

The Benefit of Addressing Malalignment In Revision Surgery for Proximal Junctional Kyphosis Following ASD Surgery

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STUDY DESIGN: Retrospective cohort study

OBJECTIVE: Understand the benefit of addressing malalignment in revision surgery for PJK.

SUMMARY OF BACKGROUND DATA: Proximal junctional kyphosis(PJK) is a common cause of revision surgery for ASD patients. During a revision, surgeons may elect to perform a proximal extension of the fusion, or also correct the source of the lumbo-pelvic mismatch.

METHODS: Recurrent PJK following revision surgery was the primary outcome. Revision surgical strategy was the primary predictor(proximal extension of fusion alone compared to combined sagittal correction and proximal extension). Multivariable logistic regression determined rates of recurrent PJK between the two surgical groups with lumbo-pelvic surgical correction assessed through improving ideal alignment in one or more alignment criteria(Global Alignment and Proportionality[GAP],Roussouly-type, and Sagittal Age-Adjusted Score[SAAS]).

RESULTS: 151 patients underwent revision surgery for PJK. PJK occurred at a rate of 43.0%, and PJF at 12.6%. Patients proportioned in GAP post-revision had lower rates of recurrent PJK(23% vs 42%;OR: 0.3,95% CI:[0.1-0.8];p=.024). Following adjusted analysis, patients who were ideally aligned in 1 of 3 criteria (Matching in SAAS and/or Roussouly matched and/or achieved GAP proportionality) had lower rates of recurrent PJK (36% vs 53%;OR: 0.4,95% CI:[0.1-0.9];p=.035) and recurrent PJF(OR: 0.1,95% CI:[0.02-0.7];p=.015). Patients ideally aligned in 2 of 3 criteria avoid any development of PJF(0% vs. 16%, p<.001).

Conclusion: Following revision surgery for proximal junctional kyphosis, patients with persistent poor sagittal alignment showed increased rates of recurrent proximal junctional kyphosis compared with patients who had abnormal lumbo-pelvic alignment corrected during the revision. These findings suggest addressing the root cause of surgical failure in addition to proximal extension of the fusion may be beneficial.

Key-words:

Proximal junctional failure, proximal junctional kyphosis, PJK, PJF, revision, adult spinal deformity, lumbo-pelvic correction, sagittal correction, proximal extension, recurrent PJK

- We sought to evaluate patients undergoing revision surgery for PJK and compare outcomes between those who only had proximal extension of the fusion to those who had proximal fusion extension combined with sagittal correction.
- We hypothesized that patients with sagittal correction and proximal extension of the fusion construct would have lower rates of PJK recurrence following the revision procedure.
- In patients undergoing revision surgery for proximal junctional kyphosis, those who maintained poor sagittal alignment showed worse clinical outcomes compared with patients who had their abnormal lumbo-pelvic mismatch corrected in combination with proximal extension of the fusion construct.
- These findings suggest addressing the root cause of surgical failure in addition to proximal extension of the fusion may be beneficial for patient outcomes and reduce the likelihood of recurrent PJK following revision surgery.

INTRODUCTION

The prevalence of adult spinal deformity is increasing in parallel with the general aging of the population, with rates as high as 68% for patients over the age of 65.¹ Surgical correction of sagittal deformity is often used to restore quality of life and improve clinical outcomes.^{2,3} The goals of ASD corrective surgery rely on achieving appropriate sagittal alignment in order to restore optimal spinal balance for healthy function.^{4,5}

Despite the improvements in spine surgery and numerous benefits of surgical correction, proximal junctional kyphosis (PJK), one of the most common complications of ASD surgery, continues to be a challenge for physicians, with studies reporting rates of PJK as high as 61% post-operatively.^{6,7} PJK development may not necessarily require intervention, however in cases of severe or progressive deformity, unremitting or severe pain, or potential compromise of neural components, surgery is often required.^{6,7} Studies show the rates of patients that develop PJK requiring revision surgery range from 10% up to 47%.⁶⁻⁸

Surgical correction of proximal junctional kyphosis generally involves proximal extension of the fusion by at least two or three levels from the previously upper instrumented vertebrae, and in some cases may require extension beyond three levels in order to obtain a pre-revision junctional angle that is neutral or lordotic.⁷ However, there is currently a paucity in literature regarding a critical decision that surgeons must make when revising PJK: whether to solely extend the construct of the fusion or to additionally address the root cause by correcting sagitto-pelvic alignment.

In this context, we sought to evaluate patients undergoing revision surgery for PJK and compare outcomes between those who only had proximal extension of the fusion to those who had

proximal fusion extension combined with sagittal correction. We hypothesized that patients with sagittal correction and proximal extension of the fusion construct would have lower rates of PJK recurrence following the revision procedure.

MATERIALS AND METHODS

Study Design

We conducted a retrospective review of a prospective, multicenter adult spinal deformity database. Prior to enrollment and initiation of the study, Institutional Review Board approval was obtained. Patients were consecutively enrolled from thirteen participating centers with dataset inclusion criteria consisting of adult spinal deformity operative patients >18 years undergoing surgical revision due to proximal junctional kyphosis. The database consists of patients who were enrolled for PJK revision surgery, as well as those already enrolled who developed PJK necessitating surgical correction.

Data Collection and Radiographic Parameters

Standardized forms were utilized for data collection to obtain demographic and surgical parameters. Baseline demographic characteristics collected were age, body mass index (BMI), Charlson comorbidity index (CCI), sex, and frailty, as assessed by the Passias et al. ASD-FI.¹⁰ Operative details compiled included levels fused, operative time, estimated blood loss, surgical approach, osteotomy usage [Smith-Petersen (SPO); three-column osteotomy (3CO): pedicle

subtraction (PSO), vertebral column resection (VCR)], interbody usage [anterior (ALIF), posterior (PLIF), transforaminal (TLIF), lateral (LLIF or XLIF)], and decompressions. Free-standing full length lateral spine radiographs (36'' cassette) were collected and analyzed utilizing SpineView® (ENSAM, Laboratory of Biomechanics, Paris, France) software according to previously published validated and standardized techniques.^{11,12} Routine audits, data checks and yearly updates by a dedicated research team at each institution, in conjunction with the central ISSG research staff, ensured the database was consistently maintained at a high standard of quality. Patients with available pre-revision and post-revision radiographic data available were analyzed.

Definition of Proximal Junctional Kyphosis and Proximal Junctional Failure

Proximal junctional kyphosis (PJK) was defined by a follow-up, radiographically-measured PJK angle of less than or equal -10° and a difference from baseline to follow-up in PJK angle of less than or equal to -10° . Proximal junctional failure (PJF) was defined using the Lafage et al. criteria of a 2-year PJK angle of $< -28^{\circ}$, and a 2-year difference in PJK angle of $< -22^{\circ}$, or revision surgery for PJK before 2 years post-operation.

Defining Alignment Schemas

Three different alignment criteria were used: the Global Alignment and Proportion (GAP) score, age-adjusted alignment goals as postulated by Lafage et al., and the Roussouly Classification System.¹³⁻¹⁵ The GAP score includes five total components: relative pelvic version (measured

minus ideal sacral slope), relative lumbar lordosis (measured minus ideal lumbar lordosis), lordosis distribution index (L4-S1 lordosis divided by L1-S1 lordosis multiplied by 100), and relative spinopelvic alignment (measured minus ideal global tilt), and an age factor. Patients are then grouped based on the score out of 13: Proportioned (0-2), Moderately Disproportioned (3-6), and Severely Disproportioned (7+).¹³ The Sagittal Age-Adjusted Score (SAAS) is an aggregated form of the earlier published formulas for age-adjusted realignment by Lafage et al.¹⁴ This score is composed of three sagittal parameters (PI-LL, PT and T1PA). For these three parameters, points were assigned based on offset from age-adjusted targets, and zero points were granted if the parameter was within a ten-year window above and below the patient's age, deemed 'Match'. One point was added or subtracted for each twenty-year window above or below the Match range, respectively (10 to 30 years, 30 to 50 years, etc). The total SAAS score was calculated by adding the score of each component (PI-LL, PT, and T1PA). SAAS was sub-categorized into "Under" if the total score was less than -1, "Match" if between -1 and +1, or "Over" if greater than +1.¹⁴ The Roussouly Classification System assigns a patient to one of four types utilizing sacral slope, known as their "theoretical" type. Pizones et al. later modified the system to include a "current" type based on pelvic incidence minus lumbar lordosis. In this system patients are considered as achieving ideal alignment when their preoperative "current" type was restored to their "theoretical" type.¹⁶

Statistical Analysis

In this investigation, recurrent PJK following revision surgery was the primary outcome and revision surgical strategy was considered the primary predictor, with proximal extension of

fusion alone compared to sagittal correction and proximal extension in combination. Baseline unadjusted comparisons were made between patients who solely had a proximal extension of fusion and those who also had sagittal correction in combination. Paired sample t-tests were used to assess radiographic alignment pre-revision and post-revision. Multivariable logistic regression analysis, controlling for baseline deformity in the corresponding classification (GAP, SAAS, Roussouly), osteoporosis, frailty, CCI, BMI, UIV prior to revision and post-revision, number of levels fused, 3CO usage, and the pre-revision SVA and PJK angle, was used to determine rates of recurrent PJK between those patients who had a proximal extension of the fusion and those who had a proximal fusion extension as well as lumbo-pelvic surgical correction, which was assessed through achieving an ideal alignment in one or more alignment criteria schemas. Receiver operator characteristics (ROC) curve method was utilized to assess area-under-the curve (AUC). Apparent model performance was measured by the Hosmer-Lemeshow (H-L) goodness-of-fit test. Statistical Analysis was performed using SPSS software (v25.0, Armonk, NY, USA).

RESULTS

Overall Cohort Overview and Pre-Operative vs Post-Operative Radiographic Profile

There were 151 adult spinal deformity patients all undergoing revision surgery for PJK that met inclusion criteria. Mean patient age was 65.5 ± 9.0 years, body mass index of 28.6 ± 6.0 kg/m², Charlson Comorbidity Index (CCI) of 2.1 ± 1.7 , modified ASD-frailty index was 8.8 ± 4.8 with 74% of patients being female and 19.4% presenting with a diagnosis of osteoporosis. Patients

had their first postoperative follow-up visit of 3.3 ± 3.1 months (median: 1.8 months) where radiographic images were taken. Pre-revision and post-revision radiographic profile in Table 1. Patients showed improvement across all radiographic parameters tested after revision surgery (all $p < .05$; Table 1). Radiographic profile based on GAP proportionality, SAAS, and Roussouly types pre-revision and post-revision in Table 2.

Surgical Overview

Operatively, patients had a mean of 11 ± 5 levels fused, estimated blood loss of 1327.6 ± 1459.7 mL, and operative time of 309 ± 137 minutes. By surgical approach, 87.0% were posterior-only, 13.0% underwent a combined approach. Regarding surgical details, 74.8% had an osteotomy, and 31.5% of patients had a 3-column osteotomy. The most common UIV was T4 (20.5%), followed by T3 (16.6%), T10 (9.9%), T5 (9.3%) and T2 (8.6%).

Patients with Proximal Extension of Fusion and Correction of Sagittal Alignment

By matching Roussouly type, 21 patients (13.9%) went from a mismatch to appropriate alignment. Of the 97 patients unmatched in the Sagittal Age-Adjusted Score (SAAS) pre-revision, 18 patients (18.6%) went from unmatched to matched post-revision. Of 102 patients disproportioned in GAP pre-revision, 35 patients (34.3%) improved to proportioned in GAP post-revision.

Rates of Recurrent PJK, PJF, and Revisions for PJK

After revision surgery, 65 patients (43.0%) developed recurrent PJK and 19 (12.6%) patients developed proximal junctional failure. Neither osteoporosis, CCI, or frailty had unadjusted correlation to develop of either PJK (all $p > .6$) or PJF (all $p > .5$) post-revision.

Outcomes Analysis Between Patients with Proximal Fusion Extension vs Fusion Extension and Lumbo-pelvic Correction

Patients proportioned in GAP post-revision had lower rates of recurrent PJK (23% vs 42%; OR: 0.3, [95% CI: 0.1-0.8]; $p = .024$). Conditional inference decision tree modeling established patients with a post-operative PT less than 27 had lower rates of recurrent PJK (33% vs 54%, OR: 0.4, 95% CI: 0.2-0.9, $p = 0.023$). In a categorical alignment adjusted analysis, patients who were ideally aligned in 1 of 3 criteria (improved to matched from unmatched in SAAS and/or Roussouly target was met and/or achieved GAP proportionality) had lower rates of recurrent PJK (36% vs 53%, OR: 0.4, 95% CI: 0.1-0.9, $p = .035$). Controlling for osteoporosis, frailty, CCI, BMI, UIV prior to revision and post-revision, number of levels fused, 3CO usage, and the pre-revision SVA, PJK angle, GAP score, patients meeting at least 1 of 3 incremental criteria remained significantly less likely to develop PJF (OR: 0.1, 95% CI [0.02-0.7]; $p = .015$). Adjusted analysis revealed patients meeting two of three criteria did not have lower rates of PJK (40% vs. 47%, $p = .392$), but did not develop any PJF (0.0% vs. 15.5%, $p < .001$). Incorporating the same covariates into a generalized linear model when testing those patients meeting at least 1 of 3 realignment criteria, an area under the curve for PJK (AUC: 0.713; H-L: 6.8, $p = .557$) and PJF (AUC: 0.893; H-L: 9.5, $p = .309$) was derived.

Surgical Details of Patients Aligned in 2 of 3 Categorical Criteria

Of the 41 patients that were aligned in 2 of 3 criteria, 27 patients had at least one SPO, 9 had a PSO, and 4 had a VCR. Usage of inter-body fusions was as follows: 6 patients had an ALIF, 1 patient had a PLIF, 2 had a TLIF, 6 had an LLIF. Patients had a mean of 12 levels fused.

DISCUSSION

Restoration of optimal sagittal alignment has proven to be highly beneficial in adult spinal deformity surgery. However, in cases of revision surgery for PJK, there is no consensus on whether patients should have lumbo-pelvic realignment along with proximal fusion extension or focus on the proximal fusion correction alone.¹⁷⁻¹⁹ Proximal fusion alone would be less invasive, likely associated with a lower complication profile and potentially faster recovery from the revision. However, if extension alone is also associated with a higher rate of PJK, correction of sagittal alignment may be the more sound surgical strategy. In this study, we found addressing the underlying sagittal imbalance in patients with PJK demonstrated lower rates of recurrent PJK and PJF.

Numerous studies discuss the high rate of revision surgeries in PJK patients, with Cerpa et al. identifying rates as high as 47% for PJK in their ASD population.^{6,7,20-24} Specifically among patients who already underwent revision for PJK, Kim et al. found that the rates of recurrent PJK were as high as 45.7%, with 5.7% of patients requiring another revision surgery. Although the complication profile and potential for additional reoperations is high in these patients, Lenke et al. found substantial improvements in both ODI and SRS-Total post-revision, emphasizing the importance of revising patients who otherwise have a reduced quality of life.²⁵

Several studies have analyzed the effects that baseline and post-operative alignment may have on the failure at the proximal junction.^{27,30,31} A study by Kim et al. identified a greater degree of correction in SVA and lumbar lordosis (LL) present in patients who developed PJF, while another study found overcorrection in age-adjusted SVA and PI-LL was associated with increased PJK.³¹ This is similar to the findings of our study, where patients undergoing revision surgery for PJK had a higher recurrence of PJK when overcorrected post-operatively.

Although literature shows PJK development is likely multifactorial, several risk factors have been identified.³² Hostin et al. found that a higher upper instrumented vertebrae (UIV) may be protective of PJK development, with more thoracolumbar patients than upper thoracic UIV patients developing PJK.³³ Multiple studies have also shown non-modifiable risk factors such as age and osteoporosis may also predispose patients to the development of PJK and subsequent need for revision surgery.^{6,34,35} In addition to these factors, a study by Katsura and colleagues found that an offset from an ideal age-adjusted alignment is an independent predictor of PJK and subsequent revision surgery, highlighting the important role sagittal malalignment plays both in the development of PJK and recurrent PJK and PJF following revision.^{8,36,37}

Although PJK revision is a fairly common procedure, literature on the surgical approach for cases of proximal junctional failure is currently limited, and there has yet to be a consensus on appropriate management. Martini and colleagues describe their approach for 21 patients requiring PJF revision. For patients without loss of correction and malalignment, authors performed proximal extension of the fusion with minimal stiffness and biomechanical load at the

UIV while reducing lumbar lordosis at the inferior portion of the construct. In patients with sagittal and/or coronal malalignment, authors recommended correcting through usage of a “tie” rod or “kickstand” rod.²⁶ The authors emphasis on restoring sagittal alignment is congruent with the clinical message of our findings.

Ligamentous and muscular damage at the UIV has been associated with development of PJK.²⁷⁻

²⁹ In a study by Daniels et al., author analyzed the effects of caudal fusion extension in revision surgery of 40 patients. Patients with an unaltered UIV had subsequent PJK rates of 24.2%, while implant exchange had rates of 42.9%. Additionally, 0% of patients with caudal extension alone developed subsequent PJF. Treatment consisted of 87.5% of patients undergoing fusion to sacropelvis with 40% undergoing a three-column osteotomy. The authors noted substantial improvements in sagittal alignment and patient-reported outcomes, highlighting the potential for lumbo-pelvic correction without proximal fusion extension in treatment of PJK revision cases.²⁸ Similarly, Lenke et al. concluded in a study of 20 PJK revision patients the importance of appropriate matching pelvic incidence and lumbar lordosis to reduce the rates of recurrent PJK.²⁵ These findings, along with the findings of our study, emphasize the utility in correcting patients to ideal alignment, either through proportionality, shape, or age-adjusted values without proximal extension alone or overcorrecting malalignment.

Limitations

There are several potential limitations to this work. Foremost, this remains a retrospective review with resultant patient heterogeneity and the potential for selection, indication, expertise and

surveillance bias. There was a 10-year enrollment period and there may also be an influence of secular trends that we are unable to control for. While the sample was relatively large for a condition such as PJK following ASD surgery, the event rate remains confiscatory and limited our statistical approach, especially in the context of examining the effects of variables on PJF, in which only 19 occurrences were seen. While the Roussouly classification and GAP score were initially correlated to outcomes, further follow-up studies have demonstrated inconsistent results and this should be taken into account when evaluating the outcomes of the present study. Furthermore, these analyses should be viewed as exploratory and the findings hypothesis generating and not prescriptive, as future prospective studies should rigorously examine the effect and type of realignment in PJK revision surgery. The fact remains that these results should be validated in a larger cohort of patients before more definitive recommendations are possible.

CONCLUSIONS

In patients undergoing revision surgery for proximal junctional kyphosis, those who maintained poor sagittal alignment demonstrated reoccurrence of junctional kyphosis and failure more often compared with patients who had their abnormal lumbo-pelvic mismatch corrected in combination with proximal extension of the fusion construct. These findings suggest addressing the root cause of surgical failure in addition to proximal extension of the fusion may be beneficial to reduce the likelihood of recurrent junctional pathologies following revision surgery.

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Table 1. Pre-revision and post-revision radiographic profile.

Paired Sample Analysis				
	Value Pre-Revision	Value Post-Revision	Paired Differences Mean \pm Std. Deviation	Sig. (2-tailed)
SS	27.89	32.79	-4.90 \pm 7.68	p<.001
PT	26.59	21.92	4.67 \pm 7.53	p<.001
PI	54.5	54.7	-.22 \pm 2.90	p=.360
PI-LL	12.31	0.95	11.35 \pm 17.65	p<.001
L1-S1	42.18	53.75	-11.58 \pm 17.69	p<.001
T10-L2	-26.41	-12.46	-13.95 \pm 18.38	p<.001
T1-T12	-56.7	-61.74	5.04 \pm 16.81	p=.001
C2-C7	20.18	16.5	3.68 \pm 11.05	p<.001
C7-S1 SVA	76.99	25.06	51.93 \pm 70.59	p<.001
C2-S1 SVA	109.98	60.07	49.91 \pm 74.17	p<.001

*Bold values indicate significance

Table 2. Pre-revision and post-revision radiographic breakdown by alignment criteria.

Radiographic Criteria	Pre-Revision	Post-Revision
SRS-Schwab Parameters		
Pelvic Incidence Minus Lumbar Lordosis (PI-LL):	<ul style="list-style-type: none"> • 73 patients (48.3%) low deformity • 26 patients (17.2%) moderate deformity • 47 patients (31.1%) high deformity 	<ul style="list-style-type: none"> • 111 patients (73.5%) low deformity • 23 patients (15.2%) moderate deformity • 10 patients (6.6%) high deformity
Pelvic Tilt (PT):	<ul style="list-style-type: none"> • 33 patients (21.9%) low deformity • 60 patients (39.7%) moderate deformity • 53 patients (35.1%) were high deformity 	<ul style="list-style-type: none"> • 56 patients (37.1%) low deformity • 62 patients (41.1%) moderate deformity • 26 patients (17.2%) high deformity
Sagittal Vertical Axis (SVA):	<ul style="list-style-type: none"> • 49 patients (32.5%) were low deformity • 36 patients (23.8%) moderate deformity • 58 patients (38.4%) high deformity 	<ul style="list-style-type: none"> • 88 patients (58.3%) low deformity • 38 patients (25.2%) moderate deformity • 18 patients (11.9%) high deformity
Age-Adjusted Parameters		
Pelvic Incidence Minus Lumbar Lordosis (PI-LL):	<ul style="list-style-type: none"> • 25 patients (16.6%) matched • 48 patients (31.8%) overcorrected • 65 patients (43.0%) undercorrected 	<ul style="list-style-type: none"> • 26 patients (17.2%) matched • 84 patients (55.6%) overcorrected • 27 patients (17.9%) undercorrected
Pelvic Tilt (PT):	<ul style="list-style-type: none"> • 38 patients (25.2%) matched • 35 patients (23.2%) overcorrected • 67 patients (44.4%) undercorrected 	<ul style="list-style-type: none"> • 43 patients (28.5%) matched • 58 patients (38.4%) overcorrected • 37 patients (24.5%) undercorrected
Sagittal Vertical Axis (SVA):	<ul style="list-style-type: none"> • 32 patients (21.2%) matched • 34 patients (22.5%) overcorrected 	<ul style="list-style-type: none"> • 35 patients (23.2%) matched • 70 patients (46.4%) overcorrected

	<ul style="list-style-type: none"> • 70 patients (46.4%) undercorrected 	<ul style="list-style-type: none"> • 33 patients (21.9%) undercorrected
SAAS (Sagittal Age-Adjusted Score)	<ul style="list-style-type: none"> • 28.5% matched • 27.7% overcorrected • 39.7% undercorrected 	<ul style="list-style-type: none"> • 23.2% matched • 55.8% overcorrected • 18.8% undercorrected
Roussouly Type		
“Current” Roussouly using sacral slope (SS):	<ul style="list-style-type: none"> • 4 patients (2.6%) type one • 98 patients (64.9%) type two • 33 patients (21.9%) type three • 11 patients (7.3%) type four 	<ul style="list-style-type: none"> • 31 patients (20.5%) type one • 2 patients (1.3%) type two • 68 patients (45.0%) type three • 43 patients (28.5%) type four
“Theoretical” Roussouly using pelvic incidence (PI):	<ul style="list-style-type: none"> • 1 patient (0.7%) type one • 36 patients (23.8%) type two • 67 patients (44.4%) type three • 42 patients (27.8%) type four 	<ul style="list-style-type: none"> • 1 patient (0.7%) type one • 78 patients (51.7%) type two • 48 patients (31.8%) type three • 17 patients (11.3%) type four
GAP Proportionality	<ul style="list-style-type: none"> • 28 patients (18.5%) were proportioned • 52 patients (34.4%) were moderately disproportioned • 47 patients (31.1%) were severely disproportioned. 	<ul style="list-style-type: none"> • 47 patients (31.1%) were proportioned • 74 patients (49.0%) were moderately disproportioned • 16 patients (10.6%) were severely disproportioned.