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SURGERY

Identification of Decision Criteria for Revision Surgery Among Patients With Proximal Junctional Failure After Surgical Treatment of Spinal Deformity

Robert Hart, MD,* Ian McCarthy, PhD,†‡ Michael O'Brien, MD,§ Shay Bess, MD,¶ Brett Line, MS,¶ Oheneba Boachie Adjei, MD,‖ Doug Burton, MD,** Munish Gupta, MD,†† Christopher Ames, MD,‡‡ Vedat Deviren, MD,§§ Khaled Kebaish, MD,¶¶ Christopher Shaffrey, MD,‖‖ Kirkham Wood, MD,*** Richard Hostin, MD,§ and International Spine Study Group†††

Study Design. Multicenter, retrospective, consecutive case series.

Objective. This study aims to identify demographic and radiographical characteristics that influence the decision to perform revision surgery among patients with proximal junctional failure (PJF).

Summary of Background Data. Revision rates after PJF remain relatively high, yet the decision criteria for performing revision surgical procedures are not uniform and vary by surgeon. A better understanding of the factors that impact the decision to perform revision surgery is important in order to improve efficiency of surgical treatment of adult spinal deformity.

Methods. A cohort of 57 patients with PJF was identified retrospectively from 1218 consecutive patients with adult spinal deformity. PJF was identified on the basis of 10° postoperative increase in kyphosis between upper instrumented vertebra (UIV) and UIV +2, along with 1 or more of the following: fracture of the vertebral body of UIV or UIV +1, posterior osseoligamentous disruption, or pullout of instrumentation at the UIV. Univariate statistical analysis was performed using *t* tests and Fisher exact tests. Multivariate analysis was performed using logistic regression.

Results. Twenty-seven (47.4%) patients underwent revision surgery within 6 months of the index operation. Regression results revealed that patients with combined posterior/anterior approaches at index were significantly more likely to undergo revision ($P = 0.001$) as were patients with more extreme proximal junctional kyphosis angulation ($P = 0.034$). Patients sustaining trauma were also significantly more likely to undergo revision ($P = 0.019$). Variables approaching but not reaching significance as predictors of revision included female sex ($P = 0.066$) and higher sagittal vertical axis (SVA) ($P = 0.090$).

Conclusion. The decision to perform revision surgery is complicated and varies by surgeon. Factors that seem to influence this decision include traumatic etiology of PJF, severity of proximal junctional kyphosis angulation, higher SVA, and female sex. Factors that were expected to influence revision but had no statistical effect included soft tissue *versus* bony mode of failure, age, levels fused, and upper thoracic *versus* thoracolumbar proximal junction.

Key words: adult spinal deformity, revision surgery, proximal junctional failure.

Level of Evidence: 2

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From the *Oregon Health Sciences University, Portland, OR; †Institute for Health Care Research and Improvement, Baylor Health Care System, Dallas, TX; and ‡Southern Methodist University, Dallas, TX; §Baylor Scoliosis Center, Plano, TX; ¶Rocky Mountain Scoliosis and Spine, Denver, CO; ‖Department of Orthopedic Surgery, Hospital for Special Surgery, New York, NY; **Department of Orthopedic Surgery, University of Kansas Medical Center, Kansas City, KS; ††Department of Orthopedic Surgery, University of California Davis, Sacramento, CA; ‡‡Department of Neurological Surgery, University of California San Francisco, San Francisco, CA; §§Department of Orthopedic Surgery, University of California San Francisco, San Francisco, CA; ¶¶Department of Orthopedic Surgery, Johns Hopkins University, Baltimore, MD; ‖‖Department of Neurological Surgery, University of Virginia, Charlottesville, VA; ***Massachusetts General Hospital, Boston, MA; and †††Denver, CO.

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Address correspondence and reprint requests to Ian McCarthy, PhD, Baylor Scoliosis Center, 4708 Alliance Blvd, Ste 800, Plano, TX 75093; E-mail: ianmccarthy.econ@gmail.com

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Proximal junctional kyphosis (PJK) is a recognized complication for patients undergoing posterior segmental instrumented fusion for spinal deformity.[1–5] However, the criteria for defining clinically significant PJK, its incidence, and the basis for its development vary in the literature. According to previous findings, PJK has not been found to generate significant clinical or quality-of-life issues.[1,4] This is not the case, however, for more severe cases of PJK, sometimes termed "topping-off syndrome," proximal junctional

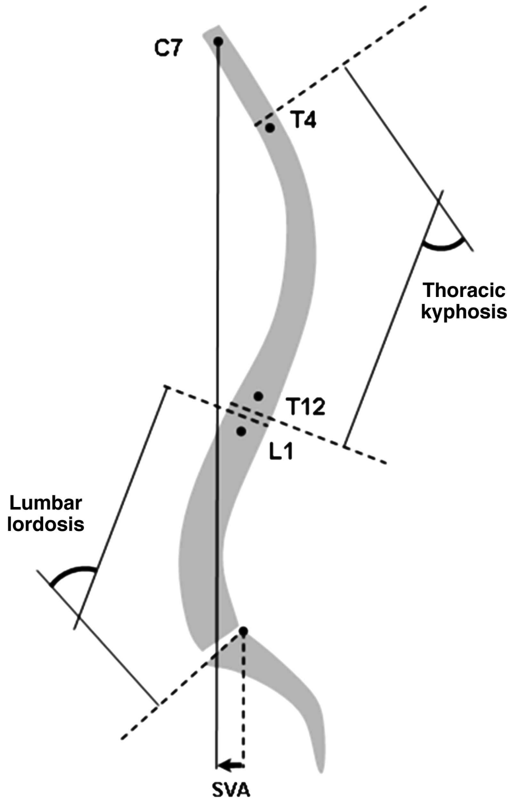

Figure 1. Illustration of sagittal vertical axis (SVA). Spinal measurements included thoracic kyphosis, thoracolumbar kyphosis, lumbar lordosis, maximal kyphosis, maximal lumbar lordosis, and SVA.

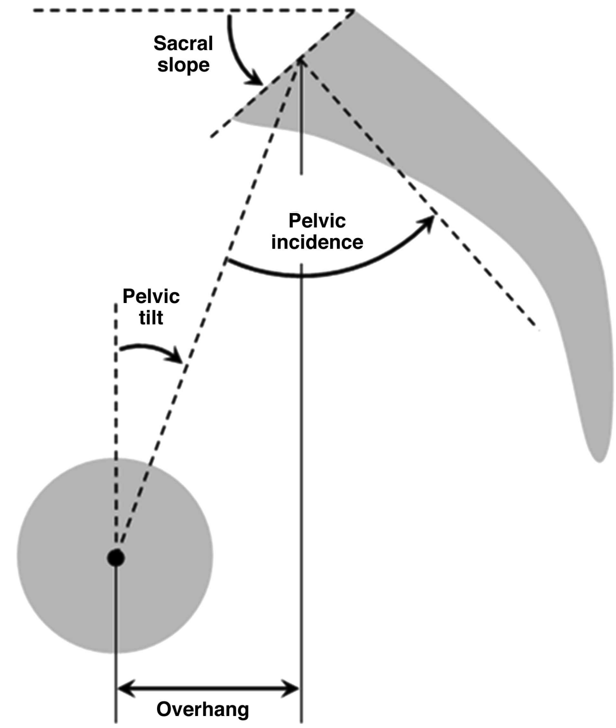

Figure 2. Illustration of pelvic incidence. Pelvic measurements included pelvic tilt, sacral slope, and pelvic incidence.

acute collapse, or fractures of the vertebrae at the top of long pedicle screw constructs.[2,6–9] We have chosen to define these severe cases of PJK as proximal junctional failures (PJFs) to distinguish between severe junctional changes and more common, but less severe, PJK.

PJF typically occurs in the early postoperative period and may result from reciprocal changes in the unfused portions of the spine as well as increased loads and motion in the mobile segments adjacent to a long-level fusion. Given the frequent need for extension of instrumentation proximal to these failures, the occurrence of PJF has clear clinical and economic significance. From a clinical standpoint, revisions subject the patient to additional risks of perioperative complications, and from an economic perspective, revisions nearly double the total cost of surgical treatment. For example, Hart *et al*[8] estimated an average cost of $77,432 for revision surgery after PJF.

Given the recognized clinical and economic issues associated with revision surgical procedures, it is imperative to examine guidelines for proper revision surgery candidate selection. The goal of this study is therefore to identify radiographical, demographic, and surgical variables that affect surgeons' decision to perform revision surgery for patients experiencing PJF.

MATERIALS AND METHODS

A cohort of 57 PJF patients has previously been identified retrospectively from 1218 consecutive patients with adult spinal deformity treated with posterior spinal instrumentation and arthrodesis at 10 different centers.[10] Institutional review board approval was obtained at all sites. PJF was defined as a change of more than 10° of kyphosis between the upper instrumented vertebra (UIV) and the vertebra 2 levels above the UIV (UIV +2), along with 1 or more of the following: fracture of the vertebral body of UIV or UIV +1, posterior osseoligamentous disruption, or pullout of instrumentation at the UIV. Previous research has found that, if a failure occurs, it is likely to occur within the first few months after index surgery.[2,11] Therefore, the 28-week window in which PJF was assessed appropriately captures failures in this study.

Inclusion criteria consisted of diagnosis of adult spinal deformity, age 18 years or older at the time of surgery, and at least one of the following radiographical criteria: scoliotic curve (idiopathic or degenerative) more than 30°, sagittal imbalance greater than 5 cm, coronal imbalance greater that 5 cm, thoracic kyphosis greater than 60° (T3 or T5–T12), lumbar lordosis less than 30°, or thoracolumbar kyphosis (T10–L2) greater than 20°. Subjects required an accessible preoperative clinical chart, operative summary, postoperative hospital chart, and pre- and postoperative radiographical films (full length coronal and sagittal) for study inclusion. In addition to radiographical measures, additional data collected on each patient included age, sex, body mass index (BMI), preoperative diagnosis, and surgical details such as fusion levels, location of UIV, and type of instrumentation used.

Radiographical Analysis

All subjects underwent radiographical imaging of the spinopelvic axis using 36-in. radiographs. Digital films were obtained

TABLE 1. Summary Statistics

Count	All (n = 57)	No Revision (n = 30)	Revision (n = 27)	*P*
Age, yr	65.48 (8.87)	66.70 (8.87)	63.48 (8.72)	0.174*
≥60	45 (78.9%)	25 (83.3%)	20 (74.1%)	0.519†
30–59	12 (21.1%)	5 (16.7%)	7 (25.9%)	
Female	45 (78.9%)	26 (86.7%)	19 (70.4%)	0.195†
BMI	27.29 (5.66)	28.22 (6.78)	26.32 (4.11)	0.217*
Time to failure	10.23 (7.51)	11.3 (7.68)	9.15 (7.30)	0.287*
Levels fused	9.68 (3.22)	9.80 (3.31)	9.56 (3.19)	0.778*
Source of failure				
Trauma	6 (10.5%)	1 (3.3%)	5 (18.5%)	0.091†
Screw pullout	5 (8.8%)	2 (6.7%)	3 (11.1%)	0.449†
Fracture	32 (56.1%)	16 (53.3%)	16 (59.3%)	0.428†
Soft tissue	20 (35.1%)	12 (40.0%)	8 (29.6%)	0.579†

For continuous variables, values within parentheses indicate standard deviations. For discrete or categorical variables, values within parentheses indicate percentages.
**P value based on 2-tailed t test.*
†P value based on Fisher exact test.
BMI indicates body mass index.

or films were digitized using a Vidar scanner (Vidar Systems Corp, Herndon, VA) with 75 dpi resolution and 12 gray levels and assessed using Spineview (Surgiview, Paris, France).[12,13] For study inclusion, patients were required to have complete radiographical data, including good-quality 36-in. standing anteroposterior and lateral radiographs from preoperation, early postoperation, and after the junctional failure. Radiographs were required to demonstrate all the vertebrae from C7 to S1, as well as the acetabuli and femoral heads.

Spinal measurements included thoracic kyphosis (TK; Cobb angle superior endplate of T5 to inferior endplate of T12), thoracolumbar kyphosis (TLK; Cobb angle superior endplate of T10 to inferior endplate of L2), lumbar lordosis (LL; Cobb angle superior endplate of T12 to superior endplate of S1), maximal kyphosis (max TK), maximal lumbar lordosis (max LL), and sagittal vertical axis (SVA; distance C7 plumb line to posterior superior corner sacrum; Figure 1). Pelvic measurements included pelvic tilt (PT; angle between the vertical line and the line through the midpoint of the sacral plate to axis of femoral heads), sacral slope (SS; angle between the horizontal and superior S1 endplate), and pelvic incidence (PI; angle between the perpendicular to superior S1 endplate at its midpoint and the line connecting this point to the center of the femoral heads) (Figure 2). The proximal junctional angle was defined as the caudal endplate of the UIV to the cephalad endplate of 2 supra-adjacent vertebrae above the UIV as previously described.[1,14]

Statistical Analysis

Statistical analyses were performed to identify differences among patients who underwent revision surgery after PJF and those who did not. Differences in categorical data were evaluated using the Fisher exact test, whereas differences in continuous data were assessed using the Student *t* test. Statistical significance was set at $\alpha = 0.05$ for all tests. Logistic regression models were also estimated to assess the impact of different independent variables on the probability of receiving revision. Statistical analyses were performed using Stata version 12.1 (StataCorp, College Station, TX) and R version 2.14.1 (R Foundation, R-Project.org).

RESULTS

Fifty-seven cases of PJF were analyzed. Twenty-seven of the 57 (47.4%) patients underwent revision surgery within 6 months of the index operation. Table 1 summarizes the age, sex, BMI, surgical details, and source of failure of the 57 patients, including those who were revised and those who were not. Patients undergoing revision surgery were on average younger, with lower BMI, and identified with PJF sooner relative to those who did not undergo revision. However, no significant differences emerged in any of the comparisons between the revision and nonrevision deformity groups using single variable *t* tests and Fisher exact tests.

From Table 1, fracture was indicated as the most common mechanism of failure (56%), followed by soft tissue failure (35%), and screw pullout (9%). In addition, 6 patients (11%) experienced failure as a result of trauma, all of which were fractures. Minor differences emerged in the mechanism of junctional failure between the revision and nonrevision groups, with trauma rates for the revision group higher than that for the nonrevision group; however, again these observed differences in failure mechanisms between the 2 groups were not statistically significant.

TABLE 2. Logistic Regression Results

Observations	64		
Log likelihood	−20.60		
Count R2	0.89†		
Adjusted count R2	0.741†		
	Coefficient	**Standard Error**	***P***
Constant	−7.54	5.99	0.208
Age	−0.08	0.07	0.227
BMI	0.04	0.09	0.681
Female	−2.55	1.15	0.027
Time to PJF	−0.20	0.08	0.013
Fracture	2.79	1.99	0.161
Trauma	4.34	1.97	0.027
Soft tissue failure	2.66	1.78	0.135
SVA*	0.06	0.10	0.500
PJK angulation*	0.14	0.06	0.032
Pelvic tilt*	0.02	0.06	0.754
Fusion to UT spine (UT)	18.72	8.76	0.033
Total levels fused (levels)	0.63	0.55	0.253
Interaction of UT and levels	−1.54	0.78	0.049
Anterior/posterior approach	4.93	1.48	0.001

*"SVA", "PJK angulation," and "pelvic tilt" represent each patient's worst respective measure during the 1-year follow-up period.

†"Count R2" denotes the percent of observations accurately predicted to be revised. "Adjusted Count R2" denotes the improvement in predictive power compared with a simple random assignment with 50% chance of revision.

BMI indicates body mass index; PJF, proximal junctional failure; SVA, sagittal vertical axis; PJK, proximal junctional kyphosis; UT, upper thoracic.

We also estimated a logistic regression model specifying revision as a function of several independent variables, including age, BMI, sex, time to failure, SVA, PJK angulation, PT, and total levels fused, as well as indicator variables for trauma, mechanism of failure (*e.g.*, soft tissue failure or fracture, with screw pullout as the omitted category), fusions with UIV in the upper thoracic (UT, T2–T5) region of the spine, and combined posterior/anterior approaches.

Table 2 summarizes the logistic regression results and presents the coefficient estimates and the respective standard errors and *P* values. As illustrated in the table, patients with combined posterior/anterior approaches at index were significantly more likely to undergo revision after PJF ($P = 0.001$) as were patients with more extreme PJK angulation ($P = 0.034$). Trauma was the only mode of failure that showed a significant effect on the probability of revision, with patients sustaining trauma more likely to have a revision ($P = 0.019$). Variables approaching but not reaching significance as predictors of revision included female sex ($P = 0.066$) and higher SVA ($P = 0.090$).

DISCUSSION

This study analyzed the role of demographic and surgical data on spine surgeons' decision to perform revision surgery. With a multicenter review and detailed analysis of 57 patients experiencing PJFs, the analysis identified 27 patients who underwent revision and extension of their fusion within 6 months of their index surgery. Factors that seemed to influence the decision to undergo revision included a traumatic etiology of PJF, severity of PJK angulation, higher SVA, and female sex. These findings are consistent with other studies in this area.[2,8] Interestingly, the strongest predictor in this analysis was the use of a combined anterior/posterior approach at the index operation. Other parameters that we expected to influence revision, such as soft tissue *versus* bony mode of failure, patient age and BMI, levels fused, and upper thoracic *versus* thoracolumbar proximal junction, did not show significant relationships with the decision to revise.

Emergence of the extent of PJK and SVA as predictors of surgical revision likely relates to the impact of the recurrent deformity on the patients. The clinical impact of sagittal imbalance among patients with spinal deformity is well documented.[15,16] In addition, higher levels of kyphosis and sagittal imbalance may also affect surgeons' perception of the severity of the PJF and the potential for progression and instability. The higher revision rate for patients with a traumatic etiology of PJF may also be a proxy for a higher severity of the failure.

The impact of female sex and combined posterior/anterior approaches on decision making are harder for us to explain. Sex-specific impacts of recurrent deformity and pain are one possible explanation. Surgeons' choice of combined approaches may relate to the severity of a given patients' deformity, but may also be related to individual surgeons' practice patterns. Ultimately, variation in patient complaints regarding similar deformity and pain levels and variation in an individual surgeon's indication for revision play a role in surgical decision making.[17]

One limitation of this study is the lack of a clear classification system to differentiate severity of PJF. Although work is ongoing to develop a suitable classification system for PJF, we are unable to apply it in this study, because factors including patients' pain levels and advanced imaging allowing better definition of the structural instability related to the PJF were not available.

Another limitation of this study is our relatively small sample size, which likely limits the power of our statistical analysis. Nonetheless, considering this study's focus on patients with PJF, the sample size is large compared with other studies in the literature. Common measures of model fit also reveal that our logistic regression model is highly predictive of revision surgical procedures. For example, measures of model fit presented in Table 2 indicate that our model accurately predicts revision surgical procedures for 89% of patients.

Ultimately, this study identifies factors that seem to influence surgeons' decision to perform revision surgery for patients experiencing PJF. The revision rate of 47% again demonstrates the more substantial clinical impact of PJF as opposed to PJK. Future research in this area is needed both to reduce the incidence of PJF after adult spinal deformity surgery and to define severity and indications for revision surgery when patients do experience this complication.

➢ Key Points

- ❑ Fifty-seven cases of PJF were identified from a retrospective review of 1218 consecutive patients with adult spinal deformity treated with posterior spinal instrumentation and arthrodesis at 10 different centers. Twenty-seven of the 57 (47.4%) patients underwent revision surgery within 6 months of the index operation.
- ❑ From logistic regression analysis, factors that influence the probability of revision included a traumatic etiology of PJF, severity of PJK angulation, higher SVA, and female sex. The strongest predictor of revision surgery in this analysis was the use of a combined anterior/posterior approach at the index operation.
- ❑ Parameters that were expected to influence revision, such as soft tissue *versus* bony mode of failure, patient age and BMI, levels fused, and upper thoracic *versus* thoracolumbar proximal junction, did not show significant relationships with the decision to revise.

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