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CASE SERIES

Compensation from mild and severe cases of early proximal junctional kyphosis may manifest as progressive cervical deformity at two year follow-up

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Abstract

Background Postoperative reciprocal changes (RC) in the cervical spine associated with varying factors of proximal junctional kyphosis (PJK) following fusions of the thoracopelvic spine are poorly understood.

Purpose Explore reciprocal changes in the cervical spine associated with varying factors (severity, progression, patient age) of PJK in patients undergoing adult spinal deformity (ASD) correction.

Patients and methods Retrospective review of a multicenter ASD database. Inclusion: ASD patients > 18 y/o, undergoing fusions from the thoracic spine (UIV: T6-T12) to the pelvis with two-year radiographic data. ASD was defined as: Coronal Cobb angle ≥ 20°, Sagittal Vertical Axis ≥ 5 cm, Pelvic Tilt ≥ 25°, and/or Thoracic Kyphosis ≥ 60°. PJK was defined as a ≥ 10° measure of the sagittal Cobb angle between the inferior endplate of the UIV and the superior endplate of the UIV + 2. Patients were grouped by mild (M; 10°–20°) and severe (S; > 20°) PJK at one year. Propensity Score Matching (PSM) controlled for CCI, age, PI and UIV. Unpaired and paired t test analyses determined difference between RC parameters and change between time points. Pearson bi-variate correlations analyzed associations between RC parameters (T4-T12, TS-CL, cSVA, C2-Slope, and T1-Slope) and PJK descriptors.

Results 284 ASD patients (UIV: T6: 1.1%; T7: 0.7%; T8: 4.6%; T9: 9.9%; T10: 58.8%; T11: 19.4%; T12: 5.6%) were studied. PJK analysis consisted of 182 patients (Mild = 91 and Severe = 91). Significant difference between M and S groups were observed in T4-T12 Δ1Y(− 16.8 v − 22.8, P = 0.001), TS-CLΔ1Y(− 0.6 v 2.8, P = 0.037), cSVAΔ1Y(− 1.8 v 1.9, P = 0.032), and C2 slopeΔ1Y(− 1.6 v 2.3, P = 0.022). By two years post-op, all changes in cervical alignment parameters were similar between mild and severe groups. Correlation between age and cSVAΔ1Y(R = 0.153, P = 0.034) was found. Incidence of severe PJK was found to correlate with TS-CLΔ1Y(R = 0.142, P = 0.049), cSVAΔ1Y(R = 0.171, P = 0.018), C2SΔ1Y(R = 0.148, P = 0.040), and T1SΔ2Y(R = 0.256, P = 0.003).

Conclusions Compensation within the cervical spine differed between individuals with mild and severe PJK at one year postoperatively. However, similar levels of pathologic change in cervical alignment parameters were seen by two years, highlighting the progression of cervical compensation due to mild PJK over time. These findings provide greater evidence for the development of cervical deformity in individuals presenting with proximal junctional kyphosis.

Keywords Deformity · Complications · Alignment · Mechanical · Reciprocal

Introduction

Achieving optimal correction in adult spinal deformity (ASD) surgery involves favorable reciprocal alignment changes (RC) that occur in un-fused portions of the spine. As each spinal segment directly influences the orientation of adjacent regions [1], the chain of alignment extends up from the pelvis cephalad toward the base of the skull. The foundation for this dynamic is the interaction between the pelvis and the adjacent lumbar vertebrae [1–5]. Thus, the entire spine works together in maintaining upright posture [6]. When any portion of the spine is altered, as in corrective ASD fusion or decompensation, un-fused segments may

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undergo dynamic changes in response to the initial change [7–11].

Proximal junctional kyphosis (PJK), defined radiographically as a greater than 10° change in the kyphosis angle between the inferior endplate of the uppermost-instrumented vertebra (UIV) and the superior endplate of the vertebra positioned two vertebral bodies above the UIV [12, 13], directly disrupts sagittal spinopelvic equilibrium. In severe disturbances of the sagittal profile, global alignment and the ability to maintain level gaze are directly affected [2, 14].Additionally, increased decompensation contributes to increased energy expenditure, muscular pain and fatigue over time [2, 15–17]. In patients experiencing proximal junctional kyphosis following corrective ASD fusion, these are major concerns.

Very little previous research has focused on the long-term effects of PJK on sagittal alignment with respect to un-fused regions of the spine. One work by Protopsaltis et al. has shown that PJK can result in eventual cervical deformity [31]. However, what still remains unknown is whether or not the degree of PJK angle directly influences this development. Therefore, we explored the reciprocal alignment changes that occurred in the unfused thoracic and cervical spines of individuals experiencing varying degrees of PJK following corrective ASD thoraco-pelvic spinal fusions [18].

According to the literature, the reported prevalence of proximal junctional kyphosis in adult spinal deformity individuals ranges from 10% to 41% [13, 19–22]. With such a significant percentage of the ASD population at risk for developing PJK, a greater understanding of how the spine changes in response to this phenomenon is necessary. Additionally, surgical revision of PJK is not always pursued [12, 23, 24], as the rationale for re-operation is highly variable and strongly dependent upon clinical judgement [23]. Thus, a greater understanding of how the spine adjusts to the stress of proximal junctional kyphosis over time is important for establishing specific alignment change thresholds that guide clinical decision-making for the surgical revision of PJK.

Methods

Patient population and data collection

This study was a retrospective review of a multi-center database including ASD patients consecutively enrolled from 2008 to 2015. Institutional Review Board (IRB) approval was obtained prior to study enrollment at each of the 12 participating sites and informed patient consent was acquired prior to enrollment, as well. Inclusion criteria for this database included the following: patients ≥ 18 years of age seeking treatment, operative or otherwise, for ASD. Radiographic parameters used to define adult spinal deformity in this database were coronal Cobb angle ≥ 20°, sagittal vertical axis ≥ 5 cm, pelvic tilt ≥ 25°, and/or thoracic kyphosis > 60°. Patients with spinal deformity of neuromuscular etiology, and those experiencing active infection or malignancy were excluded from this database.

Patients that underwent spinal fusions extending from the mid- or lower- thoracic spine (T6-T12) to the pelvis (S1-Illium), with 1Y or 2Y post-operative radiographic follow-up were included in this analysis. Individuals that underwent fusion for ASD with a posterior upper-most instrumented vertebra (UIV) above T6 were excluded in order to monitor a degree of thoracic compensation in the unfused spine, along within the cervical spine. Descriptive variables collected for study consisted of demographic data (age, sex, body mass index (BMI), Charlson Comorbidity Index (CCI), and race) as well as surgical variables (approach, and positioning of the UIV). Pelvic incidence, as measured radiographically, was collected and utilized in propensity score matching (PSM) to control for baseline deformity.

Alignment proximal to the site of fusion was determined radiographically in each patient. The change in these metrics between time-points was defined as reciprocal change (RC). RC parameters included cervical sagittal vertical axis (cSVA), C2 slope (C2S), T1 slope (T1S), T1 slope minus cervical lordosis (TS-CL), and cervical lordosis (CL), T4-T12 thoracic kyphosis (T4-T12 TK), and T2-T12 thoracic kyphosis (T2-T12 TK). Alignment was collected at baseline (BL), 1-year (1Y) post-operative, and 2-year (2Y) post-operative time-points. Baseline to 1Y and baseline to 2Y change in these metrics was determined for analysis. Measures of PJK angle were collected at the 6-week and 1-year post-op time points.

Propensity score matched study cohorts

Proximal junctional kyphosis was defined as a ≥ 10° measure of the sagittal Cobb angle between the inferior endplate of the UIV and the superior endplate of the vertebra positioned two vertebral bodies above the UIV [12, 13]. Individuals were initially stratified according to degree of proximal junctional kyphosis determined at the 1-year post-operative time-point (mild v severe). The mild PJK cohort included patients exhibiting a proximal junctional kyphosis angle ≥ 10° but ≤ 20°, while individuals in the severe PJK cohort presented with proximal junctional kyphosis > 20° post-operatively [19, 25, 26]. After stratification, these two groups were propensity score matched (PSM) to control for baseline Charlson Comorbidity Index score, age, pelvic incidence, and UIV.

Table 1 Descriptive data for total population (n = 284)

Demographic data	
Age	64.4 ± 8.8 y/o
Sex	74.7% F
BMI	28.6 ± 6.2 kg/m^2
CCI	2.0 ± 1.8
Race	
White	93.1%
Black	3.0%
Hispanic	1.7%
Asian	0.9%
Other	1.3%
Surgical data	
Approach	
Posterior only	73.3%
Combined anterior–posterior	26.7%
Distribution of posterior UIV	
T6	1.2%
T7	0.8%
T8	5.3%
T9	10.1%
T10	58.7%
T11	18.2%
T12	5.7%

BMI Body mass index, *CCI* Charlson comorbidity index

Statistical analysis

Following propensity score matching, paired t-test analysis compared both baseline and 1Y RC parameters, in addition to baseline and 2Y RC parameters within the PJK cohort. Un-paired t-test analysis compared baseline to 1Y and baseline to 2Y reciprocal changes between mild and severe PJK cohorts. Pearson bi-variate correlation analysis compared BL-1Y and BL-2Y reciprocal changes with patient age, the incidence of severe PJK and the incidence of progressive PJK. Patients labelled with progressive PJK experienced proximal junctional kyphosis at the 6-week post-op time-point, in addition to an increase in PJK angle occurring between 6-weeks and 1-year following surgery. This phase of analysis included propensity score matched mild and severe PJK individuals, in addition to the non-PJK patients originally identified to meet inclusion criteria. All data analysis was performed with SPSS software (version 21.0, Armonk, NY, USA).

Results

Descriptive data of overall patient population

The total patient population included 284 ASD individuals (mean age: 64.4 ± 9.3 y/o, 73.9% F, 28.8 ± 6.0 kg/m^2, 2.0 ± 1.8). Race was distributed in the following manner within our population: 92.2% White, 3.7% Black, 1.9% Hispanic, 1.1% Asian, and 1.1% other. 71.8% of patients underwent posterior only approach, while 28.2% underwent combined approach. Posterior UIV following index fusion was distributed in the following manner: T6: 1.1%; T7: 0.7%; T8: 4.6%; T9: 9.9%; T10: 58.8%; T11: 19.4%; T12: 5.6%. 17.3% of individuals underwent re-operation following their index surgery (Table 1). This population included 137 mild PJK patients, 99 severe PJK individuals, and 48 non-PJK individuals. Progressive PJK occurred in 104 patients.

Comparison between baseline and 1 year alignment in all PJK individuals

Following propensity score matching, the PJK population (n = 182) exhibited no statistical differences between baseline and 1-year measures of cSVA, C2 slope, T1 slope, TS-CL, and cervical lordosis. Significant increase between baseline and 1-year measures of T2-T12 thoracic kyphosis (− 36.8° ± 15.2 to − 56.8° ± 14.0, $P < 0.001$) and T4-T12 thoracic kyphosis (− 32.5° ± 14.3 to − 52.3° ± 13.2, $P < 0.001$; Table 2). 95.0% of these patients had full radiographic data present for the 1-year post-operative time-point.

Comparison between baseline and 2 year alignment in all PJK individuals

When comparing baseline and 2-year alignment measures, significant increase was observed in cSVA (27.7° ± 14.2 to 30.4° ± 14.8, $P = 0.006$), C2 slope (14.6° ± 11.6 to 18.7° ± 12.6, $P < 0.001$), T1 slope (30.9° ± 11.1 to 34.6° ± 11.3, $P < 0.001$) and TS-Cl (16.3° ± 11.4 to 20.7° ± 12.0, $P < 0.001$). Cervical lordosis remained similar between time-points while both T2-T12 and T4-T12 thoracic kyphosis increased (T2-T12: − 37.0° ± 14.3 to − 57.9° ± 14.7, $P < 0.001$; T4-T12: − 32.7° ± 14.2 to − 52.2° ± 13.7, $P < 0.001$; Table 3). 2-year radiographic follow-up data was present in 59.9% of these patients.

Table 2 Comparison between the baseline to 1-year alignment in all PJK individuals

	Baseline	1 year	*P* value
cSVA (mm)	28.8 ± 13.7	29.0 ± 13.5	0.826
C2 slope (°)	16.0 ± 12.1	16.5 ± 12.1	0.573
T1 slope (°)	31.8 ± 11.9	32.6 ± 11.0	0.332
TS-CL (°)	17.6 ± 11.6	18.8 ± 12.0	0.138
CL (°)	13.2 ± 14.5	13.3 ± 14.7	0.949
T2-T12 TK (°)	− 36.8 ± 15.2	− 56.8 ± 14.0	**< 0.001***
T4-T12 TK (°)	− 32.5 ± 14.3	− 52.3 ± 13.2	**< 0.001***

cSVA Cervical sagittal vertical axis, *TS-CL* T1 slope minus cervical lordosis, *CL* cervical lordosis, *T2-T12 TK* thoracic kyphosis, *T4-T12 TK* T4-T12 thoracic kyphosis

*Bold indicates significance of $P < 0.05$

Comparison of reciprocal changes between mild and severe PJK individuals: baseline to 1 year

Propensity score matching yielded 91 patients in the mild PJK cohort and 91 patients in the severe PJK cohort. Comparison of baseline to 1-year reciprocal changes showed the mild group to experience decreases in cSVA, C2 Slope, and TS-CL while the severe cohort exhibited increases in these parameters (cSVA: − 1.8° ± 10.4 v 1.9° ± 10.8, $P = 0.032$; C2 Slope: − 1.6° ± 9.4 v 2.3° ± 10.9, $P = 0.022$; TS-CL: − 0.6° ± 8.7 v 2.8° ± 11.0, $P = 0.037$). The severe PJK cohort reported greater increase in both T2-T12 (− 16.6° ± 11.4 v − 23.5° ± 12.6, $P < 0.001$) and T4-T12 thoracic kyphosis (− 16.8° ± 10.9 v − 22.8° ± 12.9, $P = 0.001$) when compared with the mild PJK cohort (Table 4).

Comparison of reciprocal changes between mild and severe PJK individuals: baseline to 2 year

Comparison between the baseline to 2-year reciprocal changes of mild and severe PJK cohorts showed the severe group to experience greater increase in T1 slope than the mild PJK group (1.9° ± 8.4 v 5.5° ± 8.6, $P = 0.024$). Additionally, the severe group exhibited greater increase in T2-T12 thoracic kyphosis (− 17.7° ± 11.0 v − 24.1° ± 13.5, $P = 0.007$). No other reciprocal changes were observed to be different between mild and severe PJK groups (Table 5).

Correlation analysis: baseline to 1-year

Correlation analysis included 230 individuals (mild PJK: n = 91; severe PJK: n = 91; no PJK: n = 48). Relation between baseline to 1Y increase in cSVA and increased age was observed (R = 0.153, $P = 0.034$). Additionally, the incidence of severe PJK correlated with increase in cSVA (R = 0.171, $P = 0.018$), C2 slope (R = 0.148, $P = 0.040$), T1 slope (R = 0.147, $P = 0.027$), TS-CL (R = 0.142, $P = 0.049$), T2-T12 TK (R = − 0.330, $P < 0.001$), and T4-T12 TK (R = − 0.314, $P < 0.001$). Incidence of progressive PJK correlated with increases in both T2-T12 TK (R = − 0.211, $P = 0.010$) and T4-T12 TK (R = − 0.249, $P = 0.002$; Table 6).

Correlation analysis: baseline to 2-year

During correlation analysis of baseline to 2-year reciprocal changes, increased age was observed to correlate with increase in cSVA (R = 0.337, $P < 0.001$) and T2-T12 TK (R = − 0.176, $P = 0.043$). Incidence of severe PJK exhibited significant relation to increase in T1 slope (R = 0.256, $P = 0.003$), cervical lordosis (R = 0.209, $P = 0.029$), T2-T12 TK (R = − 0.273, $P < 0.001$), and T4-T12 TK (R = − 0.174, $P = 0.046$).

Table 3 Comparison between the baseline to 2-year reciprocal changes of no PJK and PJK individuals

	Baseline	2 year	*P* value
cSVA (mm)	27.7 ± 14.2	30.4 ± 14.8	**0.006***
C2 slope (°)	14.6 ± 11.6	18.7 ± 12.6	**< 0.001***
T1 slope (°)	30.9 ± 11.1	34.6 ± 11.3	**< 0.001***
TS-CL (°)	16.3 ± 11.4	20.7 ± 12.0	**< 0.001***
CL (°)	14.0 ± 14.8	13.5 ± 16.0	0.647
T2-T12 TK (°)	− 37.0 ± 14.3	− 57.9 ± 14.7	**< 0.001***
T4-T12 TK (°)	− 32.7 ± 14.2	− 52.2 ± 13.7	**< 0.001***

cSVA Cervical sagittal vertical axis, *TS-CL* T1 slope minus cervical lordosis, *CL* cervical lordosis, *T2-T12 TK* thoracic kyphosis, *T4-T12 TK* T4-T12 thoracic kyphosis

*Bold indicates significance of $P < 0.05$

(+) Denotes lordosis and (−) denotes kyphosis

Table 4 Comparison between the baseline to 1-year reciprocal changes of mild and severe PJK individuals

	Mild group	Severe group	*P* value
Δ1Y cSVA (mm)	− 1.8 ± 10.4	1.9 ± 10.8	**0.032***
Δ1Y C2 slope (°)	− 1.6 ± 9.4	2.3 ± 10.9	**0.022***
Δ1Y T1 slope (°)	− 0.7 ± 10.2	2.2 ± 10.6	0.064
Δ1Y TS-CL (°)	− 0.6 ± 8.7	2.8 ± 11.0	**0.037***
Δ1Y CL (°)	0.1 ± 10.5	0.0 ± 11.3	0.965
Δ1Y T2-T12 TK (°)	− 16.6 ± 11.4	− 23.5 ± 12.6	**< 0.001***
Δ1Y T4-T12 TK (°)	− 16.8 ± 10.9	− 22.8 ± 12.9	**0.001***

cSVA Cervical sagittal vertical axis, *TS-CL* T1 slope minus cervical lordosis, *CL* cervical lordosis, *T2-T12 TK* thoracic kyphosis, *T4-T12 TK* T4-T12 thoracic kyphosis

*Bold indicates significance of $P < 0.05$

(+) Denotes lordosis and (−) denotes kyphosis

Table 5 Comparison between the baseline to 2-year reciprocal changes of mild and severe PJK individuals

	Mild group	Severe group	*P* value
Δ2Y cSVA (mm)	1.7 ± 8.8	3.4 ± 9.5	0.372
Δ2Y C2 slope (°)	3.6 ± 10.5	4.4 ± 9.5	0.715
Δ2Y T1 slope (°)	1.9 ± 8.4	5.5 ± 8.6	**0.024***
Δ2Y TS-CL (°)	4.3 ± 9.9	4.5 ± 9.0	0.940
Δ2Y CL (°)	− 3.2 ± 11.0	1.3 ± 11.8	0.064
Δ2Y T2-T12 TK (°)	− 17.7 ± 11.0	− 24.1 ± 13.5	**0.007***
Δ2Y T4-T12 TK (°)	− 17.9 ± 9.9	− 21.1 ± 13.8	0.153

cSVA Cervical sagittal vertical axis, *TS-CL* T1 slope minus cervical lordosis, *CL* cervical lordosis, *T2-T12 TK* thoracic kyphosis, *T4-T12 TK* T4-T12 thoracic kyphosis

*Bold indicates significance of $P < 0.05$

(+) Denotes lordosis and (−) denotes kyphosis

Progressive PJK was associated with increases in T2-T12 TK (R = − 0.272, $P = 0.009$) and T4-T12 TK (R = − 0.254, $P = 0.015$; Table 7).

Case example (Fig. 1)

61-year-old female with idiopathic scoliosis underwent thoracolumbar spine surgery. Baseline imaging on left, with immediate postoperative in middle, and two-year on right (Fig. 1). Patient presented two years later with persistent back and neck pain and a pronounced neck flexion. Worsening cervical parameters were seen with PJK development at one year postoperatively.

Discussion

The alteration of sagittal alignment, whether through decompensation or corrective ASD fusion, has reciprocal effects on the orientation of adjacent spinal regions [1, 7–10]. In the setting of proximal junctional kyphosis, these compensatory mechanisms are poorly defined. Thus, we followed PJK individuals and analyzed their reciprocal alignment changes in order to determine how the spine adjusts to the stress of proximal junctional kyphosis over time. We stratified patients by the degree of PJK angle and report significant differences the in cervical and thoracic alignment changes of mild and severe PJK individuals at the 1-year and 2-year post-operative time-points.

Comparison of the baseline to 1-year reciprocal changes of mild and severe PJK individuals revealed significant differences in cSVA, C2 slope and TS-CL alignment parameters. Patients presenting with mild PJK experienced decreases in cSVA, C2 slope and TS-CL, while the severe PJK group experienced increases in these metrics by 1Y post-op. As increased measures of TS-CL and cSVA are typically associated with cervical deformity [27–30], the baseline to 1Y reciprocal changes experienced by severe PJK individuals are of a pathologic nature, while those exhibited by the mild PJK group represent compensation. By 2-years post-op, both mild and severe cohorts experienced these pathologic increases in TS-CL and cSVA, suggesting that proximal junctional kyphosis will develop into cervical deformity if left untreated [31].

Additionally, mild and severe PJK cohorts exhibited similar increases in C2 slope between baseline and the 2-year post-op time-point. Increased C2 slope typically presents with loss of cervical lordosis in cervical deformity patients, often requiring adjustment of the C0-C2 region for maintaining level gaze [32]. We do not report any significant loss in cervical lordosis within our PJK population, however our results, in conjunction with previous research [31], support the theory that PJK results in cervical deformity. Therefore, we hypothesize that untreated PJK will result in degenerative loss of cervical lordosis over time. In some patients, PJK results in initial hyperlordosis to maintain horizontal gaze and only in its end stages does it progress to kyphosis. As the cervical spine is hypermobolie compared to the

Table 6 Correlation analysis of descriptive factors and baseline to 1-year change in alignment parameters

	Age	Severe PJK	Progressive
Δ1Y cSVA			
R	0.153	0.171	0.064
P value	**0.034***	**0.018***	0.472
Δ1Y C2 slope			
R	0.032	0.148	− 0.005
P value	0.655	**0.040***	0.958
Δ1Y T1 slope			
R	0.022	0.147	0.116
P value	0.736	**0.027***	0.163
Δ1Y TS-CL			
R	0.029	0.142	− 0.024
P value	0.691	**0.049***	0.787
Δ1Y CL			
R	− 0.028	0.024	0.126
P value	0.703	0.737	0.157
Δ1Y T2-T12 TK			
R	− 0.075	− 0.330	− 0.211
P value	0.257	**< 0.001***	**0.010***
Δ1Y T4-T12 TK			
R	− 0.092	− 0.314	− 0.249
P value	0.163	**< 0.001***	**0.002***

cSVA Cervical sagittal vertical axis, *TS-CL* T1 slope minus cervical lordosis, *CL* cervical lordosis, *T2-T12 TK* thoracic kyphosis, *T4-T12 TK* T4-T12 thoracic kyphosis

*Bold indicates significance of $P < 0.05$

(+) Denotes lordosis and (−) denotes kyphosis

Table 7 Correlation analysis of descriptive factors and baseline to 2-year change in alignment parameters

	Age	Severe PJK	Progressive
Δ2Y cSVA			
R	0.337	0.161	0.143
P value	**< 0.001***	0.092	0.212
Δ2Y C2 slope			
R	0.137	0.055	0.077
P value	0.154	0.567	0.501
Δ2Y T1 slope			
R	0.040	0.256	0.150
P value	0.645	**0.003***	0.157
Δ2Y TS-CL			
R	0.093	0.013	0.064
P value	0.333	0.889	0.578
Δ2Y CL			
R	− 0.038	0.209	0.114
P value	0.695	**0.029***	0.319
Δ2Y T2-T12 TK			
R	− 0.176	− 0.273	− 0.272
P value	**0.043***	**< 0.001***	**0.009***
Δ2Y T4-T12 TK			
R	− 0.148	− 0.174	− 0.254
P value	0.089	**0.046***	**0.015***

cSVA Cervical sagittal vertical axis, *TS-CL* T1 slope minus cervical lordosis, *CL* cervical lordosis, *T2-T12 TK* thoracic kyphosis, *T4-T12 TK* T4-T12 thoracic kyphosis

*Bold indicates significance of $P < 0.05$

thoracic spine, it may be the case that this reciprocal change progresses slowly.

Further, baseline to 2-year reciprocal changes in T1 slope and T2-T12 thoracic kyphosis were significantly greater in the severe PJK cohort, when compared with the mild PJK cohort. These findings show that adjustment of the spine in response to severe proximal junctional kyphosis eventually localizes on the cervico-thoracic junction. It has been hypothesized that T1 slope directly influences cervical alignment, just as pelvic incidence influences the alignment of the lumbar spine. Previous research with this focus has reported relation between measures of T1 slope and cervical lordosis, showing that individuals with increased measures of T1 slope require an increased level of cervical lordosis to maintain level gaze [33–35]. Complimentary increase in cervical lordosis was not observed at the 2Y post-operative time-point, thus, the spine is unable to properly compensate for the stress of PJK on its own. Also, the present study is not investigating the upper thoracic UIV, which is a different aspect in itself.

As a whole, these findings provide greater evidence for the development of cervical deformity following the occurrence of proximal junctional kyphosis early in the postoperative period. The manifestation of cervical deformity is not influenced by the severity of PJK by two-year follow-up, suggesting that surgical revision of all forms of this complication may be necessary in order to prevent the development of future cervical deformity.

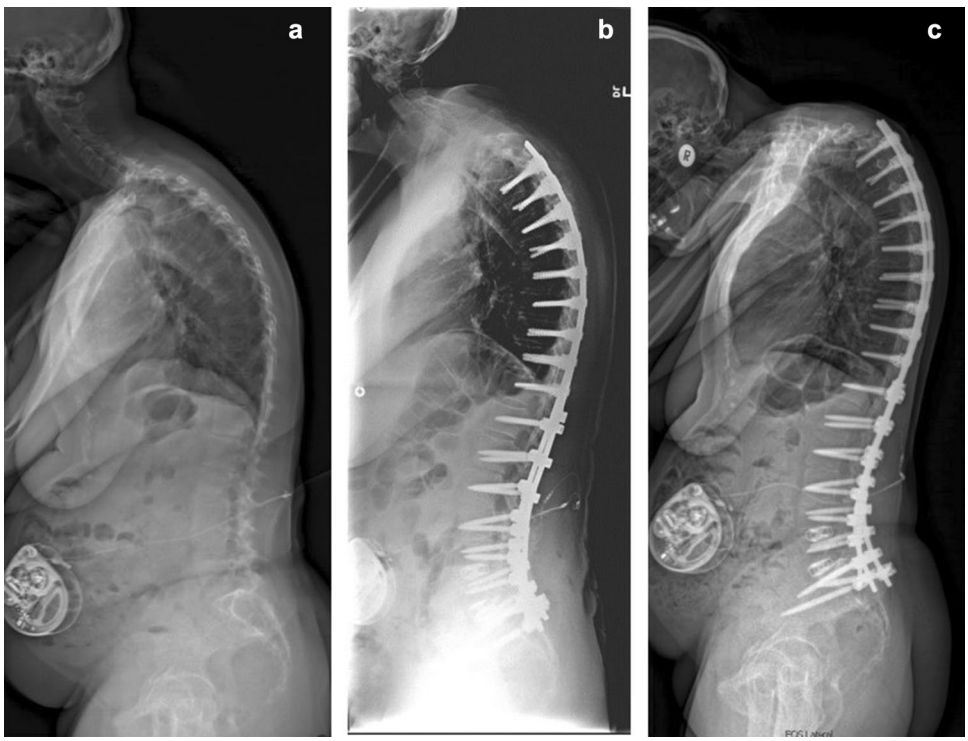

Fig. 1 Patient Imaging

Limitations

This study is not without its limitations. Foremost, radiographic alignment data was assessed out to two years, whereas progression of cervical compensation following thoracolumbar deformity correction may extend further into the postoperative period. Therefore, follow-up should be maintained further into the postoperative course for each ASD patient to determine the lasting effects of the findings found in this study. In addition, radiographic alignment data at each follow-up time point was only available in 51% of patients meeting inclusion criteria, leaving the outcomes of the remaining population the ability to confound the results of this cohort. Further, our patient population included 37 patients that had received re-operation throughout the course of this study. Additionally, this study is susceptible to selection bias, as the patients followed for analysis were not consecutively enrolled. None the less, this work provides valuable insight into the proximal junctional kyphosis phenomenon and its reciprocal effects of adjacent regions of the spine over time.

Conclusion

Individuals experiencing mild and severe proximal junctional kyphosis experience different levels of reciprocal change in cervical and upper thoracic alignment parameters by the 1 year and 2 year post-operative time points. Mild PJK individuals compensate for this phenomenon with decreases in cSVA, C2 slope and TS-CL within 1 year of operation, while severe PJK individuals experience pathologic increases in these parameters within this timeframe. Although further determination of the longer-term effects needs to be observed, both groups of PJK patients experienced similar levels of pathologic increase in these metrics by two-year follow-up. Together, these findings provide greater evidence for the development of cervical deformity if proximal junctional kyphosis is left untreated.

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Data availability Data is available upon request with appropriate access permissions.

Declarations

Conflict of interest Peter G Passias MD–Reports personal consulting fees for Spinewave, Zimmer Biomet, DePuy Synthes, and Medicrea outside the submitted work.

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