Revision Surgery for Proximal Junctional Failure: A Single-center Analysis of 1180 Adult Spinal Deformity Patients with Long-term Follow-up

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Introduction

Adult spinal deformity (ASD) presents as a spectrum of thoracolumbar and lumbar spine abnormalities including sagittal imbalance, iatrogenic spinal deformity, and adult idiopathic or degenerative scoliosis. It is often characterized by asymmetric and degenerative changes that may cause impingement of neural elements. This, in turn, may lead to progressive deformity, neurological deficits, and pain. Surgical intervention has become an important treatment option for symptomatic ASD.[1] Correction of spinal deformity is usually performed via posterior approach. A long-segment fusion construct with segmental pedicle screw and rod instrumentation is often combined with a variety of osteotomies to improve spinal alignment. However, long-segment fixation may accelerate degenerative changes to adjacent unfused vertebrae due to increased segment motion and intervertebral stress.[2-4] Proximal junctional kyphosis (PJK) is a common radiographical finding that occurs at the proximal junction between fused and mobile spinal segments with incidence rates as high as 46% after posterior instrumented spinal fusion.[5] Proximal junctional failure (PJF) represents a more severe form of PJK associated with vertebral fracture, disruption of the posterior ligamentous complex, and/or instrument failure.[6] The prevalence of PJF has been reported to be 39.3% in patients who undergo spinal deformity fusion surgery and is often accompanied by sagittal imbalance and neurologic deficit.[7] Revision surgery is often needed for correction, which may entail proximal extension of instrumentation and fusion above the affected junctional pathology. There have been only a few studies that investigate revision strategies for PJK and PJF, and even fewer that report the incidence of recurrent junctional pathology after revision.[8]

Objective

The objective of this study is to report the incidence of PJF and recurrent PJF at a large single-institution after instrumented fusion to the pelvis indicated for ASD. Presenting neurological deficit(s), mechanisms of failure, revision strategies, and radiographic outcomes after revision surgery are then analyzed to elucidate predictive factors.

Methods

Retrospective review of 1180 ASD patients who underwent surgical correction at a single-institution by five surgeons (2009-2021) was performed. Inclusion criteria included a diagnosis of treated with posterior instrumented fusion to the pelvis. This series included both primary and revision surgeries. The average follow-up after revision was 3.1 ± 2.0 years. Fifty-four patients met the inclusion criteria and developed PJF following surgery. The patients were then divided into three groups based on the location of their uppermost instrumented vertebra (UIV): upper thoracic (T2-T6, 10 patients), lower thoracic (T8-T11, 35 patients), and the lumbar spine (L1–L3, 9 patients). For this study, PJF was defined by: (1) PJK defined previously by Glattes et al.; (2) fracture of the vertebral body of the UIV or UIV+1, screw pullout at the UIV, or soft-tissue posterior ligamentous disruption; and (3) neurological deficit at the time of presentation. Mechanisms of PJF were separated into two groups: (1) vertebral fracture or screw pullout and (2) soft-tissue disruption. Clinical data and surgical details were identified. Radiographic parameters measured include the proximal junctional angle (PJA) of the uppermost instrumented vertebra (UIV), C7 sagittal vertical axis (SVA), T4-T12 thoracic kyphosis (TK), L1-S1 lumbar lordosis (LL), pelvic tilt (PT), and pelvic incidence (PI)-LL mismatch (PI-LL). Ideal age-specific alignments were calculated.[9] A negative offset, defined as the difference between the patient's and ideal age-specific alignment, denotes an overcorrection.

Results

Location of UIV	Upper Thoracic (N = 10)	Lower Thoracic (N = 35)	Lumbar (N = 9)	*P*
Patient Demographics				
Age (years)	67.0 ± 6.8 (68 [52-76])	64.5 ± 6.3 (66 [51-74])	64.6 ± 8.9 (69 [50-75])	0.594
Sex (no. of pts.)				0.511
Male	5 (50.0%)	16 (45.7%)	4 (44.4%)	
Female	5 (50.0%)	19 (54.3%)	5 (55.6%)	
BMI (kg/m^2)	30.3 ± 3.8 (30.1 [22.9-37.5])	29.7 ± 6.1 (29.6 [16.9-39.0])	32.2 ± 7.1 (34.1 [19.9-41.6])	0.438
Osteoporosis (no. of pts.)	6 (60.0%)	9 (25.7%)	1 (11.1%)	**0.045***
Rheumatoid arthritis (no. of pts.)	4 (40.0%)	5 (14.3%)	1 (11.1%)	0.156
Diabetes mellitus (no. of pts.)	1 (10.0)	9 (25.7%)	6 (66.7)	**0.017***
Current or former tobacco use (no. of pts.)	5 (50.0%)	14 (40.0%)	5 (55.6%)	0.666
Previous spine surgery (no. of pts.)	7 (70.0%)	19 (57.1%)	4 (44.4%)	0.546
Neurological deficit(s) at failure				
Radiculopathy	9 (90.0%)	17 (48.6%)	7 (77.8%)	**0.032***
Myelopathy	5 (50.0%)	19 (54.3%)	2 (22.2%)	0.227
Central Canal Stenosis	5 (50.0%)	29 (82.9%)	8 (88.9%)	0.136
Motor Deficits	4 (40.0%)	9 (25.7%)	5 (55.6%)	0.957
Bowel and/or Bladder Incontinence	0 (0%)	3 (9.6%)	2 (22.2%)	0.969
Spinal Cord Injury	3 (30.0%)	5 (14.3%)	1 (11.1%)	0.187
Failure Modes				
Fracture or Screw Pullout (no. of pts.)	5 (50.0%)	28 (80.0%)	8 (88.9%)	**<0.001***
Soft-tissue Failure (no. of pts.)	5 (50.0%)	7 (20.0%)	1 (11.1%)	0.089
Age-Specific Alignment Before Revision				0.816
Overcorrected	2 (20.0%)	5 (14.3%)	0 (0%)	
Undercorrected	8 (80.0%)	30 (85.7%)	9 (100.0%)	
Age-Specific Alignment After Revision				0.333
Overcorrected	4 (40.0%)	12 (34.3%)	1 (11.1%)	
Undercorrected	6 (60.0%)	23 (65.7%)	8 (88.9%)	
Primary Surgery				
Operative Time (min.)	451 ± 97 (405.5 [346-627])	373 ± 114 (366 [93-743])	297 ± 85 (296 [160-409])	**0.011***
Estimated blood loss (mL)	2672 ± 1971 (1700 [900-7000])	1240 ± 626 (1200 [100-3000])	983 ± 628 (1200 [250-2000])	**<0.001***
Bone morphogenic protein (no. of pts.)	2 (20.0%)	17 (48.6%)	1 (11.1%)	0.054
Demineralized bone matrix (no. of pts.)	5 (50.0%)	13 (37.1%)	3 (33.3%)	0.711
Number of osteotomies (no.)	6.8 ± 3.0 (7 [2-13])	3.3 ± 2.8 (3 [0-9])	1.2 ± 2.0 (0 [0-5])	**<0.001***
No osteotomies	0 (0%)	6 (17.1%)	6 (66.7%)	**0.003***
Only posterior column (no. of pts.)	9 (90.0%)	24 (68.9%)	3 (33.3%)	**0.031***
≥ 1 3-column (no. of pts.)	1 (10.0%)	5 (14.3%)	0 (0%)	0.884
Number of rods (no.)	2.4 ± 0.7 (2 [2-4])	2.3 ± 0.6 (2 [2-4])	2.1 ± 0.3 (2 [2-3])	0.540
Supplemental rods (no. of pts.)	3 (30.0%)	8 (22.9%)	1 (11.1%)	0.606
Revision Surgery				
Operative Time (min.)	303 ± 111 (337.5 [159-515])	307 ± 95 (299 [158-558])	274 ± 104 (293 [126-449])	0.677
Estimated blood loss (mL)	950 ± 625 (825 [200-2250])	1207 ± 1023 (1000 [250-4700])	747 ± 317 (800 [250-1100])	0.341
Bone morphogenic protein (no. of pts.)	3 (30.0%)	16 (45.7%)	0 (0%)	0.139
Demineralized bone matrix (no. of pts.)	4 (40.0%)	17 (48.6%)	7 (77.7%)	0.208
Number of osteotomies (no.)	2.0 ± 1.7 (2 [0-4])	2.6 ± 1.9 (3 [0-7])	2.6 ± 2.8 (2 [0-8])	0.698
No osteotomies	3 (30.0%)	9 (25.7%)	3 (33.3%)	0.889
Only posterior column (no. of pts.)	5 (50.0%)	23 (65.7%)	6 (66.7%)	0.642
≥ 1 3-column (no. of pts.)	2 (20.0%)	3 (8.6%)	0 (0%)	0.597
Number of rods (no.)	3.1 ± 0.9 (3 [2-5)]	3.3 ± 0.9 (3[2-6])	2.7 ± 0.9 (2 [2-4])	0.170
Supplemental rods (no. of pts.)	8 (80.0%)	28 (80.0%)	4 (44.4%)	0.085

Recurrence of PJF	Non-recurrence (N = 38)	Recurrence (N = 16)	*P*
Patient Demographics			
Age (years)	65.4 ± 6.9 (67 [50-76])	64.0 ± 6.7 (66 [51-74])	0.483
Sex (no. of pts.)			0.071
Male	17 (44.7%)	3 (18.9%)	
Female	21 (56.4%)	13 (81.3%)	
BMI (kg/m^2)	29.4 ± 5.4 (29.6 [16.9-39.9])	31.8 ± 6.4 (32.1 [22.2-41.6])	0.164
Comorbidities			
Osteoporosis (no. of pts.)	13 (30.8%)	3 (26.6%)	0.256
Rheumatoid arthritis (no. of pts.)	5 (15.4%)	5 (26.6%)	0.118
Diabetes mellitus (no. of pts.)	11 (30.8%)	5 (26.6%)	0.866
Current or former tobacco use (no. of pts.)	20 (51.3%)	4 (26.6%)	0.062
Previous spine surgery (no. of pts.)	22 (59.0%)	9 (53.3%)	0.911
Revision Surgery			
Levels extended proximally	5.0 ± 1.8 (5 [1-8])	6.0 ± 2.0 (7 [2-9])	0.087
Operative time (min.)	301 ± 103 (294 [126-558])	301 ± 90 (317 [158-449])	0.996
Estimated blood loss (mL)	1054 ± 908 (800 [200-4700])	1137 ± 832 (1000 [350-3500])	0.762
Age-Specific Alignment After Revision			0.536
Overcorrected	11 (28.9%)	6 (37.5%)	
Undercorrected	27 (71.0%)	10 (62.5%)	
Radiographic Parameters After Revision			
ΔPT°	-3.6 ± 4.1	-4.6 ± 5.1	0.481
ΔLL°	1.6 ± 7.3	2.9 ± 6.1	0.542
ΔPI-LL°	-2.3 ± 6.1	-1.1 ± 5.9	0.531
ΔSVA (mm.)	-23.3 ± 30.8	-20.0 ± 40.3	0.743
ΔTK°	-4.4 ± 9.5	-4.6 ± 7.3	0.945

Figure: Revision strategies for PJF after fusion to the pelvis stratified by UIV. A heat map (A) is used to identify T5, T10, and L2 as the most common vertebrae for PJF, with more red vertebrae indicating more frequent failure. Extension of fusion after PJF (B) is then visualized for each group individually. Red circles represent the average primary UIV for each cohort (upper thoracic: T4.0 ± 1.1, lower thoracic: T10.0 ± 0.7, and lumbar: L1.8 ± 0.7). The mean extension of fusion is indicated with arrows. Of note, the upper thoracic cohort was divided into two groups, one in which revision crossed the cervicothoracic junction and another that did not.

Conclusions

A comparative analysis of indications and revision strategies for PJF is presented. Of 1180 ASD patients, 54 (4.6%) developed PJF and underwent revision 17.6 ± 16.1 months after their primary surgery. Regarding mechanisms of PJF, soft-tissue disruption was most common in the upper thoracic group ($P = 0.089$). Vertebral fracture and screw pullout were most common in both the lower thoracic and lumbar groups ($P < 0.001$). Of patients in the upper thoracic group, 40.0% were extended above the cervicothoracic junction. In the lower thoracic and lumbar spine groups, 91.4% and 88.9% of patients were extended to the upper thoracic and lower thoracic spine, respectively. A total of 26 patients (48.1%) required a second revision surgery 18.7 ± 15.2 months after their first. Sixteen of the 26 patients (27.8%) were revised for new-onset PJF. Patient-specific and radiographic risk factors for recurrent PJF could not be elucidated. Recurrent PJF was found to be the most common complication following revision surgery, and strategies for revision must be tailored to the individual patient for desired outcomes.

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