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Recurrent Proximal Junctional Kyphosis

Incidence, Risk Factors, Revision Rates, and Outcomes at 2-Year Minimum Follow-up

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Study Design. Retrospective comparative cohort study.

Objective. Assess the incidence, risk factors, and outcomes of recurrent proximal junctional kyphosis (r-PJK) in PJK revision patients.

Summary of Background Data. Several studies have identified the incidence and risk factors for PJK after primary surgery. However, few studies have reported on PJK recurrence after revision for PJK.

Methods. A multicenter database of patients who underwent PJK revision surgery with minimum 2-year follow-up was analyzed. Demographic, operative, and radiographic outcomes were compared in patients with r-PJK and patients without recurrence no-Proximal Junctional Kyphosis (n-PJK). Postoperative Scoliosis Research Society-22r, Short Form-36, and Oswestry Disability Index were compared. Preoperative and most recent spinopelvic, cervical, and cervicothoracic radiographic parameters were compared. Univariate and multivariate analyses were used to determine r-PJK risk factors. A predictive model was formulated based on our logistic regression analysis.

Results. A total of 70 patients met the inclusion criteria with an average follow-up of 21.8 months. The mean age was 66.3 ± 9.4 and 80% of patients were women. Before revision, patients had a proximal junctional angle angle of $-31.7° \pm 15.9°$. The rate of recurrent PJK was 44.3%. Logistic regression showed that prerevision thoracic pelvic angle (odds ratio [OR]: 1.060 95% confidence interval [CI] 1.002; 1.121; $P = 0.042$) and prerevision C2-T3 sagittal vertical axis (SVA; OR: 1.040 95% CI [1.007; 1.073] $P = 0.016$) were independent predictors of r-PJK. Classification with these parameters yielded an accuracy of 72.7%, precision of 80.6%, and recall of 73.5%. When examining correction, or change in alignment with revision surgery, we found that change in SVA (OR: 0.981 95% CI [0.968; 0.994] $P = 0.005$) was the only predictor of r-PJK with accuracy of 66.7%, precision of 74.2%, and recall of 69.7%.

Conclusion. Patients after PJK revision surgery had a recurrence rate of 44%. Logistic regression based on the prerevision variables showed that prerevision thoracic pelvic angle and prerevision C2-T3 SVA were independent predictors of r-PJK.

Key words: C2-T3 sagittal vertical axis, complications, proximal junctional kyphosis, recurrent proximal junctional kyphosis, spine deformity, spine revision, thoracic pelvic angle.

Level of Evidence: 4

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Proximal junctional kyphosis (PJK) occurs in 30% to 40% of adult deformity cases and approximately 10% to 15% of these patients require revision surgery. Many studies have reported the risk factors associated with PJK including bone quality, the integrity of the posterior tension band, rigidity of construct, over correction in addition to other surgical characteristics.[1–11] Despite the number of studies performed on this topic, no single risk factor has been identified as the sole cause for PJK.[1] For this reason, it is generally accepted that PJK is a multifactorial issue that will likely require a multifactorial approach for a solution.

When revision of PJK is required, it generally involves extending the fusion more proximal to correct the kyphotic segment and stabilize the spine in a more appropriate sagittal position. Although it is not well reported in the literature, adult deformity surgeons have seen often experience recurrence of PJK despite a revision surgery for PJK. These recurrences are concerning because the cost of revision surgery for PJK is estimated to cost more than

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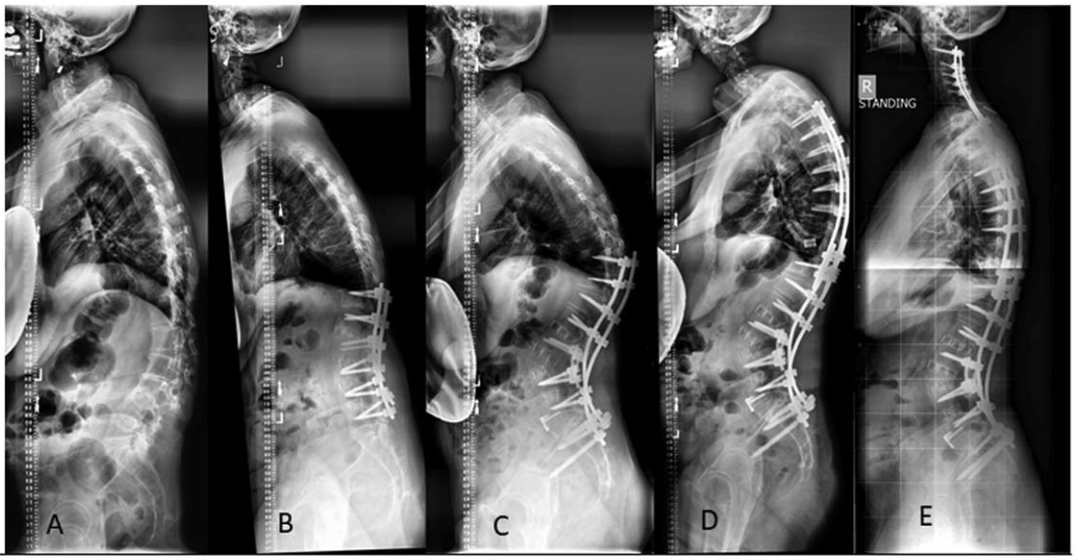


PI	50.9	50.0	75.7	74.0	74.5
PT	29.6	31.6	29.8	32.1	21.8
PI-LL	30.6	23.5	-6.5	-6.8	-6.7
TK	-26.6	-49.3	-81.1	-65.9	-47.7
SVA	80.8	216.0	138.7	30.7	36.2
TPA	27.6	41.2	33.8	24.7	18.7
C2-T3 SVA	76.1	84.1	89.2	147.4	57.2
C2-T3	17.9	11.2	18.4	-31.3	-15.4

Figure 1. A Case Example of multiple recurrent proximal junctional kyphosis (PJK). Preoperative image (**A**), followed by radiographs after the index procedure (**B**). The patient developed PJK (**C**) and was subsequently revised (**D**) and developed recurrent PJK (**E**). The pre-op C2-T3 SVA was 89 mm in (**C**) before the revision (**D**). See above for measurements. LL indicates lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis; TK, thoracic kyphosis; TPA, thoracic pelvic angle.

$55,000 and up to $195,000 per episode.[6,7] These costs and complications associated with PJK revision cases demonstrate the significant burden of recurrent PJK (Figure 1). Despite this, risk factors for PJK recurrence are poorly defined in the literature.[2]

The purpose of this study is to report the incidence of recurrent PJK and compare these patients with a cohort of patients who did not develop recurrent PJK to compare demographic and radiographic risk factors associated with recurrent PJK.

MATERIALS AND METHODS

Patient Selection

This study is a retrospective review of a prospective multicenter database of adult patients with spinal deformity. The inclusion criteria for the overall database were adult patients (age >18-year old) with a radiographic sign of spinal deformity in the coronal and/or sagittal plane. The exclusion criteria were as follows: neuromuscular, postinfectious, oncologic, post-traumatic deformities, and ankylosing spondylitis. For the current analysis, we only retained patients who were revised for PJK following their index deformity procedure, and had at least five levels of fusion. Following revision for PJK, these patients were separated into two cohorts: (1) patients who developed recurrent PJK (r-PJK) and (2) patients who did not develop recurrent PJK no-Proximal Junctional Kyphosis (n-PJK).

Data Collection

Patient demographic data (age at revision, sex), radiographic data, and timing data (*i.e.*, follow-up time points and timing of revision surgery) were collected.

All radiographs were measured using validated software (SpineView, Laboratory of Biomechanics, ENSAM-ParisTech, Paris).[12] Radiographs were taken utilizing AP and lateral scoliosis 36' cassette films or full-body imaging with patients in the standing position with arms in the hands on shoulder position previously described.[13]

The proximal junctional angle (PJA) was defined as the sagittal Cobb angle between the inferior endplate of the upper instrumented vertebra (UIV) and the superior endplate of the vertebra 2 levels above (UIV+2). PJK was defined by prior published criteria described by Glattes *et al*[14] (PJA > or = 10°, and greater than 10° increase from pre-op comparative imaging). Radiographic measurements included pelvic incidence (PI), pelvic tilt (PT), PI to lumbar lordosis mismatch (PI-LL), thoracic pelvic angle (TPA),[15] sagittal vertical axis (SVA), and cervical parameters including T1 slope, cervical lordosis (C2–7), cervical SVA, C2-T3 angle (CTA), and C2-T3 SVA (CTS).

TABLE 1. Pre- to Postalignment for the Entire Cohort

	Prerevision	Postrevision	*P*
PT	26.4 ± 10.5	24 ± 9.7	0.006
PI-LL	5.7 ± 17.3	3.4 ± 14.6	0.113
T10-L2	−27.1 ± 21.3	−14.2 ± 14.8	<0.001
T2-T12	−63.8 ± 17.3	−64.9 ± 15	0.450
TPA	24.2 ± 12.3	19.2 ± 10.6	<0.001
SVA	63.1 ± 65.2	31.1 ± 59.5	<0.001
PJA	−31.7 ± 15.9	−16.6 ± 12.6	<0.001

LL indicates lumbar lordosis; PI, pelvic incidence; PJA, proximal junctional angle; PT, pelvic tilt; SVA, sagittal vertical axis; TPA, thoracic pelvic angle.

Statistical Methods

Statistical analysis included descriptive data of our cohort and comparison between the n-PJK and r-PJK groups. Chi-square test and Mann-Whitney *t* test was used to compare variables. Three logistic models were then used to determine predictors of r-PJK: a first model to examine prerevision alignment parameters, a second one to examine correction and a third model that considered both prerevision alignment and correction. In each model, demographic variables and radiographic variables with $P < 0.1$ on the univariate analysis were included.

RESULTS

Description of Revision Cohort

A total of 70 patients met inclusion criteria at an average follow-up of 21.8 months. The mean age was 66.3 ± 9.4 and 80% of patients were female. Before their revision surgery, 94.3% of patients were fused to the sacrum/ilium. When undergoing their revision for PJK, 74.3% of patients had a UIV in the lower thoracic (LT) spine (most commonly T10: 41.4%, or T11: 12.9%) and 25.7% had a UIV in the upper thoracic (UT) spine (most commonly T4: 11.4% or T3: 8.6%).

The prerevision and postrevision alignments are summarized in Table 1. Before revision, patients had a PJA angle of $-31.7^\circ \pm 15.9^\circ$; there was no significant difference in the PJA between the UT and LT UIV groups. Following revision surgery, there was no significant difference in PI-LL, but the PJA angle was significantly corrected by $15.1^\circ \pm 19.2^\circ$ and associated to a significant decrease in PT ($\Delta PT = -2.4^\circ \pm 6.9^\circ$), a significant decrease in the thoracolumbar kyphosis ($\Delta T10\text{-}L2 = 13^\circ \pm 17.4^\circ$), and global alignment ($\Delta TPA = -5.2^\circ \pm 9.1^\circ$; $\Delta SVA = -33 \pm 72$ mm).

At the time of revision, the fusion was extended proximally by 8.5 ± 2.9 levels. Most patients were extended to the UT spine. Following revision, 6 patients (8.6%) had UIV in the LT spine, 50 (71.4%) in the UT spine, and 14 (20%) in the cervical spine. Of the patients fused to the UT spine, most were to T4 (22.9%), T3 (25.7%), or T2 (12.9%). Of those patients fused to the cervical spine, eight (11.4%) underwent a fusion to C1 or C2 and one patient underwent an occipital fusion.

Incidence of Recurrent Proximal Junctional Kyphosis

Out of the 70 patients included in this analysis 32 (45.7%) developed a recurrent PJK. The analysis after stratification by UIV location revealed that r-PJK occurred in 2 of 13 (15.4%) of the patients with a UIV in the cervical spine, 27 of 50 (54%) of the patients with an UIV in the UT spine, and 3 of 6 (50%) of the patients with an UIV in the thoracolumbar area.

Risk Factors for Recurrent Proximal Junctional Kyphosis

There were no significant differences in age, sex, or follow-up in the r-PJK and n-PJK groups (Table 2). Similarly, the two groups were similar with regard to their distribution of prerevision and postrevision UIV.

When comparing prerevision radiographic alignment, the r-PJK cohort had higher TPA, higher SVA, and higher C2-T3 SVA than the n-PJK cohort (Table 3). These parameters indicate larger anterior malalignment in the r-PJK cohort. When comparing the *correction* obtained in the revision surgery, the r-PJK cohort tended to have a larger correction of the global sagittal alignment (TPA and SVA; Table 4). There were no differences in cervical changes between the two cohorts.

Logistic regression based on the prerevision variables showed that prerevision TPA (odds ratio [OR]: 1.060 95% confidence interval [CI] 1.002; 1.121; $P = 0.042$) and prerevision C2-T3 SVA (OR: 1.040 95% CI [1.007; 1.073]; $P = 0.016$) were independent predictors of r-PJK. Classification with these parameters yielded an accuracy of 72.7%, precision of 80.6%, and recall of 73.5%. When examining correction, or change in alignment with revision surgery, we found that change in SVA (OR: 0.981 95% CI [0.968; 0.994]; $P = 0.005$) was the only predictor of r-PJK with accuracy of 66.7%, precision of 74.2%, and recall of 69.7%. Finally, when combining preoperative alignment and correction, we found that only the change in SVA was a significant predictor of r-PJK. Our summary model is shown in Table 5.

Additional Revision Surgery

Following the PJK revision surgery, a total of four (5.7%) patients sustained an additional revision surgery. Three of

TABLE 2. Demographic Information for the Entire Cohort and for n-PJK and Recurrent Proximal Junctional Kyphosis

	All	no-PJK	PJK	*P*
N (%)	70	27 (46.6%)	31 (53.4%)	–
Age	66.3 ± 9.4	65.8 ± 11.4	66.5 ± 7.8	0.794
Sex	80% F	85.2% F	74.2% F	0.348
Mean FU	21.8 m ± 16.6	18.8 m ± 15.0	24.6 m ± 18.6	0.291
Prerevision UIV	LT: 86.2%	LT: 85.2%	LT: 87.1%	1.000
	UT: 13.8%	UT: 14.8%	UT: 12.9%	
Postrevision UIV	LT: 10.3%	LT: 11.1%	LT: 9.7%	1.000
	UT: 86.2%	UT: 85.2%	UT: 87.1%	
	≥C7: 3.4%	≥C7: 3.7%	≥C7: 3.2%	

LT indicates lower thoracic; n-PJK, no-proximal junctional kyphosis; PJK, proximal junctional kyphosis; UIV, upper instrumented vertebra; UT, upper thoracic.

TABLE 3. Prerevision Alignment for the Entire Cohort and for n-PJK and Recurrent Proximal Junctional Kyphosis

	All	n-PJK	r-PJK	*P*
Thoracolumbar alignment				
PI	54.7 ± 13	52.6 ± 11.7	54.3 ± 14.3	0.624
PT	26.4 ± 10.5	24.2 ± 8.3	29.5 ± 12.7	0.070
PI-LL	5.7 ± 17.3	2.8 ± 13.6	8.9 ± 21.6	0.215
T10-L2	−27.1 ± 21.3	−28.1 ± 18.5	−35.1 ± 19	0.161
T2-T12	−63.8 ± 17.3	−59.8 ± 16.3	−64.7 ± 15.2	0.245
TPA	24.2 ± 12.3	21.1 ± 9.1	28.8 ± 14.3	0.021
SVA	63.1 ± 65.2	49.4 ± 65.2	85.5 ± 63.9	0.040
Cervical alignment				
C2-T3	18.4 ± 19.3	18.2 ± 16.6	23.8 ± 19.7	0.263
C2-T3 SVA	80.4 ± 22.9	68.7 ± 19.7	83.8 ± 20.7	0.008
C2-C7	21 ± 16.6	18.3 ± 18.2	23.9 ± 15	0.219
C2-C7 SVA	36 ± 15.1	31 ± 14.5	36.1 ± 14.5	0.209
T1 slope	42 ± 13.9	37.1 ± 13.3	43 ± 11.1	0.074
PJK angle	−31.7 ± 15.9	−28.3 ± 17.3	−36.7 ± 14.9	0.052

LL indicates lumbar lordosis; PI, pelvic incidence; PJK, proximal junctional kyphosis; PT, pelvic tilt; SVA, sagittal vertical axis; TPA, thoracic pelvic angle.

TABLE 4. Change in Alignment for the Entire Cohort and for n-PJK and Recurrent Proximal Junctional Kyphosis

	All	n-PJK	r-PJK	*P*
Thoracolumbar alignment				
PT change	−2.4 ± 6.9	−2.1 ± 6.7	−3.3 ± 7.5	0.528
PI-LL change	−2.3 ± 12.2	−0.8 ± 11.1	−6 ± 13.9	0.121
T10-L2 change	13 ± 17.4	15 ± 19.9	15.1 ± 15.7	0.971
T2-T12 change	−1.4 ± 15.4	−3.3 ± 12.6	−5.7 ± 15	0.518
TPA change	−5.2 ± 9.1	−3.6 ± 7.7	−9.1 ± 9.9	0.025
SVA change	−33.3 ± 71.9	−18.7 ± 75.1	−64.7 ± 60.3	0.013
Cervical alignment				
C2-T3 change	−9.6 ± 17.9	−5.7 ± 17.7	−14.9 ± 18.5	0.072
C2-T3 SVA change	5.5 ± 23	14.1 ± 22.6	4.6 ± 22.6	0.129
C2-C7 change	−1.4 ± 11.4	1.5 ± 10.6	−1.9 ± 10.3	0.243
C2-C7 SVA change	4.7 ± 13.1	7.3 ± 13.6	4.9 ± 13.1	0.509
T1 slope change	2.5 ± 12	5.4 ± 10.8	4.2 ± 11.7	0.675
PJK angle change	15.1 ± 19.2	12.6 ± 20.5	17.8 ± 19.5	0.327

LL indicates lumbar lordosis; PI, pelvic incidence; PJK, proximal junctional kyphosis; PT, pelvic tilt; r-PJK, recurrent proximal junctional kyphosis; TPA, thoracic pelvic angle.

TABLE 5. Summary Predictive Model for Recurrent Proximal Junctional Kyphosis

Model	Parameters	P	OR	95% CI	Accuracy	Precision	Recall	F1-Score
0	*None*	–			42.60%	42.60%	100.00%	0.597
1	Prerevision TPA	0.042	1.060	[1.002–1.121]	72.70%	80.60%	73.50%	0.769
	Prerevision C2-T3 SVA	0.016	1.040	[1.007–1.073]				
2	Change in SVA	0.005	0.981	[0.968–0.994]	66.70%	74.20%	69.70%	0.719

CI indicates confidence interval; OR, odds ratio; SVA, sagittal vertical axis; TPA, thoracic pelvic angle.

the four patients were revised for a new onset of PJK, and the last one was revised for rod fracture at the level of the osteotomy. Among the 30 r-PJK patients with a UIV within the thoracolumbar area (*i.e.*, excluding those with an UIV within the cervical spine), 3 (10%) sustained an additional surgery for recurrent PJK.

DISCUSSION

In this study, the incidence of recurrent PJK was 45.7% with a rate greater than 50% when the revision fusion UIV was below C7. In addition, the rate of revision surgery for r-PJK was 5.7%. The major risk factors associated with recurrent PJK were increased anterior malalignment, especially in the cervicothoracic radiographic parameters (Table 3). Other radiographic risk factors included increased TPA, SVA, and C2-T3 SVA. Similar to PJK after ''index'' procedures, r-PJK was also correlated with increased SVA correction.[8] Our multivariate analysis confirmed this association, an increased in preoperative C2-T3 SVA, TPA, and increased SVA correction were identified as independent predictors of r-PJK with increased SVA correction being the most persistent predictor of r-PJK.

The alignment of the unfused segments above a region of PJK can possibly provide insight into the level selection at the time of revision surgery to minimize the risk for recurrence. Our data indicated a high prerevision C2-T3 SVA (postindex PJK) as a high-risk factor for recurrence, whereas patients with a lower C2-T3 SVA were less at risk for recurrent PJK (Tables 2 and 3). Because this study is not prospective, it is uncertain if the revision operation (Figure 1C) for PJK had been extended up to C2 (due to the high C2-T3 SVA seen) could have avoided the interim admission and revision surgery (Figure 1D), that occurred between the revision and the final follow-up radiographs (Figure 1E). In contrast, the patient in Figure 2 who underwent successful revision without recurrence had a lower C2-T3 SVA. As mentioned previously, this is a potential cost-savings of up to $195,000, when considering not only the surgical costs, but of all costs associated with the admission.[6,7]

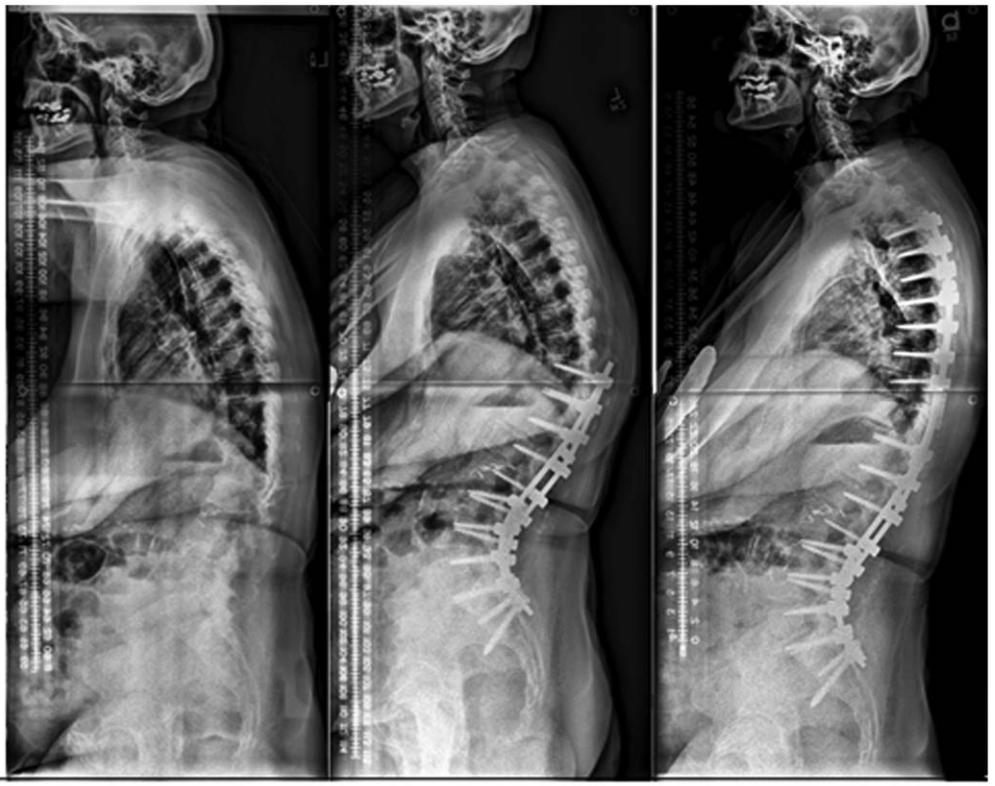
To our knowledge, one prior study reported their experience with revision PJK cases.[2] In their study, Kim *et al*[2] reported their experience with 32 patients who underwent revision surgery for PJK due to fracture and no-fracture etiologies. They reported a recurrent PJK rate of 19% and an overall revision surgery rate of 6%.[2] They did not compare their characteristics to normal controls without PJK. They reported outcomes after revision surgery were similar regardless of the etiology of the PJK.

Several studies have identified radiographic risk factors associated with PJK including excessive LL compared to age-matched controls and excessive SVA corrections.[8] In another study, SVA corrections over 9 cm and larger LL corrections were associated with a high PJK risk.[8] None of the prior studies, however, focused on recurrent PJK cases. Through our multivariate analysis, we saw that increased SVA correction was associated with an increased risk of r-PJK.

The association between increased SVA correction and r-PJK is perhaps not entirely unsurprising as patients with r-PJK also had increased preoperative SVA (r-PJK: 85.5 ± 63.9 *vs.* n-PJK: 49.4 ± 65.2). This increased baseline SVA in the r-PJK group translated to larger attempted SVA corrections intraoperatively, whereas the n-PJK group was corrected by only 18.7 ± 75.1 mm, the r-PJK group was corrected by 64.7 ± 60.3 mm. As we have come to appreciate the importance of age-appropriate targets for PJK, we should also consider that there might be prerevision alignment-based targets when revising patients with PJK. In addition, for the vast majority of the patients, the PJK consisted in a cranial extension of the posterior fusion without any change in PI-LL. Because several authors have demonstrated than an excess of LL *versus* age-alignment targets[8,16] can be a risk factor for PJK, one could argue that the PJK surgery may have failed to address the root cause of the initial PJK.

The main limitations of this study are those inherent to the retrospective study design. For this reason, strong conclusions to guide management or to provide radiographic correction guidelines are not possible with this data. However, our multivariate analysis provided significant ORs for the identified risk factors, and a prospective study to apply these principles can be designed to have more conclusive data (Table 5).

In conclusion, we provide a comparative cohort analysis of recurrent PJK in this subset of patients undergoing revision surgery for PJK. Our data demonstrated a high incidence of r-PJK with a revision surgery rate of 10% in the r-PJK subgroup. This is particularly concerning due to the high costs associated with PJK revisions. We identified significant radiographic parameters that may prove to be helpful in revision cases to minimize the chances of developing r-PJK. As with index cases, judicious SVA correction is critical to reducing the risk of r-PJK.



PI	55.0	51.5	51.0
PT	32.6	21.3	23.0
PI-LL	11.7	-13.1	-11.5
TK	-36.8	-60.2	-47.5
SVA	76.3	6.8	-56.6
TPA	28.5	14.0	9.9
C2-T3 SVA	104.1	77.3	87.4
C2-T3	9.7	10.1	-9.2

Figure 2. A case of nonrecurrent proximal junctional kyphosis (PJK). Left to right; pre-op, post-op with PJK, revision for PJK. The C2-T3 SVA pre-op for the revision for PJK was 75 mm. Refer to figure for all radiographic parameters. LL indicates lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; SVA, sagittal vertical axis; TK, thoracic kyphosis; TPA, thoracic pelvic angle.

➢ Key Points

- ❑ The rate of recurrent PJK was 44.3%.
- ❑ Logistic regression showed that prerevision TPA (OR: 1.060 95% CI [1.002; 1.121]; $P = 0.042$) and prerevision C2-T3 SVA (OR: 1.040 95% CI [1.007; 1.073]; $P = 0.016$) were independent predictors of r-PJK.
- ❑ When examining correction, or change in alignment with revision surgery, we found that change in SVA (OR: 0.981 95% CI [0.968; 0.994]; $P = 0.005$) was the only predictor of r-PJK.

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