SVA, T1S – CL, and CK in unison, we aimed to target those patients with stricter CDs.

While typically presented as the first line of management, the utility of nonoperative ASD treatment is contested. Indeed, surgery for ASD is consistently well supported in the literature, but studies have been finding value in nonoperative treatment for ASD from a HRQoL standpoint.[26–28] Liu et al noted that though operative ASD patient did demonstrate significant mean improvement and met minimal clinically important difference (MCID) thresholds, nonoperative patients still improved in at least 1 outcome measure at 1-year follow-up.[29] Specifically, nonoperative ASD patients significantly improved in SRS pain evaluation from baseline to 1 year, and more than 50% gained MCID in 1 year Oswestry Disability Index, SRS pain, SRS appearance, and SRS mental scores.[29] In one of the few studies looking at CD in nonoperative patients, Schwartz et al observed a worsening in CK ($> 10°$, similar to our criteria for deformity) for pediatric posttraumatic patients receiving conservative treatment.[30] The progression of CD noted in our present study parallels this study's results. The development of CD as secondary to ASD, as seen in this study, clearly demonstrates the need for further inquiry into the mechanistic progression of these spinal deformities, and how treatment can influence it.

Limitations

This study is limited in its retrospective design, and that the primary inclusion criterion for inclusion into the multicenter database was an ASD diagnosis. Further, current HRQoL measures are not specific to cervical pathology. Thoracolumbar deformity may also overwhelming influence currently utilized HRQoL metrics. A lack of HRQoL sensitivity for cervical pathology may limit its ability to accurately capture the clinical effects of CD development. Variations in radiographic protocol (patient positioning, especially) may also exist between enrollment sites, thereby potentially impacting radiographic determination of deformity and measurements. Incomplete short-term follow-up data was a limitation belonging to the multicenter database used as well. While all patients within this study had complete baseline, 1-year, and 2-year follow-up data, investigation of shorter follow-up time points (< 1 year) are needed for a more complete assessment of CA changes amongst nonoperative ASD patients. Additionally, though our implemented definitions for CD and CA have been previously used in the literature, these criteria still warrant further study and refinement. Lastly, a large proportion of included patients in this study were female, thereby potentially limiting the generalizability of these results.

Conclusion

This study is the first assessing cervical radiographic changes concomitant with established thoracolumbar sagittal deformities in nonoperative patients at extended follow-up. Of 143 nonoperative ASD patients, 61.5% of patients were classified as cervically aligned at baseline; subsequent de novo regional deformities occurred at 1- and 2-year intervals, with a peak at 2 years (41.7%). The most consistent form of new-onset CD was CK at each year. Progressive CDs manifested independently of thoracolumbar profile changes. Increased baseline C2-C7 SVA, C2 slope, and a prior surgical history increased new-onset CD odds at 1 and 2 years. These findings underscore the importance of full radiographic assessment and screening for CD at first visit among ASD patients for those individuals at risk for developing CD, particularly in cases seeking nonoperative care to optimize prolonged treatment.

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