Original Article

Effect of age-adjusted alignment goals and distal inclination angle on the fate of distal junctional kyphosis in cervical deformity surgery

ABSTRACT

Background: Age-adjusted alignment targets in the context of distal junctional kyphosis (DJK) development have yet to be investigated. Our aim was to assess age-adjusted alignment targets, reciprocal changes, and role of lowest instrumented level orientation in DJK development in cervical deformity (CD) patients.

Methods: CD patients were evaluated based on lowest fused level: cervical (C7 or above), upper thoracic (UT: T1–T6), and lower thoracic (LT: T7–T12). Age-adjusted alignment targets were calculated using published formulas for sagittal vertical axis (SVA), pelvic incidence-lumbar lordosis (PI-LL), pelvic tilt (PT), T1 pelvic angle (TPA), and LL-thoracic kyphosis (TK). Outcome measures were cervical and global alignment parameters: Cervical SVA (cSVA), cervical lordosis, C2 slope, C2–T3 angle, C2–T3 SVA, TS-CL, PI-LL, PT, and SVA. Subanalysis matched baseline PI to assess age-adjusted alignment between DJK and non-DJK.

Results: Seventy-six CD patients included. By 1Y, 20 patients developed DJK. Non-DJK patients had 27% cervical lowest instrumented vertebra (LIV), 68% UT, and 5% LT. DJK patients had 25% cervical, 50% UT, and 25% LT. There were no baseline or 1Y differences for PI, PI-LL, SVA, TPA, or PT for actual and age-adjusted targets. DJK patients had worse baseline cSVA and more severe 1Y cSVA, C2–T3 SVA, and C2 slope ($P < 0.05$). The distribution of over/under corrected patients and the offset between actual and ideal alignment for SVA, PT, TPA, PI-LL, and LL-TK were similar between DJK and non-DJK patients. DJK patients requiring reoperation had worse postoperative changes in all cervical parameters and trended toward larger offsets for global parameters.

Conclusion: CD patients with severe baseline malalignment went on to develop postoperative DJK. Age-adjusted alignment targets did not capture differences in these populations, suggesting the need for cervical-specific goals.

Keywords: Age-adjusted, alignment targets, cervical deformity, distal junctional kyphosis, inclination angle

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INTRODUCTION

Cervical deformity (CD) corrective surgery has been shown to provide substantial improvements in health-related quality of life, especially for patients with severe neurologic impairments, disruption of horizontal gaze, and multilevel degeneration.[1-3] Despite these positive outcomes, rates of adverse events and rates of reoperation following CD-corrective surgery remain relatively high, with junctional kyphosis posing a particularly unique and problematic complication in surgical CD populations.[4] Defined as loss of alignment >10° between the superior endplate of the lowest instrumented vertebra and the inferior endplate of the adjacent distal vertebra, distal junctional kyphosis (DJK) may lead to inferior postoperative pain and disability outcomes, loss of surgical correction, and costly revision surgery.[5]

Preoperative radiographic alignment has previously been identified as a key factor associated with the development of DJK following CD-corrective surgery. A recent analysis of 101 surgical CD patients showed malalignment of thoracic kyphosis (TK), cervical kyphosis, and cervical sagittal vertical axis (cSVA) to each be associated with a five-to six-fold increase in the risk of 1-year postoperative DJK.[6] Additional studies have also identified age-associated diseases such as osteoporosis to increase the risk of junctional kyphosis following spine surgery.[7] These findings combined with recent research establishing age-specific radiographic alignment targets for deformity patients, prompt interest in assessing the age-specific effects of alignment on the development of DJK; however, to date, there are no studies in the literature investigating this relationship.[8]

This study aimed to assess age-adjusted alignment targets in the context of DJK. Specifically, this study assessed whether failing to achieve ideal age-adjusted radiographic alignment following CD-corrective surgery corresponded with an increased risk of DJK at 1-year postoperative. Furthermore, as CD-corrective surgery has also been associated with reciprocal changes in distal alignment, this study sought to assess the relationship between postoperative reciprocal changes, orientation of the lowest instrumented vertebra level, and DJK.

METHODS

Patient population

This study is a retrospective review of a prospectively collected multicenter database of CD patients. Internal Review Board approval was obtained at each participating site before study initiation, and informed consent was given by each included patient. Inclusion criteria for the database were patients ages ≥18 years, and radiographic evidence of CD at baseline assessment, defined as the presence of at least one of the following: cervical kyphosis (C2–C7 Cobb angle >10°), cervical scoliosis (C2–C7 coronal Cobb angle >10°), C2–C7 sagittal vertical axis (SVA) (cSVA) >4 cm, or chin-brow vertical angle (CBVA) >25°. CD patients meeting radiographic inclusion with available baseline and 1-year follow-up data were included in this study. Patients with active tumors or infections were excluded from the study.

Data collection and radiographic parameters

Demographic and clinical data collected included patient age, sex, body mass index (BMI), prior cervical surgery, and Charlson Comorbidity Index. Surgical data collected included operative time, estimated blood loss, surgical approach, off-label use of bone morphogenetic protein 2, osteotomy use and number of osteotomies, levels fused, and instrumentation used.

Patients were evaluated using full-length free-standing lateral spine radiographs (36 "long-cassette) at baseline and 1-year postoperative follow-up visit. Radiographs were analyzed using dedicated and validated software (SpineView®; ENSAM, Laboratory of Biomechanics, Paris, France) at a single center with standard techniques.[9-11] Measured cervical spine parameters included cSVA (offset from the C2 plumb-line and the posterosuperior corner of C7), C2–C7 lordosis (CL: Cobb angle between C2 inferior endplate and C7 inferior endplate), T1 slope minus CL (TS-CL: mismatch between T1 slope and cervical lordosis), C2–T3 angle and SVA, and CBVA (angle subtended between the vertical line and the line from the brow to the chin). Measured spinopelvic parameters [Figure 1] included: SVA (SVA: C7 plumb line

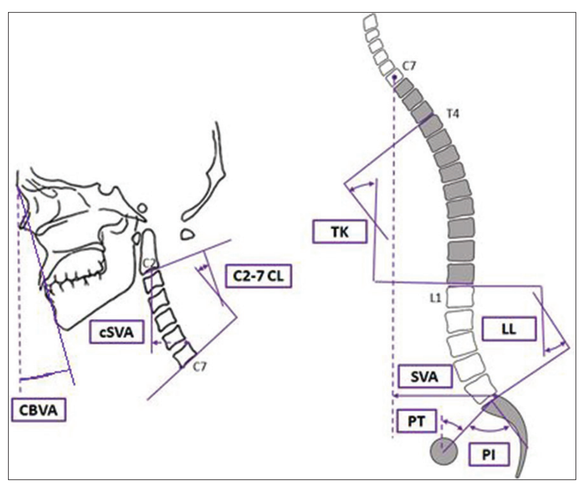

Figure 1: Schematic of measured sagittal alignment parameters for the cervical and global spinopelvic spinal regions. cSVA = cervical sagittal vertical axis; C2–C7 CL = cervical lordosis; CBVA = Chin-brow vertical angle; TK = Thoracic kyphosis; LL = Lumbar lordosis; SVA = Sagittal vertical axis; PT = Pelvic tilt; PI = Pelvic incidence

relative to the posterior-superior corner of S1), pelvic incidence (PI) minus lumbar lordosis (LL) (mismatch between PI and LL), and pelvic tilt (PT: angle between the vertical and the line through the sacral midpoint to the center of the two femoral heads).

LIV parameters were measured for this cohort and included: DJK angle (angle between the LIV superior endplate and the LIV + 2 inferior endplate) and LIV-inclination (angle between the best-fit line crossing the vertebral body center of LIV-2 to LIV and the vertical). In order to eliminate the impact of variable patient positioning on these measurements, C2 slope was added to LIV-inclination, providing a measurement in patient reference system. These two last parameters were used to quantify the orientation of the last fused segment versus the global orientation as well as versus the spinal shape.

Radiographic DJK was defined as the development of an angle $<-10°$ from the end of fusion construct to the 2nd distal vertebra, or a change in this angle by $<-10°$ from baseline to postoperative, as previously published.[4,6] In addition, patients were categorized into three groups based on the location of the UIV: patients with a UIV in the cervical spine were grouped into the cervical group, patients with a UIV between T1 and T6 were grouped into the upper thoracic (UT), and patients with a UIV between T7 and T12 were grouped into the lower thoracic (LT) group.

Age-adjusted alignment targets

Age-adjusted alignment ideal targets were calculated using published formulas for SVA, PI-LL, PT, T1 pelvic angle (TPA), and LL-TK.[8] The difference between the actual alignment for each parameter and the age-adjusted ideal was calculated and called the offset. Patients were divided by age into groups: <40, 40–65, or >65 years.

Statistical analysis

Demographic and clinical variables were assessed using Chi-squared and *t*-tests for the categorical and continuous variables, respectively. Comparisons between patients meeting radiographic criteria for DJK and those who did not (non-DJK) were performed and included demographic, surgical, and radiographic assessments. Patients were also sub-stratified by the location of the LIV to compare the LIV parameters between DJK and non-DJK patients. We also performed an analysis assessing the offset between the actual and age-adjusted ideal alignment targets for this cohort. A sub-analysis matched for baseline PI to assess age-adjusted alignment between DJK and non-DJK. Two-sided $P<0.05$ was considered statistically significant. All statistical analyses were done using the SPSS software version 23 (IBM, Armonk, NY, USA).

RESULTS

Patient population

Out of 89 eligible patients, 76 CD patients were included in this study; 63% of them were female, the mean age was 61.3 years (±10.6), and the mean BMI was 29.5 kg/m^2 (±8.3). The mean length of fusion was 6.9 levels (±2.9).

The UIV was in the cervical spine in 26.3% (n = 20), UT in 63.2% (n = 48), and LT in 10.5% (n = 8) of the cases. The mean preoperative cervical and global sagittal alignment is summarized in Table 1.

From preoperative to 1-year postoperative, CD patients significantly improved in some global and cervical parameters: TK increased from −38.3° to −42.4°, TS-CL decreased from 35.6° to 27.6°, decreased in C2 slope from 36.2° to 26.6°, and trended toward a significant decrease in cSVA from 44.8 to 40.4 mm [Table 1]. At 1-year follow-up, the rate of DJK was 26.3% (n = 20), with four patients requiring a reoperation for their DJK.

Comparing distal junctional kyphosis and nondistal junctional kyphosis patients in radiographic alignment

The breakdown of LIV for DJK patients was: 25% cervical, 50% UT, and 25% LT. The breakdown of LIV for non-DJK patients was 27% cervical LIV, 68% UT, and 5% LT. Baseline demographics, comorbidities, and frailty did not significantly differ between DJK and non-DJK patients [Table 2].

There were no significant differences between DJK and non-DJK patients in baseline, 1-year postoperative, or pre- to post-operative changes in alignment for PI, PI-LL, SVA, TPA, or PT [all $P > 0.05$, Table 3]. DJK patients had more severe baseline cSVA than non-DJK patients (55 mm v 41 mm,

Table 1: Radiographic assessment of the entire cervical deformity cohort at baseline and 1-year postoperative

Radiographic parameter	Preoperative	Postoperative	P
Pelvic incidence (°)	52.93±11.43	52.94±11.62	0.941
SVA (mm)	1.28±72.26	21.5±69.71	0.003*
Pelvic tilt (°)	18.59±11.7	18.53±11.31	0.924
PI-LL (°)	1.04±19.02	2.16±18.1	0.325
T1 pelvic angle (°)	12.73±13.01	14.44±12.47	0.036*
T4-T12 thoracic kyphosis (°)	−38.26±15.59	−42.38±15.74	<0.001*
C2-C7 CL (°)	−6.94±21.39	6.21±16.34	<0.001*
cSVA (mm)	44.78±25.49	40.37±18.42	0.055
C2-T3 Angle (°)	−16.27±21.51	−1.99±17.87	<0.001*
C2-T3 SVA (mm)	75.45±40.89	75.25±28.8	0.952
TS-CL (°)	35.62±18.8	27.65±13.41	0.001*
C2 slope (°)	36.25±20.21	26.61±14.32	<0.001*

*Statistical significance. SVA-Sagittal vertical axis, PI-LL-Pelvic incidence minus lumbar lordosis, CL-Cervical lordosis, TS-T1 slope, TS-CL-T1 slope and cervical lordosis

P = 0.027) and trended toward a higher baseline C2–T3 SVA as well (90.8 mm vs. 65.9 mm, P = 0.053). Postoperatively, DJK patients had more residual cervical malalignment than non-DJK patients, as measured by cSVA, C2–T3 angle, C2–T3 SVA, TS-CL and C2 slope [Table 3].

Comparing distal junctional kyphosis and nondistal junctional kyphosis patients in age-adjusted alignment targets

By age group, there were two patients under the age of 40, 45 patients between 40 and 65 years, and 29 patients over 65 years old. In assessing patients' 1-year postoperative alignment, we assessed the distribution of patients who met their age-adjust alignment ideals for PT, PI-LL, SVA, TPA, and LL-TK and compared differences in distribution between DJK and non-DJK patients. The distribution of patients who were matched, overcorrected, and undercorrected as compared to their age-adjusted ideals is displayed in Table 4. Comparisons between DJK and non-DJK patients using offsets between actual and age-adjusted ideal alignment revealed no significant differences [Table 5]. When controlling for baseline PI, offsets between actual and ideal alignment in these parameters did not differ, though DJK patients trended toward a larger SVA offset (DJK: −33.8 mm, non-DJK: 7.9 mm, P = 0.09).

Table 2: Baseline demographic, clinical, and neurologic assessment compared between patients with and without distal junctional kyphosis

	DJK	Non-DJK	P
Age (years)	59.68±11.7	61.9±10.2	0.429
Sex (% female)	13 (65.0)	35 (62.5)	0.533
BMI (kg/m^2)	30.7±9.7	29.1±7.9	0.481
CCI	1.07±0.96	0.88±1.3	0.612
Frailty	0.40±0.09	0.42±0.09	0.411
Depression (%)	7 (35.0)	16 (28.6)	0.394
Osteoporosis (%)	2 (10.0)	8 (14.3)	0.479
Diabetes (%)	5 (25.0)	9 (16.1)	0.284
History of smoking (%)	8 (40.0)	14 (26.9)	0.212
Baseline neurologic deficit (%)	12 (63.2)	23 (43.4)	0.113

BMI-Body mass index, CCI-Charlson comorbidity index, DJK-Distal junctional kyphosis

Distal junctional kyphosis requiring revision

Four out of twenty DJK patients required a revision surgery. DJK patients who required reoperation had significantly worse pre- to post-operative changes in all cervical alignment parameters assessed [Table 6]. DJK patients who required a reoperation trended toward larger offsets for age-adjusted alignment for global parameters (SVA offset: reop −76.9 mm v no reop −23.1 mm, P = 0.196) as compared to DJK patients who did not have a reoperation [Table 7].

LIV-inclination angle

Overall, there was no difference in LIV-inclination angle between DJK and non-DJK patients, both using the global LIV-inclination angle (20.9° ± 26.2° vs. 20.1° ± 17.9°, P = 0.875) or the patient specific one with C2 incorporated (42.6° ± 33.8° vs. 33.3° ± 25.3°, P = 0.203). However, for patients with a LIV in the UT region, DJK patients had a higher LIV-inclination angle with C2 tilt than non-DJK patients (61.9° v 41.1°, P = 0.02) and thus more anterior construct inclination.

DISCUSSION

Although DJK remains one of the most challenging complications following CD-corrective surgery, the relationship between sagittal alignment and DJK – particularly in high-risk, elderly patient populations – is under-investigated

Table 3: Comparison of preoperative alignment and postoperative alignment between distal junctional kyphosis and nondistal junctional kyphosis patients

	Preoperative			Postoperative		
	DJK	Non-DJK	P	DJK	Non-DJK	P
PI (°)	54.71±12.98	52.28±10.87	0.421	54.7±13.89	52.46±10.71	0.460
SVA (mm)	−6.26±68.89	3.89±73.83	0.601	0.53±82.85	28.39±62.45	0.122
Pelvic tilt (°)	17.93±14.82	18.83±10.5	0.770	19.25±12.31	18.16±10.97	0.714
PI-LL (°)	−1.78±26.35	2.07±15.72	0.441	−2.75±22.41	3.88±15.98	0.158
TPA (°)	11.13±16.99	13.28±11.46	0.537	13.26±15.05	14.84±11.31	0.625
T4-T12 TK (°)	−40.82±16.44	−37.33±15.32	0.395	−45.96±16.38	−40.75±15.51	0.208
C2-C7 CL (°)	−8.82±19.07	−6.21±22.37	0.656	2.36±13.81	8.43±16.35	0.143
cSVA (mm)	55.71±20.45	40.54±26.16	0.027*	50.25±17.48	36.97±17.34	0.004*
C2-T3 angle (°)	−23.14±21.06	−13.6±21.3	0.101	−11.05±15.84	2.19±16.93	0.003*
C2-T3 SVA (mm)	90.82±32.9	69.5±42.41	0.053	88.54±25.81	70.88±28.07	0.016*
TS-CL (°)	40.68±18.18	33.66±18.85	0.169	34.69±14.79	24.63±11.43	0.003*
C2 slope (°)	42.6±21.34	33.78±19.42	0.107	34.75±15.26	23.17±12.03	0.001*

*Statistical significance. PI-Pelvic incidence, SVA-Sagittal vertical axis, PI-LL-Pelvic incidence minus lumbar lordosis, TPA-T1 pelvic angle, TK-Thoracic kyphosis, CL-Cervical lordosis, TS-T1 slope, DJK-Distal junctional kyphosis. CSVA-Cervical sagittal axis, TS-CL-T1 slope and cervical lordosis in the literature. Within the body of junctional kyphosis literature that does exist, preoperative sagittal malalignment, overcorrection or overcorrection of deformity, and postoperative fusion construct inclination have all been highlighted as possible predictors of junctional kyphosis, perhaps due to increased shear stress on the distal end of the fusion construct.[6,12,13] Furthermore, as recent research suggests an interplay between age, ideal postoperative sagittal alignment, and recruitment of distal compensatory mechanisms, it is possible that failure to meet postoperative age-adjusted alignment targets may also contribute to stress on the fusion construct and subsequent DJK; however, no previous studies have explored this relationship.[8,14] As such, this study aimed to assess the relationship between DJK, age-adjusted alignment targets, reciprocal changes, and fusion construct inclination.

This study showed severe CD, both preoperatively and postoperatively, as associated with increased rates of DJK. Specifically, patients that went on to develop DJK by the 1-year postoperative interval had significantly more severe baseline cervical sagittal malalignment (cSVA), as well as more severe postoperative cervicothoracic (C2–T3 SVA) and upper-cervical (C2 slope) malalignment. Previous research suggests that the association between cervical sagittal malalignment and DJK may be due to increased slope of the transition segment, which in turn adds to the shear stress on the distal construct.[6] Further supporting this hypothesis, our

Table 4: Comparison of correction groups for age-adjusted alignment between distal junctional kyphosis and nondistal junctional kyphosis patients

	DJK (%)	Non-DJK (%)	*P*
PT			
Matched	35	26.8	0.496
Overcorrect	40	55.4	
Undercorrect	25	17.9	
PI-LL			
Matched	15.8	17.9	0.974
Overcorrect	57.9	55.4	
Undercorrect	26.3	26.8	
SVA			
Matched	25	19.6	0.837
Overcorrect	55	55.4	
Undercorrect	20	25	
TPA			
Matched	45	33.9	0.576
Overcorrect	40	53.6	
Undercorrect	15	12.5	
LL-TK			
Matched	25	16.1	0.673
Overcorrect	50	57.1	
Undercorrect	25	26.8	

SVA-Sagittal vertical axis, PI-LL-Pelvic incidence minus lumbar lordosis, TPA-T1 pelvic angle, PT-Pelvic tilt, LL-TK-Lumbar lordosis minus thoracic kyphosis, DJK-Distal junctional kyphosis

Table 5: Comparison between distal junctional kyphosis and nondistal junctional kyphosis patients based on the difference between age-adjusted ideal and actual 1-year postoperative alignment

	Offset (actual postoperative value-age-adjusted ideal)							
	PT (°)		PI-LL (°)		SVA (mm)		TPA (°)	
	Mean±SD	*P*	Mean±SD	*P*	Mean±SD	*P*	Mean±SD	*P*
Overall								
DJK	−2.4±12.3	0.492	−7.7±21.9	0.297	−30.4±73.7	0.274	−4.9±14.1	0.995
NonDJK	−4.4±10.4		−2.9±15.4		−11.4±61.7		−4.9±10.6	
40-65 year								
DJK	−1.8±13.8	0.443	−9.8±26.4	0.366	−52.5±83.5	0.123	−6.2±17.0	0.791
NonDJK	−4.8±9.9		−3.8±16.4		−13.4±67.4		−4.9±11.5	
>65 year								
DJK	−3.1±10.7	0.896	−4.9±14.8	0.579	−0.03±46.7	0.712	−3.2±9.7	0.687
NonDJK	−3.7±11.4		−1.5±13.9		−7.9±52.5		−4.8±9.3	

SVA-Sagittal vertical axis, PI-LL-Pelvic incidence minus lumbar lordosis, TPA-T1 pelvic angle, PT-Pelvic tilt, DJK-Distal junctional kyphosis, SD-Standard deviation

Table 6: Preoperative, postoperative, and pre- to post-operative changes in alignment compared between distal junctional kyphosis patients who did and did not require a reoperation

	Preoperative			Postoperative			Pre to postoperative changes		
	Reoperation	Nonreoperation	*P*	Reoperation	Nonreoperation	*P*	Reoperation	Nonreoperation	*P*
C2-C7 CL (°)	15.0 (34.2)	−13.3 (12.1)	0.014*	2.2 (15.4)	2.4 (13.9)	0.980	−18.4 (21.2)	15.7 (13.7)	0.002*
cSVA (mm)	49.7 (10.8)	56.8 (21.9)	0.597	61.5 (18.0)	47.4 (16.7)	0.154	16.4 (13.8)	−9.4 (15.9)	0.018*
C2-T3 angle (°)	−5.8 (29.8)	−26.4 (18.5)	0.123	−18.8 (21.2)	−9.1 (13.6)	0.286	−19.7 (47.0)	17.3 (18.1)	0.023*
C2-T3 SVA (mm)	88.2 (21.0)	91.3 (35.2)	0.886	110.1 (28.0)	83.2 (23.1)	0.060	26.6 (12.9)	−8.1 (26.2)	0.041*
TS-CL (°)	26.3 (27.0)	43.4 (15.8)	0.138	44.4 (24.1)	32.2 (11.4)	0.148	24.5 (7.5)	−11.1 (14.3)	0.001*
C2 slope (°)	27.5 (28.9)	45.4 (19.5)	0.189	46.6 (24.7)	31.8 (11.2)	0.081	26.6 (10.2)	−13.6 (15.2)	<0.001*

*Statistical significance. CL-Cervical lordosis, CSVA-Cervical sagittal axis, TS-CL-T1 slope and cervical lordosis, SVA-Sagittal vertical axis

Table 7: Comparison between distal junctional kyphosis patients who did and did not require a reoperation patients based on the difference between age-adjusted ideal and actual 1-year postoperative alignment

	Offset (actual postoperative value-age-adjusted ideal)							
	PT (°)		PI-LL (°)		SVA (mm)		TPA (°)	
	Mean±SD	*P*	Mean±SD	*P*	Mean±SD	*P*	Mean±SD	*P*
Reoperation	−5.9±8.5	0.508	−17.0±11.4	0.363	−76.9±122.1	0.196	−11.5±10.6	0.313
No reoperation	−1.4±12.7		−5.8±22.9		−23.0±56.7		−3.5±14.3	

SVA-Sagittal vertical axis, PI-LL-Pelvic incidence minus lumbar lordosis, TPA-T1 pelvic angle, PT-Pelvic tilt, SD-Standard deviation

study found that for patients with an LIV in the upper-thoracic spine, greater anterior inclination of the distal construct was associated with higher rates of DJK. The relationship between anterior LIV inclination and DJK may be explained by increased anterior displacement of biomechanical force, increasing the likelihood of LIV failure. This is not to say that LIV inclination angle should necessarily be incorporated into clinical practice as a radiographic predictor of DJK; rather, as it is used in the present study, LIV inclination angle offers utility as further support for the prevailing biomechanical hypothesis describing DJK development.

Interestingly, failing to reach age-adjusted ideal alignment targets for PT, PI-LL, SVA, TPA, or LL-TK was not associated with increased rates of DJK. Age-adjusted alignment targets are operative goals used by surgeons to facilitate age-appropriate correction of sagittal alignment. Incorporating age-adjusted alignment targets in the surgical planning process minimizes the risk of overcorrection for elderly patients, many of whom do not require rigorous correction of sagittal alignment to achieve age-normative health-related quality of life (HRQL) outcomes.[8] Overcorrection is frequently cited as a key factor contributing to the development of proximal junctional kyphosis and has been hypothesized as a risk factor for DJK.[12,15] Overcorrection of sagittal alignment was not associated with an increased rate of DJK in our patient population; however, when controlling for the morphological parameter of PI, larger postoperative deviation from ideal age-adjusted SVA alignment showed a trend of association with DJK, although this was not statistically significant. As analysis of age-specific lumbopelvic alignment did not show any differences between DJK and non-DJK CD patients, this may suggest the need for age-specific cervical alignment targets. To date, no age-specific cervical alignment targets exist in the literature, and development of such targets should be a key focus of future research.

It is important to note that sagittal alignment is not the only factor influencing the development of DJK. A recent study investigating top predictors of DJK following CD-corrective surgery identified combined surgical approach and Smith Petersen Osteotomy as key procedural predictors of distal failure.[6] Additional patient-related factors such as increased BMI, high PI, osteoporosis, and age have also been identified as potential risk factors for junctional kyphosis, further highlighting older patients as a particularly high-risk population.[12] Thus, while our study primarily investigates DJK in the context of age-adjusted sagittal alignment, future research should continue to assess DJK in a greater patient-related and surgical context, underscoring the disease's potentially multifactorial etiology.

Although this study shows a relationship between cervical sagittal alignment and DJK, our analysis was limited in that it did not describe associated HRQL outcomes. To accurately assess the clinical impact of DJK, it is important to distinguish asymptomatic DJK from symptomatic DJK and DJK requiring reoperation. While our study included an investigation of patients undergoing revision surgery for DJK, the analysis was limited by small sample size, as only four patients underwent DJK revision surgery. Future research should include analyses of clinical outcomes to better describe the impact DJK has on patients. Furthermore, as our analysis included 20 patients with DJK, our analysis may suffer from a lack of statistical power. Despite these limitations, the multicenter study design increases the generalizability of our findings, and our results add to the growing body of literature describing radiographic factors associated with DJK.

CONCLUSION

Surgical CD patients with severe preoperative cervical sagittal malalignment showed elevated rates of DJK at 1-year postoperative. Failure to meet age-adjusted ideal postoperative alignment was not correlated with increased rates of DJK; however, when controlling for PI, large postoperative deviation from ideal age-adjusted SVA showed a trend of association with DJK. Large anterior inclination of the distal construct was also associated with higher rates of DJK. These results provide greater insight as to the biomechanical etiology of DJK and suggest the need for cervical-specific age-adjusted alignment goals.

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Conflicts of interest

There are no conflicts of interest.

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