Proximal Junctional Kyphosis and Failure Prophylaxis Improves Cost Efficacy, While Maintaining Optimal Alignment, in Adult Spinal Deformity Surgery

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BACKGROUND AND OBJECTIVES: To investigate the cost-effectiveness and impact of prophylactic techniques on the development of proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) in the context of postoperative alignment.

METHODS: Adult spinal deformity patients with fusion to pelvis and 2-year data were included. Patients receiving PJK prophylaxis (hook, tether, cement, minimally-invasive surgery approach) were compared to those who did not. These cohorts were further stratified into "Matched" and "Unmatched" groups based on achievement of age-adjusted alignment criteria. Costs were calculated using the Diagnosis-Related Group costs accounting for PJK prophylaxis, postoperative complications, outpatient health care encounters, revisions, and medical-related readmissions. Quality-adjusted life years were calculated using Short Form-36 converted to Short-Form Six-Dimension (SF-6D) and used an annual 3% discount rate. Multivariate analysis controlling for age, sex, levels fused, and baseline deformity severity assessed outcomes of developing PJK/PJF if matched and/or with use of PJK prophylaxis.

RESULTS: A total of 738 adult spinal deformity patients met inclusion criteria (age: 63.9 ± 9.9, body mass index: 28.5 ± 5.7, Charlson comorbidity index: 2.0 ± 1.7). Multivariate analysis revealed patients corrected to age-adjusted criteria postoperatively had lower rates of developing PJK or PJF (odds ratio [OR]: 0.4, [0.2-0.8]; $P = .011$) with the use of prophylaxis. Among those unmatched in T1 pelvic angle, pelvic incidence lumbar lordosis mismatch, and pelvic tilt, prophylaxis reduced the likelihood of developing PJK (OR: 0.5, [0.3-0.9]; $P = .023$) and PJF (OR: 0.1, [0.03-0.5]; $P = .004$). Analysis of covariance analysis revealed patients matched in age-adjusted alignment had better cost-utility at 2 years compared with those without prophylaxis ($361 539.25 vs $419 919.43; $P < .001$). Patients unmatched in age-adjusted criteria also generated better cost ($88 348.61 vs $101 318.07; $P = .005$) and cost-utility ($450 190.80 vs $564 108.86; $P < .001$) with use of prophylaxis.

CONCLUSION: Despite additional surgical cost, the optimization of radiographic realignment in conjunction with prophylaxis of the proximal junction appeared to be a more cost-effective strategy, primarily because of the minimization of reoperations secondary to mechanical failure. Even among those not achieving optimal alignment, junctional prophylactic measures were shown to improve cost efficiency.

KEY WORDS: Adult spinal deformity, Spine, Cost-utility, Complex realignment, Proximal junctional kyphosis, Prophylaxis, Hook, tether, Cement

ABBREVIATIONS: ASD, adult spinal deformity; **CCI,** Charlson comorbidity index; **GAP,** Global Alignment and Proportion; **iEOC,** index episode of care; **ISSG,** International Spine Study Group; **MA,** Medicare Allowable; **MIS,** minimally invasive surgery; **ODI,** Oswestry Disability Index; **PI-LL,** pelvic incidence lumbar lordosis mismatch; **PJF,** proximal junctional failure; **PJK,** proximal junctional kyphosis; **PT,** pelvic tilt; **SAAS,** Sagittal Age-Adjusted Score; **SVA,** sagittal vertical axis; **T1PA,** T1 pelvic angle; **UIV,** uppermost instrumented vertebra.

Adult spinal deformity (ASD) is a progressive and potentially debilitating condition of the thoracic and lumbar spine, which can result in physical disability, pain, and neurological complications.[1,2] Intervention through corrective spinal surgery has shown promising results in improving mobility and functionality, as well as quality of life.[3,4] Corrective surgery, however, has been shown to carry the prospect of medical, neurological, and mechanical complications in the near and long term. Some of the most problematic midterm and long-term complications consist of proximal junctional kyphosis (PJK) or proximal junctional failure (PJF) because both conditions are associated with a high risk of revision surgery.[5] Revision surgery is not only an additional health and cost burden for patients but also severely cost inefficient for insurance companies and the corresponding health care facility, costing around $55 500 per revision operation for PJF.[5]

Recently, interest has grown in recognizing and addressing factors associated with the development of PJK and PJF.[6] These include striving to achieve age-adjusted spinopelvic realignment goals during the index procedure, as well as prophylaxis of the proximal junctional segment.[5-9] Prophylactic proximal junctional measures also have shown to minimize the risk of the development of PJK, such as through rib fixation, hybrid instrumentation with hooks, vertebral body tethers, vertebral cement augmentation, and selective material of rods.[5,7-12] Along with prophylaxis use, using established radiographic age-adjusted alignment protocols, spinal deformity patients can be even better optimized for correction within the sagittal plane and minimize risk for postoperative complications.[13]

Although previous studies have demonstrated clinical benefit of PJK and PJF prophylactic measures, there is paucity in current literature on its effects in patients relative to the achievement of optimal postoperative alignment. Through a basis of cost-evaluation, we analyzed operative patients with ASD through prophylactic measures through the usage of cement, hooks, or tethers, to investigate their effects on the development of PJK or PJF, as well as patient reported experience through quality-adjusted life year (QALY) analysis.

METHODS

Data Source and Study Design

We retrospectively queried a multicenter ASD database, collected and routinely audited by the International Spine Study Group (ISSG), to investigate the contributions of proximal junctional prophylaxis and achieving idealized alignment goals on the development of PJF and PJK in a large series of patients undergoing corrective surgery for ASD.[14-16] Institutional Review Board approval was obtained before enrollment, and all patients provided informed consent. Patients with a clinical diagnosis of ASD, aged 18 years or older, undergoing spinal corrective surgery procedures for ASD, and radiographic criteria published in previous works were included in the dataset.[17,18] The criteria for inclusion within this study constituted of patients undergoing surgical intervention for ASD, involving spinal fusion to the pelvis, with follow-up to 2 years postoperatively.

Data Collection Procedure and Radiographic Parameters

We abstracted baseline clinical and demographic characteristics for eligible patients, including age, body mass index (BMI), Charlson comorbidity index (CCI), biologic sex, and the modified ASD frailty index.[19] This was performed using standardized data collection forms. Operative details consisted of the number of levels fused, operative time, estimated blood loss, surgical approach, technique, types of osteotomies performed, degree of invasiveness as assessed by the ISSG-ASD surgical invasiveness score, usage of PJK prophylaxis, and usage of supplemental rods.[20] Clinical outcomes were collected at the preoperative visit and assessed using patient-reported outcome measures administered at regular follow-up intervals, using the Short Form-36, Scoliosis Research Society 22-item questionnaire, and the Oswestry Disability Index (ODI) modified for low back pain.

Free-standing full length lateral spine radiographs (36″ cassette) were used to assess radiographic parameters at baseline and subsequent follow-up intervals. All images were analyzed with SpineView® (ENSAM, Laboratory of Biomechanics) according to previously established and standardized techniques.[21-23] Spinopelvic radiographic parameters assessed included several metrics usually used in the assessment of adult spine deformity, including assessment of global alignment using the Global Alignment and Proportion (GAP) Score.[24,25]

Mechanisms of Prophylaxis

PJK prophylaxis was defined as the surgical application of cement, hooks, tethers, or hybrid measures during corrective surgery in the following contexts: (1) application of polymethylmethacrylate cement at the uppermost instrumented vertebra (UIV) and/or UIV + 1; (2) a transverse process hook sited at the UIV; (3) a vertebral body tether inserted at the spinolaminar junction of the UIV + 1 and/or UIV + 2.[11,12,26-28] The decision-making surrounding PJK prophylaxis technique and utilization was decided by the treating surgeon, and prophylaxis techniques have been verified by previous research studies such as by Bess et al and Line et al.[13,29]

Radiographic Classification

Age-adjusted sagittal alignment was defined corresponding to classification per the *Lafage* et al spinopelvic parameters (pelvic tilt [PT], pelvic

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incidence lumbar lordosis mismatch [PI-LL], T1 pelvic angle [T1PA], sagittal vertical axis [SVA]) and a comprehensive Sagittal Age-Adjusted Score (SAAS).[8,30] Patients were described as "Matched" if they met an ideal age-adjusted postoperative alignment, consisting of the criteria matched, undercorrected, and overcorrected. Patients were described as "Unmatched" if they did not meet ideal age-adjusted spinopelvic alignment.

Evaluation of PJK and PJF

PJK was defined by a PJK angle of <−10° and a PJK angle difference of <−10° from the preoperative imaging and on imaging at any follow-up timepoints up to 2 years postoperatively. PJF was defined by the published criteria of *Lafage* et al,[9] which denoted a PJK angle of <−28° and a difference in PJK angle of <−22° from preoperative imaging and on imaging at any follow-up time point up to 2 years, or PJK with reoperation.

Cost Analysis

Complications, comorbidities, and whether they were major, were assessed according to definitions used by CMS.[31] Reimbursement was determined based on a standardized estimate, which used a regression analysis of the employed Medicare pay-scales for all services rendered within a 30-day window. These standardized estimates also included any costs related to complications, outpatient follow-up visits, reoperations, and readmissions. Medicare Allowable (MA) rates were calculated using the year-appropriate CMS Inpatient Pricer-Payment System Tool specific to hospital and date of surgery based on the Diagnosis-Related Group for the surgery performed. Patients were divided based on if the index episode of care (iEOC) was less than or equal to MA (iEOC < MA) or greater than MA (iEOC > MA).[32]

Utility Calculation

QALY was used to measure the quality of care.[33,34] Short Form-36 was transformed into Short-Form Six-Dimension (SF-6D).[35] Using previously published methods, an equation translated SF-6D into QALYs. QALYs gained were calculated using the following equation:

$$QALYs\,gained = (Q^{i} - Q)\frac{1 - e^{-rL}}{r}$$

QALY is used as a metric of health-related quality of life, which calculates the quality of life (Q) while taking into account the life expectancy (L), (*e*) is Napier's mathematical constant, and (*r*) is the discount rate. The World Health Organization recommends a discount rate of 3% in order to account for residual decline for life expectancy with a US national average life expectancy of 78.7.[36]

Statistical Analysis

The primary outcome was cost-per-QALY at 2 years. Secondary outcomes included PJK and PJF rates. The primary predictors included alignment and use of PJK prophylaxis. The data collected at baseline were compared using *t*-tests and χ^2 tests. Multivariable analyses using logistic regression was used to analyze variables that were predictive of development of PJK or PJF at 2 years. Multivariable logistic regression with control for significant confounders (age, sex, BMI, osteoporosis diagnosis at baseline, number of levels fused, baseline deformity) was used to determine significant associations between alignment, prophylaxis use, and the development of PJK or PJF. Analysis of covariance controlling for the same factors and baseline ODI was used to determine the utility gained and cost per QALY at 2 years among patients matched and unmatched in age-adjusted alignment with and without the use of PJK prophylaxis. All *P*-values less than .05 were considered significant. All statistical analyses were conducted using SPSS, version 28.1.1 (IBM).

RESULTS

Cohort Overview

A total of 738 operative patients with ASD met inclusion criteria. The mean age in this cohort was 63.9 ± 9.9 years, 78% were female, mean BMI was 28.5 ± 5.7 kg/m^2, mean CCI was 2.0 ± 1.7, and mean modified ASD frailty index was 8.1 ± 4.9. Tables 1-3 highlight the baseline demographics, surgical details, and radiographic assessment of the cohort.

Surgical Technique Utilization

When examining the whole cohort of patients, 43.4% of patients received some form of PJK prophylaxis: 17.6% tethering at or above the UIV, 14.0% had a transverse process hook sited,

TABLE 1. Cohort Demographic Details

Cohort details	Overall	Prophylaxis	No prophylaxis	Sig.	95% CI
Mean age (y)	63.9 ± 9.9	65.2 ± 9.1	62.3 ± 10.2	<0.001	−4.5 to −1.5
Sex	78% F	77%	79%	0.357	−0.03 to 0.09
Mean BMI (kg/m^2)	28.5 ± 5.7	28.5 ± 6.0	28.4 ± 5.4	0.870	−0.94 to 0.79
Charlson Comorbidity Index	2.0 ± 1.7	2.2 ± 1.8	1.8 ± 1.6	<0.001	−0.73 to −0.19
Osteoporosis	17.9%	22%	14.3%	0.006	N/A[a]
ASD-modified frailty index	8.1 ± 4.9	8.5 ± 5.2	7.8 ± 4.8	0.099	−1.4 to 0.12
History of prior fusion	75%	77%	74.7%	0.143	N/A[a]

ASD, adult spinal deformity; BMI, body mass index.
[a]Analysis performed using Pearson χ^2.

TABLE 2. Cohort Surgical Details

Surgical details	Mean values
Length of operation (min)	316 ± 153
Estimated blood loss (mL)	1886.4 ± 1536.0
Mean levels fused (N)	11.6 ± 4.0
Length of stay	8.3 ± 5.3
Operative approach	Anterior: 0%; posterior: 64.2%; combined: 35.8%
Osteotomy performed	75%
Three-column osteotomy performed	21%
Intraoperative decompression	67%
Surgical intensive care unit admission postoperatively	65%
Invasiveness index	95.8 ± 35.6

8.1% underwent cement augmentation at the UIV, and 3.7% of patients underwent a minimally invasive approach posteriorly to avoid compromise to the supporting muscular and ligamentous structures around the UIV. When examining PJK prophylaxis utilization, 45% of procedures done using a posterior approach used PJK prophylaxis techniques (10.7% cement, 17.4% hooks, 7.7% minimally invasive surgery (MIS) posterior, 25.1% tethering), while 40% of procedures performed using a combined approach used PJK prophylaxis techniques (10.3% cement, 16.1% hooks, 1.6% MIS posterior, 12.0% tethering).

Radiographic Alignment Outcomes of Cohort

Radiographic parameter outcomes are displayed in Table 3. When assessing age-adjusted alignment postoperatively, 26.3% were matched in PT, 22.4% were matched in PI-LL, 31.6% were matched in SVA, and 35.0% were matched in T1PA. This led to 28.4% to be matched in the SAAS. The mean GAP score at 6 weeks was 4.7 ± 3.5, with 31.4% being proportioned.

TABLE 3. Cohort Radiographic Assessment at Baseline and Postoperative Follow-Up

Metric	Preoperative	Postoperative	*P* value	95% CI
SVA	79.3 ± 70.9	26.13 ± 44.7	<.001	48.4-58.0
PT	26.2 ± 10.1	20.6 ± 9.8	<.001	5.1-6.3
PI-LL	21.2 ± 19.5	2.2 ± 13.5	<.001	17.8-20.1
T1PA	25.9 ± 12.3	16.4 ± 9.6	<.001	8.7-10.2
GAP score	8.4 ± 3.8	4.7 ± 3.5	<.001	3.5-4.1

GAP, Global Alignment and Proportion; PI-LL, pelvic incidence lumbar lordosis mismatch; PT, pelvic tilt; SVA, sagittal vertical axis; T1PA, T1 pelvic angle.

Evaluation of PJK or PJF in Patients

By 2 years, 46.6% of patients developed radiographic PJK and 11.1% developed PJF. Patients developing PJK had significant differences in baseline deformity of PI-LL (22.8 vs 19.9, 95% CI: −5.78 to −.15, $P = .039$), PI (55.1 vs 57.2, 95% CI: 0.20-3.94, $P = .030$), and GAP score (9.1 vs 7.8, −1.88 to −0.77, $P < .001$) compared with those not developing either PJK or PJF. Patients developing PJF were older (66.1 vs 63.1 years, 95% CI: −5.00 to −0.89, $P = .005$), female (84% vs 74%, 95% CI: −0.19 to −0.01, $P = .033$), with more levels fused (12.6 vs 11.3, 95% CI: −2.7 to −0.54, $P = .004$) and significant differences in baseline deformity of T1PA (28.4 vs 25.0, 95% CI: −6.41 to −0.39, $P = .027$), PT (28.5 vs 25.6, 95% CI: −5.4 to −0.44, $P = .021$), and GAP score (9.5 vs 7.8, 95% CI: −2.7 to −0.81, $P < .001$) compared with those not developing either PJK or PJF.

Individual Effects of Surgical Techniques and Realignment on Development of PJK or PJF

Multivariable analyses factoring age, BMI, CCI, sex, osteoporosis, surgical invasiveness (number of levels fused), and deformity (baseline T1PA and GAP score) revealed that patients who used either the MIS posterior approach or transverse process hooks had less likelihood of development of PJK (odds ratio [OR]: 0.3, 95% CI: [0.1-0.6]; $P = .003$) and PJF (OR: 0.2, 95% CI: [0.1-0.5]; $P = .001$). Realignment to age-adjusted standards by matching in SAAS had similar effects on PJK (OR: 0.18, 95% CI: [0.06-0.52]; $P = .015$) and PJF (OR: 0.10, 95% CI: [0.04-0.22]; $P = .009$), as was realignment in T1PA (OR: 0.43, 95% CI: [0.22-0.59]; $P = .018$) and SVA (OR: 0.64, 95% CI: [0.35-0.82]; $P = .047$). Patients proportioned in GAP postoperatively were also less likely to develop PJK (OR: 0.36, 95% CI: [0.21-0.54]; $P = .024$) or PJF (OR: 0.13, 95% CI: [0.05-0.21]; $P = .008$). Figures 1 and 2 illustrate case examples of a patient from each cohort.

Effect of Surgical Techniques in Conjunction with Realignment on Development of PJK or PJF

Multivariable analyses factoring age, BMI, CCI, sex, osteoporosis, surgical invasiveness (number of levels fused), and deformity (baseline T1PA and GAP score) revealed that patients who were matched postoperatively in SAAS had lower rates of developing PJK or PJF (OR: 0.4, 95% CI: 0.2-0.8]; $P = .011$) with the use of prophylaxis and also seen for patients matching in T1PA (OR: 0.5, 95% CI: 0.3-0.8]; $P = .007$) and SVA (OR: 0.5, 95% CI: 0.3-0.8]; $P = .011$). Among those unmatched in T1PA, PILL, and PT postoperatively, the use of prophylaxis also significantly reduced the likelihood of developing PJK (OR: 0.5, 95% CI: 0.3-0.9]; $P = .023$) and PJF (OR: 0.1, 95% CI: 0.03-0.5]; $P = .004$).

Cost Analysis

Analysis of covariance controlling for age, sex, number of levels fused, baseline T1PA and GAP Score, and baseline ODI indicated that patients with ideal age-adjusted alignment and prophylaxis had similar Diagnosis-Related Group costs ($78 595.21 vs

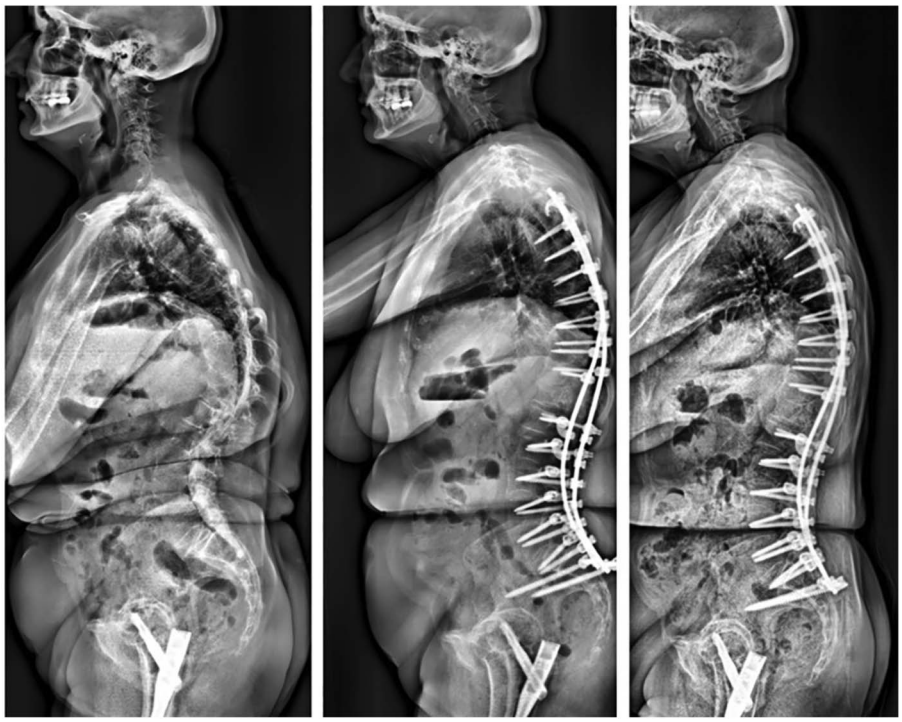

FIGURE 1. *Images from left to right (baseline, 6 week postop, 1 year postop). Case example of a 72-year-old woman who presented with chronic (5 years) of back pain. She had a medical history of hypertension and osteoporosis, with a body mass index of 28.52 kg/m^2. She had a grossly normal neurologic examination on presentation. She underwent posterior spinal fusion from T4 to the pelvis, with transverse process hooks used for PJK prophylaxis. PJK angles at 6 weeks and 1 year were −8.9 and −3.0°, respectively. PJK, proximal junctional kyphosis.*

$72 540.17; P = .402) and utility gained (0.112 vs 0.089; P = .186) compared with patients without PJK prophylaxis, resulting in a lower cost per QALY by 2 years ($361 539.25 vs $419 919.43; P < .001). In unmatched patients, the use of prophylaxis generated significantly lower costs ($88 348.61 vs $101 318.07; P = .005) and similar utility gained (0.091 vs 0.085; P = .569) compared with patients without PJK prophylaxis, resulting in a substantially lower cost per QALY by 2 years ($450 190.80 vs $564 108.86; P < .001; Table 4), primarily because of decreased costs of reoperation among patients receiving prophylactic measures.

DISCUSSION

In this study, we looked to evaluate the cost-effectiveness of PJK prophylactic measures in the development of PJK or PJF for patients undergoing spinal corrective procedures, stratified by whether ideal alignment was achieved. We examined patients based on available baseline and 2-year radiographic and HRQL data and found that when no prophylactic measures were used, patients who were ideally aligned (ie, "matched") exhibited similar PJF rates to those who were not aligned. In patients who were unmatched or not completely aligned, the use of prophylactic measures showed reduced rates of PJK and PJF. It was also found that matched patients with ideal age-adjusted alignment and prophylaxis resulted in lower cost per QALY at 2 years, which was also the case in unmatched patients. Through a cost-analysis of prophylactic use in ASD surgery cases, we found that patients receiving prophylaxis had lower associated costs mostly because of fewer reoperations and greater improvements in QALY.

The findings of this study are in concordance with previous literature demonstrating the efficacy of transverse process hooks at reducing the risk of PJK.[37,38] These hooks are reported to reduce PJK risk by decreasing stress through the UIV because of the avoidance of subperiosteal dissection in the muscles and facets surrounding the UIV.[38,39] Similarly, the implementation of minimally invasive. Although the data have predominantly been reported in the adolescent population, similar benefits have been reported in the adult population as well.[38,39] Similarly, MIS techniques (particularly with percutaneous pedicle screw placement) have also been demonstrated to prevent PJK due to the avoidance of significant disruption to the ligaments, musculature, and facet joints surrounding the UIV.[10,38-40]

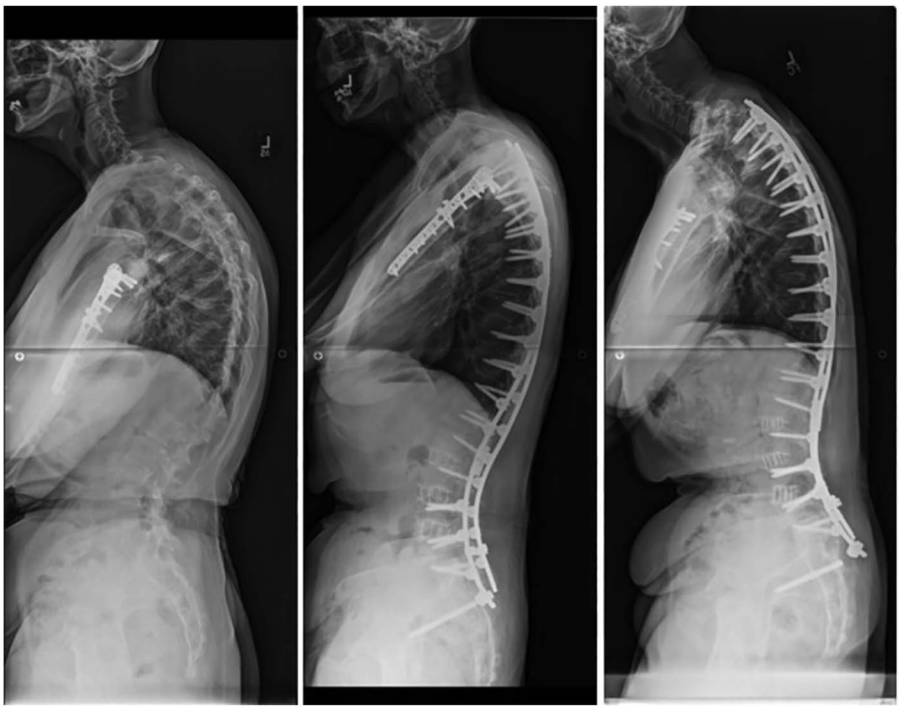

FIGURE 2. *Images from left to right (baseline, 6 week postop, 1 year postop). Case example of a 58-year-old female patient presenting with chronic back and leg pain. She had no medical history of note. Her body mass index was 25.19 kg/m^2. She had a grossly normal neurologic examination on presentation. She underwent anterior/posterior approach to deformity correction with anterior lumbar interbody fusion cages from L2 to L5 and posterior spinal fusion from T3 to the pelvis, without PJK prophylaxis at the upper instrumented vertebra. PJK angles at 6 weeks and 1 year were −6.9 and −21.7°, respectively, indicating the presence of severe PJK at 1 year postoperation. PJK, proximal junctional kyphosis.*

TABLE 4. Cost Analysis Comparisons

	Use of PJK prophylaxis	Did not incorporate PJK prophylaxis	*P* value	95% CI
Patients matched in SAAS				
Utility gained	0.112	0.089	.894	−0.02 to 0.02
Two-year QALYs	0.213	0.175	.894	−0.04 to 0.04
Two-year cost	$78 595.21	$72 540.17	.026	1337-20 453
Two-year cost per QALY	$361 539.25	$419 919.43	<.001	85 485-175 486
Patients unmatched in age-adjusted PT, PI-LL, and T1PA				
Utility gained	0.091	0.085	.372	−0.03 to 0.01
Two-year QALYs	0.176	0.165	.372	−0.06 to 0.02
Two-year cost	$88 348.61	$101 318.07	.007	3966-25 349
Two-year cost per QALY	$450 190.80	$564 108.86	<.001	146 606-270 919

PJK, proximal junctional kyphosis; QALY, quality-adjusted life year; SAAS, Sagittal Age-Adjusted Score.

The development of PJF after ASD corrective surgery is a serious complication which can result in mechanical disruption, such as implant protrusions, and worsened clinical course, such as paralysis and other neurological deficits.[41] But prophylactic techniques have not shown to have a significant impact on the incidence of PJF after ASD surgery, only the severity of PJF.[42] Previous studies have suggested that reducing the incidence of PJF has been associated with ligament augmentation by limiting junctional stress and supporting adjacent vertebral segments.[42] Once PJK/PJF has occurred, it has been reported that there is a 48% recurrence rate of PJK/PJF at the new UIV postrevision and an 82% chance of repeat revision after that.[43-46] The estimated cost of revision surgery after PJF has been reported as $77 432.[45] Other studies have examined the cost-effectiveness of prophylactic techniques, like vertebral augmentation, but our results are based on a much larger and more representative cohort, involving the use of multiple prophylactic techniques.

Other research has focused on the cost-benefit analysis of prophylactic measures used in ASD corrective surgery, and it has shown to be both a safe and cost effective method of intervention for patients.[12] Using age-adjusted alignment spinopelvic goals has also been shown to also reduce risk factors for PJK and improve surgical alignment for patients, thus reducing necessity for revision surgery.[13] Although studies have looked at each method of intervention individually, the development of PJF has not been examined in association with the use of prophylactic measures in conjunction with radiographic alignment.

We believe our results are important for surgical planning and improving patient outcomes in ASD corrective surgery. Our study findings indicate that surgeons should use a combination of intraoperative prophylactic support and age-adjusted spinal alignment criteria in ASD corrective surgery cases to optimize outcomes, minimize postoperative complications, and reduce the likelihood of mechanical failure. Our findings are also important for health care systems and third-party payers, in that they justify the use of more invasive approaches and prophylactic techniques, when practicable, despite the increased associated expense. Furthermore, the results of this study show that, if for whatever reason, idealized alignment cannot be achieved, the use of prophylaxis at the proximal junction still provides value.

Limitations

We acknowledge several limitations inherent to this research. First, using a retrospective database of patients undergoing operation by a single surgeon incurs the risk of selection, expertise, and indication bias. Second, despite the relatively large series, there still may be the prospect of confounding from restricted event rates or truncation, specifically when it comes to patient age and frailty status. Third, we realize that while we measured relative cost-effectiveness, none of the procedures considered achieved the standard cost/QALY threshold that is used to define cost-effective interventions (eg, <$150 000/QALY). Finally, we acknowledge that the statistical approach used here was exploratory in scope and the findings should not be considered prescriptive as a result. We also were unable to perform more granular cost analyses because of heterogeneity in cost at the different institutions included and a variety of institution-specific restrictions to accessing complete cost data. We acknowledge that such analyses would have further enhanced the findings of this study. This study is also limited by the lack of standardization of prophylactic techniques used because of varying practices across the multiple sites included. We envision subsequent studies that might validate these findings in other, larger, cohorts with greater clinical variation. In the interim, at a minimum, our results can be used to inform surgical planning and help patients understand the trade-offs incurred between procedural length, surgical invasiveness, and their influence on clinical outcomes.

CONCLUSION

Prophylactic techniques have demonstrated the ability to reduce postoperative risk of PJK or PJF. At the same time, these approaches increase length of surgery as well as associated costs. Despite the additional surgical cost, our results demonstrate that the optimization of radiographic realignment in conjunction with prophylaxis of the proximal junction seemed to be a more cost-effective strategy, primarily because of the minimization of reoperations secondary to mechanical failure. Even among those not achieving optimal alignment, junctional prophylactic measures were shown to improve cost efficiency.

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