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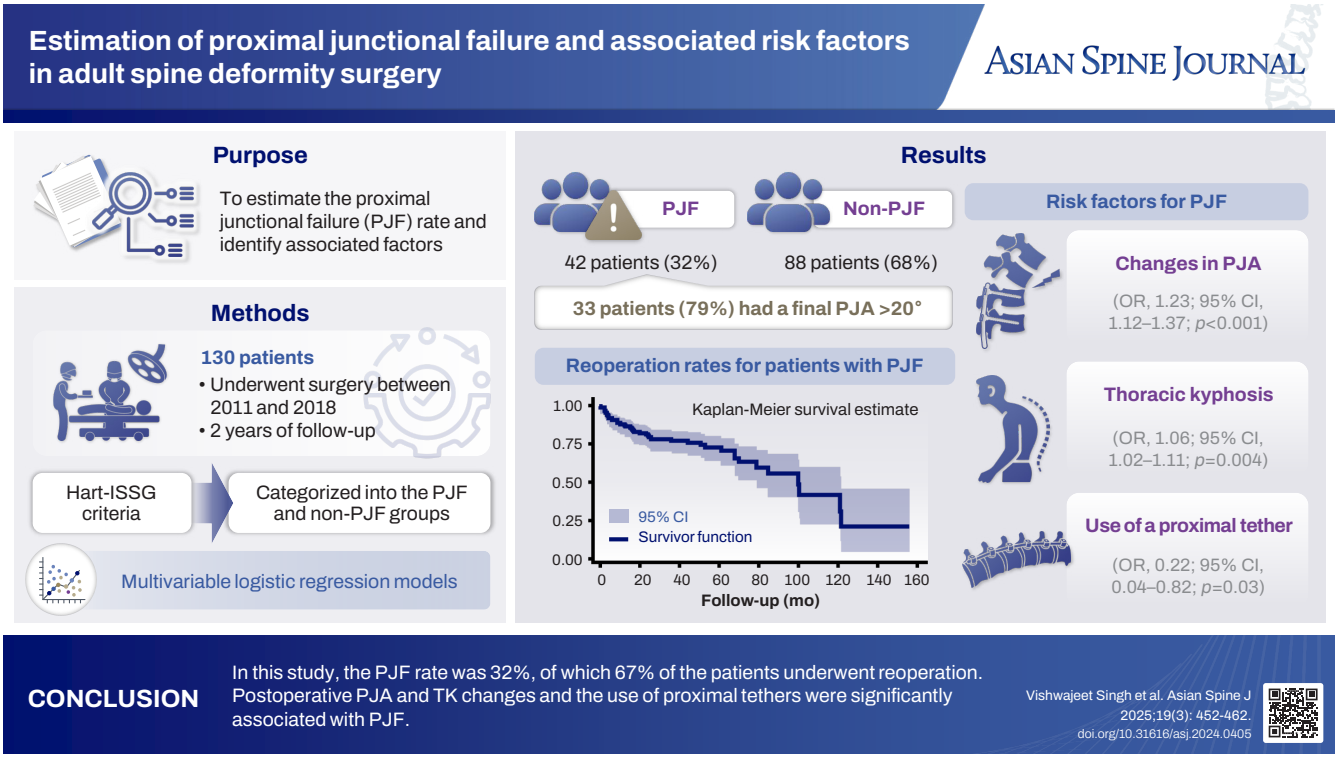

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Estimation of proximal junctional failure and associated risk factors in adult spine deformity surgery: an observational study from a single institution

Vishwajeet Singh[1], Marcelo Oppermann[2], Nathan Evaniew[3], Alexandra Soroceanu[3], Fred Nicholls[3], Bradley Jacobs[4], Kenneth Thomas[3], Ganesh Swamy[3]

Study Design: A retrospective observational cohort study.
Purpose: To estimate the proximal junctional failure (PJF) rate and identify associated factors.
Overview of Literature: Proximal junctional pathologies are challenging and common complications of adult spine deformity (ASD) surgery. However, the PJF rate was not accurately defined within the ASD cohort. A correct estimate of PJF incidence and associated factors will inform clinicians on reoperation risk and prevention strategies.
Methods: This retrospective observational study included patients with degenerative or adult idiopathic thoracolumbar deformity, extended instrumentation, sacropelvic fixation, and more than 2 years of follow-up. Patients with post-traumatic or iatrogenic sagittal malalignment were excluded. Demographic and operative data were obtained from the electronic medical records. Preoperative and follow-up scoliosis radiographs were reviewed to calculate the spinal alignment parameters. Patients were categorized into the PJF and non-PJF groups using the modified Hart-ISSG criteria, and their demographic, surgical, and radiographic parameters were compared using descriptive statistics. Multivariable logistic regression models were fitted to estimate the association measures of PJF occurrence, and their odds ratios (ORs) were reported with corresponding 95% confidence intervals (CI).
Results: Of the eligible 157 patients who underwent surgery between 2011 and 2018, 130 were included. The mean age was 64.6±8 years, and 73% of the patients were female. Moreover, 42 (32%) and 88 patients (68%) were allocated to the PJF and non-PJF groups, respectively. The mean change in the proximal junctional angle (△PJA) in the PJF group was 26°±8.2°, and 33 patients (79%) had a final PJA >20°, 4 (10%) had an additional upper instrumented vertebra (UIV)/UIV+1 fracture, and 5 (12%) had an additional screw dislodgement or fixation failure. Postoperative changes in PJA (OR, 1.23; 95% CI, 1.12–1.37; $p<0.001$), thoracic kyphosis (TK; OR, 1.06; 95% CI, 1.02–1.11; $p=0.004$), and the use of a proximal tether (OR, 0.22; 95% CI, 0.04–0.82; $p=0.03$) were associated with PJF.
Conclusions: In this study, the PJF rate was 32%, of which 67% of the patients underwent reoperation. Postoperative PJA and TK changes and the use of proximal tethers were significantly associated with PJF.

Keywords: Postoperative complications; Scoliosis; Adult spinal deformity; Proximal junction failur; Spine

Introduction

Mechanical failure at the proximal junctions remains the most challenging complication of adult spine deformity (ASD) surgery. Although a consensus definition of proximal junctional kyphosis (PJK) has been widely accepted and used, the description of proximal junctional failure (PJF) continues to evolve [1,2]. Glattes et al. [1] utilized the sagittal angle between the upper instrumented vertebra (UIV) and the vertebra above (UIV+1) to describe the proximal junctional angle (PJA). They defined PJK as having a PJA of >10° and a >10° difference in PJA between postoperative and preoperative lateral radiographs [2-5]. However, most patients identified as having PJK using this definition have been clinically asymptomatic [6]. The description appears simple because of its poor correlation with clinical outcomes [5]. A new PJK criterion has been proposed using 28° PJA and 22° PJA differences as cutoff values; however, its performance is yet to be tested in future studies [5]. PJF is increasingly employed to describe proximal junctional malalignment that requires intervention because of its strong correlation with patient outcomes [2,5,7].

PJF leads to worsening pain, disability, and neurological deficits and consequently is clinically more relevant than the radiological findings of PJK to describe junctional failure [4,7]. Apart from the magnitude of the PJA, several measurable radiological features have been included to present an objective description of PJF. PJA changes along with partial or complete fixation failure, UIV or UIV+1 fracture, or vertebral translation in the proximal junctional region strongly correlate with poor

patient outcomes [4]. These findings represent an advanced junctional issue and often require extensive revision surgery [7]. The reported incidence of PJF ranges from 1.4% to 19%; however, the studies are limited by shorter follow-up duration, heterogeneous deformity cohorts, or single-surgeon series [8,9]. Given the limited tolerance for appropriate correction, a bias exists in the databases from which the knowledge is derived toward high numbers of revision cases and, thus, high numbers of three-column osteotomies.

PJF is a highly relevant indicator of junctional pathologies to clinicians; thus, PJF rates must be established from a constrained, homogenous spinal deformity dataset. Since 2010, the investigators at the University of Calgary have primarily employed anterolateral interbody fusion (IF) approaches for degenerated lumbar disc segments, which has led to a noticeable improvement in lumbar lordosis restoration in our practice. The institutional ASD dataset was used to estimate the PJF rates in this constrained primary spinal deformity cohort treated with anterolateral IF approaches. For this study, we hypothesized that we would experience fewer PJFs with improved alignment restoration and the use of PJK prophylaxis measures. The primary objective was to estimate the PJF rate using the institutional ASD dataset. The secondary objective was to assess the performance of prophylaxis measures and alignment changes in predicting PJF.

Materials and Methods

Data source

This retrospective cohort study used the prospective institutional ASD dataset. Patient enrollment was initiated after the approval of the University of Calgary Institutional Review Board (REB19-0858). The requirement of informed consent from individual patients was omitted due to the retrospective nature of the study. Demographic information, operative notes, and complications were collected from the electronic medical records. Chart reviews, including inpatient progress reports, outpatient clinic consultations, and clinical summaries from operative notes, were reviewed to collect operative data and surgery date. Standard coronal and sagittal 36-inch (91.44 cm) preoperative scoliosis radiographs were obtained, and follow-up radiographs were repeated during the immediate postoperative period and at 3-month, 1-year, 2-year, and 5-year intervals. All patients were examined during the follow-up clinic visits. Revision surgery was offered to patients experiencing worsening pain, disability, or neurological deterioration and meeting the PJF criteria. However, the decision for reoperation was subject to the surgeon's assessment and the patient's consent for revision surgery.

Patient population

Patients had mechanical back pain and associated neurogenic leg pain refractory to nonoperative treatment. All consecutive adult patients with degenerative or adult idiopathic thoracolumbar deformity and at least one radiographic finding of malalignment (the sagittal vertical axis [SVA] >50 mm, pelvic tilt [PT] >20°, pelvic incidence–lumbar lordosis [PI–LL] mismatch >10°, Cobb angle >30°) were eligible for inclusion. Patients with >2 years of follow-up and complete radiographic series were also included. Patients with post-traumatic, iatrogenic, or postinfectious sagittal malalignment and those with neuromuscular deformity were excluded. Patients with prior multilevel decompressions and those with >1 level fusion were also excluded. The patients were evaluated and underwent surgery performed by five fellowship-trained spine surgeons with extensive experience in spinal deformity surgeries. All patients underwent multilevel IF and extended sacropelvic instrumentation. After 2014, our institution utilized various PJK prevention strategies (UIV/UIV+1 vertebroplasty, UIV to UIV+2 proximal tethers, and proximal transverse process hooks) at the discretion of the individual surgeons.

Study outcome measurements

PJA was calculated as the sagittal angle between the inferior endplate of the UIV and the superior endplate of the UIV+2. Differences in the immediate postoperative and preoperative radiographic parameters were also recorded. PJK was described using the Glattes criteria: (1) PJA >10° and (2) PJA >10° compared with the preoperative value [1]. The PJA differences between the final and preoperative radiographs were calculated and documented as ΔPJA. PJF was defined using the Hart-ISSG criteria: ΔPJA >20° or ΔPJA >20° and one of the following: UIV or UIV+1 vertebral fracture or translation, proximal fixation failure, or screw dislodgement [4]. Preoperative bone quality was assessed using a bone densitometry study (dual-energy X-ray absorptiometry), and a T-score of −2.5 or lower was defined as osteoporosis.

Covariates

The following covariates were analyzed: demographic characteristics (age, sex, prior surgery, preoperative comorbidities, and bone mineral density), surgical characteristics (UIV, osteotomy type, surgical approaches, IF levels, instrumentation levels, PJK prophylaxis measure including proximal tethers, vertebroplasty and proximal hooks), and radiological parameters (including the coronal Cobb angle, thoracic kyphosis [TK], LL, SVA, pelvic incidence [PI], PT, sacral slope [SS], PI–LL mismatch, and PJA). The UIV was categorized into the proximal thoracic (T2–T4), lower thoracic (T10–T12), and upper lumbar (L1). An independent, fellowship-trained spine surgeon evaluated the radiographs using the picture archiving and communication system (Agfa-IMPAX ver. 6.3; https://www.agfa.com/) to document the radiographic parameters. Coronal malalignment was measured as the distance of the coronal central sacral vertical line from the center of the C7 vertebra. Patient-reported outcome (PRO) scores were unavailable for all patients and were not included in this study.

Statistical analysis

Patients were categorized into two groups based on PJF occurrence, and their demographic, surgical, and radiographic parameters were reported using descriptive statistics. The distribution of each variable was assessed for normality using plots (histograms and quantile–quantile plots) and quantitative (Shapiro-Wilk) test. Continuous data and frequencies were reported as means and their respective standard deviations (medians and interquartile ranges [IQRs]), and categorical variables were reported as percentages. The bivariate association between PJF and covariates was assessed using the Fisher exact test for categorical variables and the *t*-test or their nonparametric counterparts for continuous variables.

The multivariable association between PJF and selected covariates was assessed using logistic regression models. Clinically relevant covariates were chosen based on a conceptual model that included age, sex, osteoporosis, UIV levels, PJF prophylaxis measures, and postoperative changes in alignment parameters. After the initial screening of these variables, several candidate models were developed and evaluated based on their Akaike information criterion (AIC) values, and the model showing the lowest AIC was selected as a preliminary best-fit model. To address the low event-to-variable ratio and reduce potential overfitting, Lasso regularization was applied. This method applies a penalty to the regression coefficients, shrinking the less predictive covariates toward zero and effectively excluding them from the model when they contribute minimally to the model fit. The final model retained six covariates (age, proximal hooks, proximal tethers, osteoporosis, TK changes, and PJA changes). Multicollinearity among covariates was assessed using the variance inflation factor, with values <5 indicating acceptable collinearity levels. To evaluate model estimate stability and explore the bias–variance tradeoff, bootstrap resampling with 1,000 iterations was conducted, allowing for the assessment of the variability and reliability of the parameter estimates. The adjusted associations of the final model were reported as odds ratios (OR) with 95% confidence intervals (CI) derived from the final fitted model to provide robust measures of association.

The proportion of patients with PJF requiring reoperation during follow-up was estimated. Patient follow-up was counted from the date of the index surgical procedure to the end of follow-up or death. The time-to-reoperation was assessed using the Kaplan-Meier survival curve. A two-sided p-value of <0.05 was used as a threshold to determine significance. Statistical analysis was performed with Stata MP ver. 16.2 (Stata Corp., College Station, TX, USA) and R Studio software ver. 2024.04.1+748 (RStudio, Boston, MA, USA).

Results

In total, 157 adult patients who underwent surgery between 2011 and 2018 met the inclusion criteria, of which 130 were included in the sample after applying the exclusion criteria (<2 years of follow-up, n=22; incomplete radiological series, n=5). The baseline demographic, surgical, and radiographic characteristics of the patients are summarized in Tables 1 and 2 and Supplement 1.

The mean patient age was 64.6±8 years, and 73% of patients were females. Thirty-six patients (27.6%) had a history of single-level fusion or decompression surgery, and seven patients (5.4%) had osteoporosis and were on preoperative teriparatide. The median number of comorbidities was 2 (IQR, 1). An all-anterolateral or combined (anterolateral and posterior) IF approach was used. The combined IF approach was used in 121 patients (93%). Patients underwent multiple-level IF and thoracolumbar instrumentation, including sacropelvic fixation. The median instrumentation level was 8 (IQR, 7–8). The median levels of TLIF, ALIF, and LLIF performed were 1 (IQR, 1–1), 1 (1–1), and

Table 1. Summary of the baseline demographic and radiological parameters of the patients in the study

Characteristic	All patients	No PJF	PJF	*p*-value
No. of patients	130 (100.0)	88 (67.7)	42 (32.3)	
Age (yr)	64.6±8.0	63.6±7.7	66.7±8.0	0.03
Female	95 (73.0)	61 (69.3)	34 (81.0)	0.2
Prior surgery	36 (27.6)	32 (36.3)	4 (9.5)	0.01
Severe osteoporosis	7 (5.38)	3 (3.4)	4 (9.5)	0.21
Comorbidities	2 [1]	2 [1]	2 [1]	0.81
Radiographic measures				
Cobb angle (°)	31.8±15.7	33.1±17.4	29.0±11.1	0.16
SVA (mm)	54.6±52.7	55.8±54.1	52.1±50.2	0.70
TK (°)	35.2±14.7	36.6±14.2	32.4±15.3	0.13
LL (°)	37.0±18.3	39.0±18.4	33.1±17.7	0.09
PI (°)	52.6±12.1	53.5±12.0	50.8±12.5	0.24
PT (°)	23.2±9.2	23.1±9.0	23.2±9.5	0.96
SS (°)	31.1±11.4	32.0±11.8	29.0±10.5	0.15
PI–LL (°)	15.5±18.2	14.5±17.7	17.6±19.3	0.36
PJA (°)	7.87±8.1	8.5±8.6	6.4±6.7	0.14

Values are presented as mean±standard deviation, number (%), or median [interquartile range].
PJF, proximal junctional failure; SVA, sagittal vertical axis; TK, thoracic kyphosis; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; PJA, proximal junctional angle.

Table 2. The surgical characteristics of the patients in the study

Surgical Characteristics	All patients (n=130)	No PJF (n=88)	PJF (n=42)	*p*-value
UIV				0.2
T2–T4	31 (23.8)	25 (28.4)	6 (14.3)	
T10–T12	92 (70.7)	58 (66.0)	34 (81.0)	
L1	7 (5.38)	5 (5.68)	2 (4.76)	
Osteotomy				
PCO	50 (38.4)	38 (43.1)	12 (28.5)	0.12
PSO	9 (7.0)	6 (6.8)	3 (7.1)	1.0
Proximal hooks	18 (13.8)	15 (17.0)	3 (7.1)	0.17
UIV/UIV+1 vertebroplasty	33 (25.3)	20 (22.7)	13 (31.0)	0.38
Proximal tethers	23 (17.7)	18 (20.5)	5 (12.0)	0.32
Approach				
Combined	121 (93.0)	80 (90.9)	41 (97.6)	0.27
Posterior-only	9 (7.0)	8 (9.1)	1 (2.3)	0.02
Levels of interbody fusion				
TLIF	1 (1–1)	1 (1–1)	1 (1–1)	0.40
LLIF	3 (3–4)	3 (3–4)	3 (3–4)	0.06
ALIF	1 (1–1)	1 (1–1)	1 (1–1)	0.85
No. of levels of instrumentation	8 (7–8)	8 (7–9)	8 (7–8)	0.71
Follow-up duration (yr)	4.7±2.0	4.4±2.0	5.2±2.1	0.03

Values are presented as number (%), median (interquartile range), or mean±standard deviation.
PJF, proximal junctional failure; UIV, upper instrumented vertebra; PCO, posterior column osteotomy; PSO, pedicle subtraction osteotomy; TLIF, transforaminal lumbar interbody fusion; LLIF, lateral lumbar interbody fusion; ALIF, anterior lumbar interbody fusion.

Table 3. Summary of the characteristics of patients in the PJF group

Characteristics of patients with PJF	Value
No. of patients	42/130 (32.3)
Radiographic findings	
ΔPJA (°)	26±8.15
ΔPJA>20°	33 (78.5)
ΔPJA>20° + UIV/UIV+1 fracture	4 (9.5)
ΔPJA>20° + screw dislodgement	5 (12.0)
Recurrent PJF	6/28 (21.0)

Values are presented as number/total (%), mean±standard deviation, or number (%).
PJF, proximal junctional failure; PJA, proximal junctional angle; UIV, upper instrumented vertebra.

3 (3–4), respectively. The UIV was the upper thoracic (T2–T4) in 31 (24%), lower thoracic (T10–T12) in 92 (71%), and upper lumbar (L1) in seven patients (5%). Fifty patients (38%) had posterior column osteotomies (PCO; Schwab types 1 and 2), and 9 (7%) had pedicle subtraction osteotomy. The employed PJK prophylaxis measures were proximal hooks in 18 (14%), UIV vertebroplasty in 33 (25.3%), and proximal tethers in 23 patients (17.7%). The median follow-up duration was 4.3 years (IQR, 2.5 years).

Moreover, 42 patients (32%) developed PJF, whereas no PJF developed in 88 (68%) during the follow-up. The mean patient ages in the PJF and non-PJF groups were 66.7±8 and 63.6±7.7, respectively (p=0.03). Thirty-two patients (36%) in the PJF group and 4 (10%) in the non-PJF group had a prior surgery (p=0.01). Other demographic, surgical, and preoperative radiological characteristics were comparable in both groups. Six patients (14.3%) with PJF had an upper thoracic UIV (T2–T4), and 34 (81%) had a lower thoracic (T10–T12) UIV. The mean follow-up durations for the PJF and non-PJF groups were 5.2±2.1 years and 4.4±2 years, respectively (p=0.03). The mean postop Cobb angles were 12.4°±6° in the PJF group and 18.4°±12.4° in the no-PJF group (p<0.01). The mean postop PJA values were 16.1°±7.4° in the PJF group and 13.1°±8.4° in the no-PJF group (p=0.04). Other postoperative radiological parameters were similar in both groups. Similarly, differences in the postoperative and preoperative radiological parameters were comparable in both groups, except for the difference in TK, PI–LL mismatch, and PJA. The TK differ-

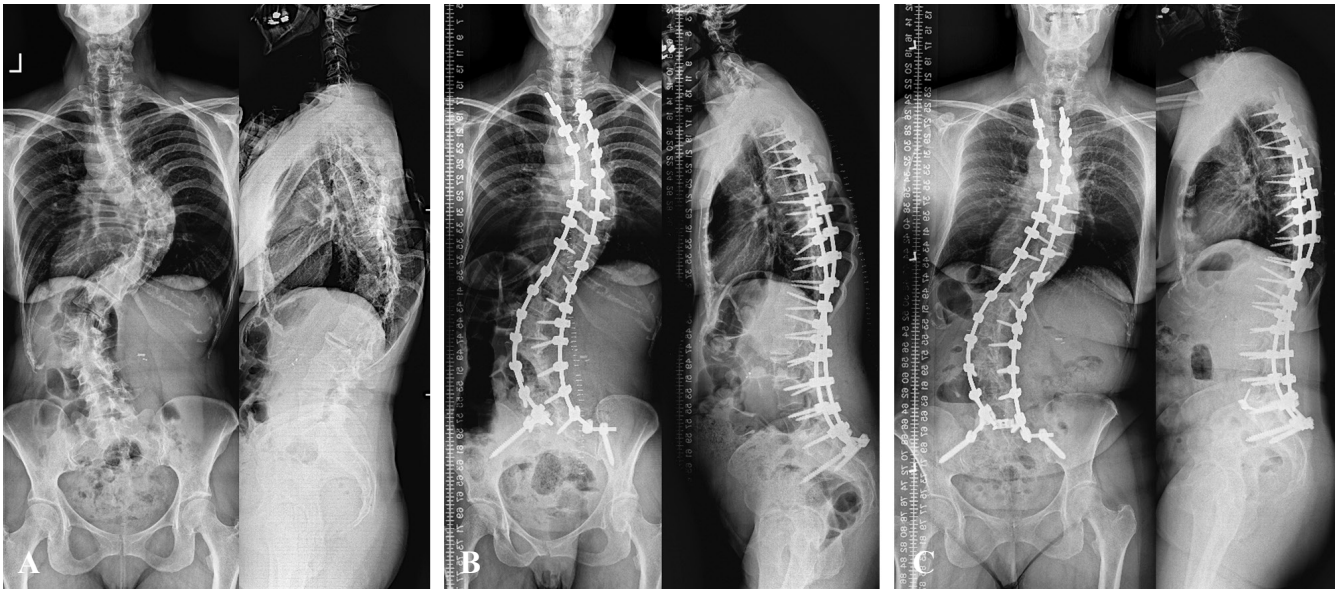

Fig. 1. Radiographs of a 50-year-old female with adult idiopathic scoliosis patient showing right thoracic, left thoracolumbar, and thoracolumbar kyphosis **(A)**. The patient underwent T3-pelvis instrumented fusion. Postoperative images demonstrate reasonable sagittal and coronal correction. Postoperative proximal junctional angle (PJA) measures 5° and a change of 2° from preoperative images **(B)**. Five-year follow-up images demonstrate maintained PJA (5°). The patient had a slight loss of coronal balance following revision surgery for L5–S1 pseudoarthrosis **(C)**.

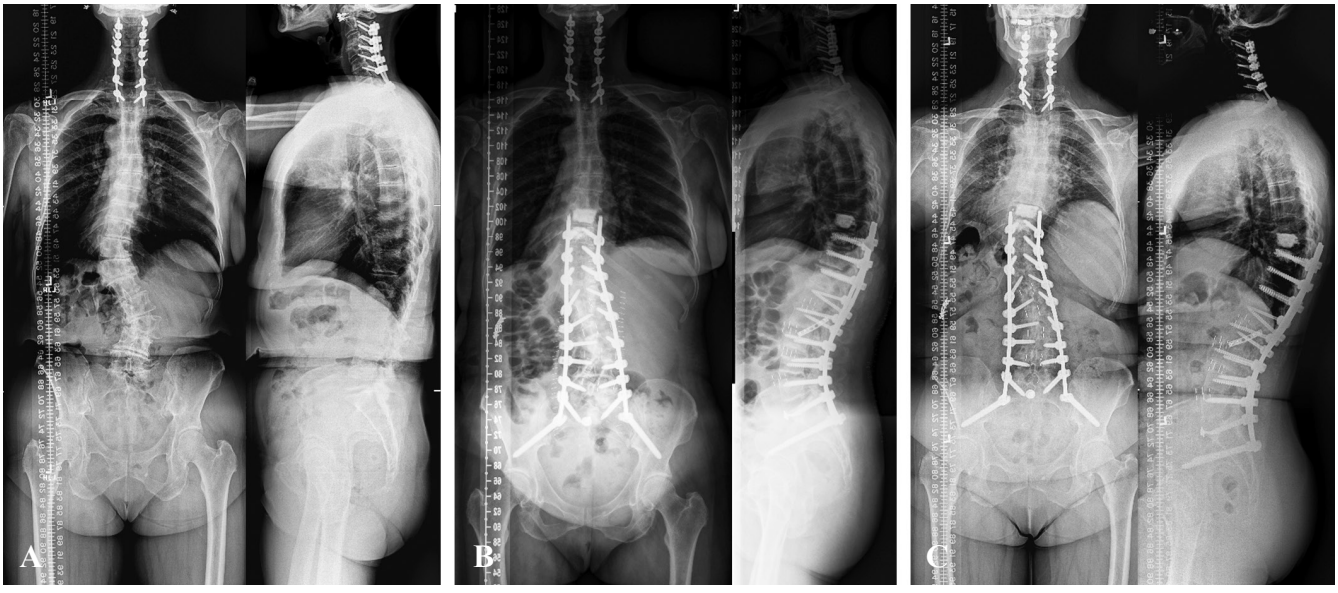

Fig. 2. Radiographs of a 68-year-old female with degenerative scoliosis show predominant right lumbar curve and lumbar kyphosis **(A)**. The patient underwent L1–S1 anterolateral interbody fusion, posterior T10-pelvis instrumented fusion, and T9–T10 vertebroplasty. Postoperative proximal junctional angle (PJA) was 10°, a difference of 5° from preoperative, as demonstrated by images obtained after the surgery **(B)**. The final PJA at 5-year follow-up images was 30°. This patient remained clinically asymptomatic despite worsening in PJA **(C)**.

ences for the PJF and non-PJF groups were 16.5°±10° and 14.6°±10.6° (p<0.01), PI–LL mismatch differences were 20.8°±16° and 15°±16° (p=0.05), and PJA differences were 10°±6.3° and 4.5°±4° (p<0.01), respectively (Fig. 1).

Characteristics of patients with PJF

At the final follow-up, 42 patients (32.3%) had PJF. Their mean ΔPJA was 26°±8.2° (Table 3). Thirty-three patients (79%) had a final PJA >20°, 4 (10%) had an additional UIV/UIV+1 fracture, and 5 (12%) had an additional screw dislodgement or fixation failure (Fig. 2).

Assessment of PJF predictors

The adjusted analysis using the multivariable regression model demonstrated a lower association between PJF and proximal hook use (OR, 0.12; 95% CI, 0.02–0.59; p=0.01) and proximal tether use (OR, 0.22; 95% CI, 0.04–0.82; p=0.03). PJF exhibited an increased association with postoperative changes in TK (OR, 1.06; 95% CI, 1.02–1.11; p<0.01) and PJA (OR, 1.23; 95% CI, 1.12–1.37; p<0.01). Bootstrapped sampling demonstrated a large uncertainty in the estimates (standard error=4.16) and high bias (−1.3) for the proximal hook variable. Other predictor variables, including age and osteoporosis, were not significantly associated with PJF (Table 4).

Table 4. Association measures of PJF and the covariates from the multivariate regression model, including their respective ORs and 95% CIs

Characteristic	OR (95% CI)	SE	*p*-value
Age	1.04 (0.98–1.11)	0.03	0.2
Proximal hooks	0.12 (0.02–0.59)	0.88	0.018
Proximal tethers**	0.22 (0.04–0.82)	0.73	0.037
Osteoporosis	4.37 (0.66–35.7)	0.99	0.14
ΔTK**	1.06 (1.02–1.11)	0.02	0.004
ΔPJA***	1.23 (1.12–1.37)	0.05	<0.001

Model Akaike information criteria=125.
PJF, proximal junctional failure; OR, odds ratio; CI, confidence interval; SE, standard error; TK, thoracic kyphosis; PJA, proximal junctional angle.
**p<0.01. ***p<0.001.

Characteristics of patients with PJF who underwent reoperation

Twenty-eight patients (67%) with PJF underwent reoperation until the last recorded follow-up. The mean time-to-reoperation from the index surgery was 12.2±10 months. Based on the Kaplan-Meier survival curve, the PJF reoperation rates were 12.3%, 19.3%, 22.6%, 23.9%, and 26.8% at 12, 24, 36, 48, and 60 months, respectively (Fig. 3). The mean ΔPJA in this subset was 26°±9.2°. Nineteen patients (68%) had a

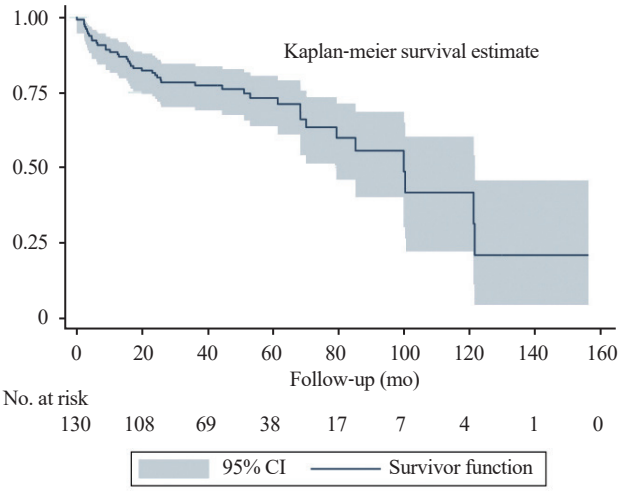

Fig. 3. The Kaplan-Meier survivor curve shows reoperation rates for patients with proximal junctional failure during their follow-up. CI, confidence interval.

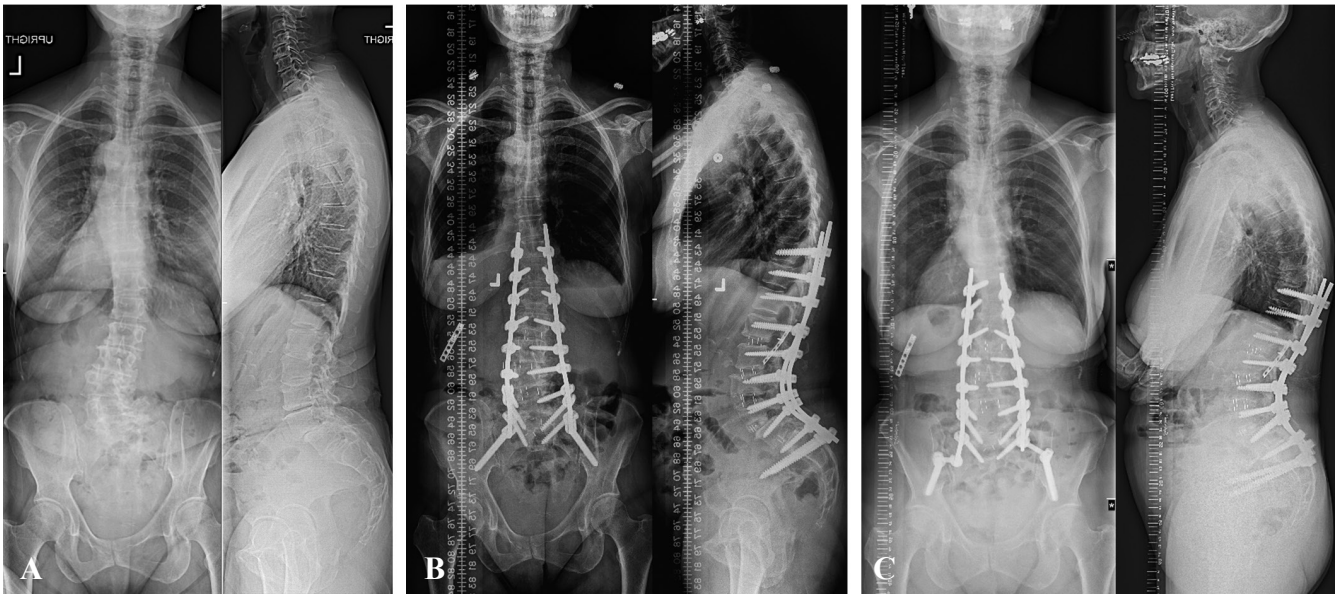

Fig. 4. Radiographs of a 70-year-old female with degenerative scoliosis, left lumbar curve, loss of lumbar lordosis, and reasonable coronal and sagittal balance **(A)**. The patient underwent L1–L4 lateral interbody fusion, L4–S1 transforaminal lumbar interbody fusion and posterior T10-pelvis instrumented fusion. Postoperative proximal junctional angle (PJA) worsened by 5° to 18° **(B)**. Eighteen months follow-up radiographs demonstrate further worsening of PJA to 35° with evidence of screw loosening. This patient was clinically symptomatic and was reoperated with the extension of instrumentation to the upper thoracic region **(C)**.

final PJA of >20°, 4 (14.2%) had an additional UIV/UIV+1 fracture, and 5 (18%) had an additional screw dislodgement or fixation failure. For those who underwent reoperations for PJFs, 6 (21%) had upper thoracic UIV, 20 (71%) had lower thoracic UIV, and 2 (7.1%) had upper lumbar UIV (Fig. 4). All patients underwent reoperation with cephalad extension of instrumentation, of which recurrent PJF developed in six patients (21%) who required reoperation (Supplement 2).

Patients with PJF who did not undergo reoperation

Fourteen patients (33%) with PJF did not consent to reoperation because their symptoms were not severe enough to consider revision surgery. The UIV was in the lower thoracic region for these 14 patients (100%). These patients had worsened final PJA without junctional fracture or fixation failure. The mean ΔPJA was 26°±5.7° (Supplement 2).

Discussion

PJF is a commonly encountered junctional complication in ASD surgeries [10,11]. Junctional failures, described as PJK using the Glattes criteria, tend to overestimate the burden of mechanical complications [5,7]. PJF strongly correlates with the PROs and reoperation risks, and the definition aids in clinical decision-making [7]. In this study, the Hart-ISSG criteria was used to define PJF, and the estimated PJF rate was 32%. Of all patients with PJF, 78% had >20° of postoperative PJA difference, 10% had an additional UIV/UIV+1 fracture or translation, and 12% had an additional fixation failure. Twenty-eight patients (67%) with PJF and 22% (28/130) of the entire cohort underwent reoperation within 2 years of the index procedure. The use of proximal tethers and the postoperative differences in PJA and TK demonstrated a significant association with PJF development.

PJK rates have been extensively studied, with reported rates varying from 17% and 61.7% [6,12]. Several large series have indicated a poor correlation between PJK and PROs or reoperations [5,6,10]. Given the limited clinical utility of the PJK definition, PJF estimation has become significant. A large retrospective series of patients with ASD reported a PJF rate of 1.4% [8]. The authors defined PJF as symptomatic PJKs that require surgery. In another study, the same authors reported a PJF rate of 19% in 119 patients with ASD using a revised PJF definition [13], where PJF was defined as increased PJA >20° from the preoperative value, PJK requiring reoperation or worsening in one Scoliosis Research Society [SRS]-Schwab sagittal modifier domain [14]. The lower PJF rate in these studies could be attributed to the inclusion of a heterogeneous patient cohort with pathology ranging from primary idiopathic to iatrogenic deformities following revision surgery or fixed sagittal imbalance. These studies have also inconsistently used sacropelvic fixation. Hart et al. [15] proposed a modification in the PJF definition by including radiological findings (UIV/UIV fracture and fixation failure or posterior ligamentous disruption) to the Glattes criteria. In their series, 57 patients (4.7%) with ASD had PJF; however, their patient population was also heterogeneous, comprising revisions, iatrogenic deformity, fixed sagittal imbalance, and inconsistent instrumentation length [15]. In the present study, PJF was defined using Hart's and additional PJA criteria (final PJA >20°) as described by Lazaro et al. [7]. In this retrospective review of 160 patients with adult thoracolumbar deformity, the authors reported a PJF rate of 28.7%. Their patient enrollment criteria were similar to ours and included patients with primary adult deformity having extended instrumentation to the pelvis. Although our PJF rate is higher than that in previous reports, it closely follows the PJF rate reported by Lazaro et al. [7].

PJK has a multifactorial etiology, which is influenced by several patient-related factors such as age, body mass index (BMI), bone mineral density, paraspinal muscle atrophy, preexisting TK, preoperative PJA, sagittal malalignment, and surgical factors such as soft tissue preservation, persistent sagittal malalignment, and sagittal under- or overcorrection [16,17]. Several strategies for achieving harmonious alignment to prevent PJK have been described, including the global alignment and proportion (GAP) scores [18] and age-appropriate SRS-Schwab alignment descriptors [19]. Various PJK prophylaxis measures have varying success [7,20]. In this study, the effect of postoperative alignment correction and prophylaxis measures on the occurrence of PJF was investigated. The postoperative changes in PJA and TK, as well as the use of proximal tethers, were significantly associated with PJF. The use of proximal hooks showed only a weak association with PJF, and its estimates had a high variability. Thus, this may be underpowered to adequately assess this association because of the considerable heterogeneity within the subset of patients treated with proximal hooks. Other changes in the alignment parameters or PJK prophylaxis measures were not associated with PJF. These findings are in contrast to those noted by Lazaro et al. [7], who reported that prophylac-

tic measures did not offer protective benefits.

Rasouligandomani et al. [18] proposed a sagittal alignment and mechanical integrated score (SAMIS) system, which adds to the biomechanical descriptors in the geometrical descriptor-based system of the GAP classification [21]. The SAMIS score is proposed to predict PJF risk better than previous prediction methods. The new SAMIS considers the bending moment to be a function of the BMI. Although BMI, a crucial PJF risk factor, was not collected for each patient in our cohort, we could not assess its effect on PJF. In the present study, no significant association was found between osteoporosis and PJF. The osteoporosis variable had a large effect size (OR, 4.37), indicating a positive association; however, the estimate showed high variability. This finding should be interpreted with caution because the heterogeneity and inadequate sample size in this subset must be considered. In addition, patients with osteoporosis were on teriparatide therapy preoperatively, and a short therapy duration may have been ineffective in preventing PJF in these patients.

In this study, 28 patients (67%) underwent reoperation. Although the decision to reoperate is multifactorial [7,12,15], the patient's perceived disability and consent are decisive. All patients with acute PJF, i.e., those with an additional fixation failure (14%) or UIV fracture or translation (18%), underwent reoperation. Patients' choices primarily determined the decision to reoperate. The reoperation rate in this study is higher than that reported in the literature [7,15]. Older patients (mean age, 66.7 years) with higher baseline sagittal decompensation (mean SVA=52 mm, mean TK=32.4°, mean PJA=6.4°) may have contributed to the higher reoperation rates in our cohort. The mean time-to-reoperation (12.2 months) was similar to that described in the literature. The Kaplan-Meier survival plot showed that most patients underwent reoperations within 2 years of the index procedure [7,15].

The result of this study demonstrates that a third of patients with ASD undergoing surgery develop PJFs, and the use of proximal tethers and postoperative PJA and TK changes are associated with PJF. This study is unique in defining the PJF rates in a constrained ASD population and further confirms the findings of Lazaro et al. [7].

The notable strengths of this study are the analysis of a homogenous patient population, patients with primary sagittal decompensation, a constrained patient cohort, and a long follow-up from the prospective institutional database. However, a few limitations require attention. Despite the consecutive patient enrollment, the results are subject to potential selection biases owing to their retrospective nature. PRO scores were not collected for all patients, and their relationship with PJF or PJF reoperations could not be ascertained. BMI and the lack of information on muscle health at the UIV levels are other significant variables not analyzed in this study. This is a multiple-surgeon series from a single institution with a similar case selection and surgical approach; however, a performance bias cannot be excluded. Nevertheless, the results of this study provide valuable information on the PJF rates and their potential risk factors. A larger prospective study incorporating BMI and PROs is warranted to further validate our findings and establish associations with PJF.

Conclusions

PJF is the most challenging junctional complication of adult spinal deformity surgery. In this study, the PJF rate was 32%, of which 67% of the patients underwent reoperation. Postoperative changes in PJA and TK and the use of proximal tethers were significantly associated with PJF.

Key Points

- This observational cohort study utilized an institutional dataset of well-defined adult spinal deformity patients to estimate the mechanical complications at the proximal junction.
- The rate of proximal junction failure (PJF) in our single-center study was 32%, with 67% of affected patients requiring reoperation.
- The causes of PJF are multifactorial. In this study, we observed a strong association between PJF and postoperative changes in the proximal junction angle as well as changes in thoracic kyphosis. Additionally, the use of proximal tethers showed moderately protective effects against PJF in our cohort.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Supplementary Materials

Supplementary materials can be available from https://doi.org/10.31616/asj.2024.0405. Supplement 1. The postoperative and the difference in the patient's postoperative to preoperative alignment parameters. Supplement 2. Summary of the characteristics of proximal junctional kyphosis patients with reoperations and without reoperations.

References

1. Glattes RC, Bridwell KH, Lenke LG, Kim YJ, Rinella A, Edwards C 2nd. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis. Spine (Phila Pa 1976) 2005;30:1643-9.
2. Alshabab BS, Lafage R, Smith JS, et al. Evolution of proximal junctional kyphosis and proximal junctional failure rates over 10 years of enrollment in a prospective multicenter adult spinal deformity database. Spine (Phila Pa 1976) 2022;47:922-30.
3. Kim YJ, Bridwell KH, Lenke LG, Cho KJ, Edwards CC 2nd, Rinella AS. Pseudarthrosis in adult spinal deformity following multisegmental instrumentation and arthrodesis. J Bone Joint Surg Am 2006;88:721-8.
4. Lau D, Funao H, Clark AJ, et al. The clinical correlation of the Hart-ISSG proximal junctional kyphosis severity scale with health-related quality-of-life outcomes and need for revision surgery. Spine (Phila Pa 1976) 2016;41:213-23.
5. Lovecchio F, Lafage R, Line B, et al. Optimizing the definition of proximal junctional kyphosis: a sensitivity analysis. Spine (Phila Pa 1976) 2023;48:414-20.
6. Kim YJ, Bridwell KH, Lenke LG, Glattes CR, Rhim S, Cheh G. Proximal junctional kyphosis in adult spinal deformity after segmental posterior spinal instrumentation and fusion: minimum five-year follow-up. Spine (Phila Pa 1976) 2008;33:2179-84.
7. Lazaro B, Sardi JP, Smith JS, et al. Proximal junctional failure in primary thoracolumbar fusion/fixation to the sacrum/pelvis for adult symptomatic lumbar scoliosis: long-term follow-up of a prospective multicenter cohort of 160 patients. J Neurosurg Spine 2022;38:319-30.
8. Yagi M, Rahm M, Gaines R, et al. Characterization and surgical outcomes of proximal junctional failure in surgically treated patients with adult spinal deformity. Spine (Phila Pa 1976) 2014;39:E607-14.
9. Park SJ, Lee CS, Chung SS, Lee JY, Kang SS, Park SH. Different risk factors of proximal junctional kyphosis and proximal junctional failure following long instrumented fusion to the sacrum for adult spinal deformity: survivorship analysis of 160 patients. Neurosurgery 2017;80:279-86.
10. Yagi M, King AB, Boachie-Adjei O. Incidence, risk factors, and natural course of proximal junctional kyphosis: surgical outcomes review of adult idiopathic scoliosis: minimum 5 years of follow-up. Spine (Phila Pa 1976) 2012;37:1479-89.
11. Kim HJ, Lenke LG, Shaffrey CI, Van Alstyne EM, Skelly AC. Proximal junctional kyphosis as a distinct form of adjacent segment pathology after spinal deformity surgery: a systematic review. Spine (Phila Pa 1976) 2012;37(22 Suppl):S144-64.
12. Lau D, Clark AJ, Scheer JK, et al. Proximal junctional kyphosis and failure after spinal deformity surgery: a systematic review of the literature as a background to classification development. Spine (Phila Pa 1976) 2014;39:2093-102.
13. Yagi M, Fujita N, Tsuji O, et al. Low bone-mineral density is a significant risk for proximal junctional failure after surgical correction of adult spinal deformity: a propensity score-matched analysis. Spine (Phila Pa 1976) 2018;43:485-91.
14. Schwab F, Ungar B, Blondel B, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine (Phila Pa 1976) 2012;37:1077-82.
15. Hart R, McCarthy I, O'brien M, et al. Identification of decision criteria for revision surgery among patients with proximal junctional failure after surgical treatment of spinal deformity. Spine (Phila Pa 1976) 2013;38:E1223-7.
16. Kim HJ, Yang JH, Chang DG, et al. Proximal junctional kyphosis in adult spinal deformity: definition, classification, risk factors, and prevention strategies. Asian Spine J 2022;16:440-50.
17. Park SJ, Lee CS, Kang BJ, et al. Validation of age-adjusted ideal sagittal alignment in terms of proximal junctional failure and clinical outcomes in adult spinal deformity. Spine (Phila Pa 1976) 2022;47:1737-45.
18. Rasouligandomani M, Del Arco A, Pellise F, Gonzalez Ballester MA, Galbusera F, Noailly J. Proximal junction failure in spine surgery: integrating geometrical and biomechanical global descriptors improves GAP score-based assessment. Spine (Phila Pa 1976) 2023;48:1072-81.
19. Lafage R, Smith JS, Elysee J, et al. Sagittal age-adjusted score (SAAS) for adult spinal deformity (ASD) more effectively predicts surgical outcomes and proximal junctional kyphosis than previous classifications. Spine Deform 2022;10:121-31.

20. Safaee MM, Deviren V, Dalle Ore C, et al. Ligament augmentation for prevention of proximal junctional kyphosis and proximal junctional failure in adult spinal deformity. J Neurosurg Spine 2018;28:512-9.

21. Yilgor C, Sogunmez N, Boissiere L, et al. Global alignment and proportion (GAP) score: development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery. J Bone Joint Surg Am 2017;99:1661-72.