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Proximal Junctional Kyphosis as a Distinct Form of Adjacent Segment Pathology After Spinal Deformity Surgery

A Systematic Review

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Study Design. Systematic review.

Objective. To review the literature on proximal junctional kyphosis (PJK) as a specific form for proximal adjacent segment pathology and report on the incidence, timing, risk factors, and effect on health-related quality of life (HRQOL) outcomes reported for PJK.

Summary of Background Data. PJK is a complication of spinal deformity surgery that can compromise outcomes and necessitate revision surgery. Multiple risk factors have been associated with PJK, making the etiology multifactorial. Knowledge of the risk factors is important for minimizing the occurrence of PJK and to allow surgeons to take measures for its prevention when possible.

Methods. A systematic search of PubMed, CINAHL, EMBASE, the Cochrane Library, and Google Scholar through February 15, 2012, was performed. The focus was on studies designed to evaluate PJK in patients who had surgery for scoliosis and/or kyphosis. Adjusted effect sizes and significance based on adjusting for confounders were reported if available, otherwise, crude risk ratios and 95% confidence intervals were calculated.

Results. The search yielded 85 citations and 8 met the criteria for inclusion. The incidence of PJK ranged from 17% to 39% and the majority seemed to occur within 2 years of surgery. The most common patient demographic associated with a higher PJK risk was increased age. Surgery-related risk factors were fusions to the sacrum, combined anterior/posterior surgery, thoracoplasty, and upper instrumented vertebra at T1–T3. Postoperative hypokyphosis or hyperkyphosis was associated with an increased risk of PJK. Despite the presence of PJK, health-related quality of life outcomes were not affected.

Conclusion. Patients at higher risk for PJK are those who are of older age, who had fusions to the sacrum, combined anterior/posterior surgery, thoracoplasty, and an upper instrumented vertebra at T1–T3. Despite the presence of PJK, no differences were noted in health-related quality of life outcomes.

Consensus Statement

1. The risk of developing PJK above a spinal deformity fusion is 17% to 39%, with most noted by 2 years postoperative.
   Level of Evidence: Moderate
   Strength of Statement: Strong
2. The risk factors of PJK development include increased age, fusion to sacrum, combined ASF/PSF, thoracoplasty, UIV at T1–T3, and nonanatomic restoration of thoracic kyphosis.
   Level of Evidence: Low
   Strength of Statement: Weak
3. The development of PJK does not seem to have a detrimental effect on HRQOL outcomes, at least in milder/nonrevision forms.
   Level of Evidence: Moderate
   Strength of Statement: Weak

Key words: scoliosis, kyphosis, spinal deformity, proximal junctional kyphosis, upper instrumented vertebra. **Spine 2012;37:S144–S164**

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Proximal adjacent segment pathology (ASP) can manifest itself in many different ways both clinically and radiographically. Proximal junctional kyphosis (PJK) is 1 specific form of radiographical ASP that can occur after reconstructive spine surgery for kyphosis and scoliosis.[1–5] Originally described radiographically as kyphosis greater than 10° between the upper instrumented vertebra (UIV) and the vertebral body 2 levels above, PJK in severe cases can lead to compromised outcomes and the need for revision surgery.[2] Since it was first described, multiple studies have attempted to elucidate the risk factors associated with its development; however, no study has been able to definitively identify a

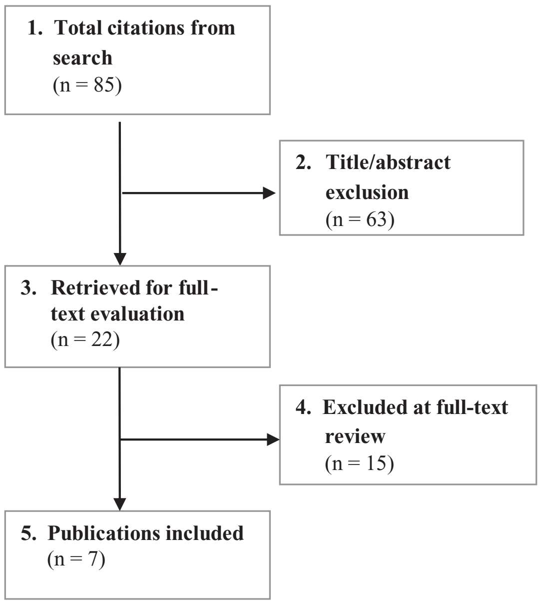

Figure 1. Flow chart showing results of literature search.

single variable associated with the development of PJK, thus its etiology is likely multifactorial.[1,3–5] Identified risk factors include combined anteroposterior surgical approach, type of instrumentation, magnitude of correction and sagittal imbalance correction, inclusion of pelvic fixation, osteoporosis, and integrity of the posterior ligamentous complex as well as the proximally instrumented vertebral level.[1,3–7]

The purpose of this systematic review was to examine the following key questions regarding PJK:

1. In persons who have had primary or revision fusion for scoliosis or kyphosis extending to the thoracolumbar or mid or proximal thoracic spine:
   a. What is the risk and timing of PJK development?
   b. What risk factors are associated with PJK development?
2. Do persons with PJK experience decreased function or quality of life?

MATERIALS AND METHODS

Electronic Literature Search

We performed a systematic search of PubMed, CINAHL, EMBASE, the Cochrane Library, and Google Scholar for literature published through February 15, 2012. The search was limited to studies written in English. Identification of studies explicitly designed to evaluate PJK and its risk and risk factors was the primary focus. Terms specific to PJK (proximal junctional kyphosis) (Title/Abstract) OR PJK OR (proximal and junction* and kypho*) as well as those related to complications of scoliosis or kyphosis surgery, diagnosis, and treatment of PJK were used. Meeting abstracts/proceedings, white papers, and editorials were excluded. Studies of adults who had primary or revision surgery for spinal deformity (scoliosis or kyphosis) that involved 5 or more vertebral levels were considered for inclusion. Articles were included if they

TABLE 1. Inclusion and Exclusion Criteria

Inclusion	Exclusion
Patient	
Persons (adult, adolescent, or pediatric) who have had:	Tumor
Spinal deformity surgery (fusion) involving 5 or more vertebral levels for scoliosis or kyphosis at the thoracolumbar junction, midthoracic and proximal thoracic spine	Infection (including tuberculosis, Pott disease)
Revision surgery (fusion) for scoliosis or kyphosis involving 5 or more vertebral levels at the thoracolumbar junction, midthoracic or proximal thoracic spine	Trauma
	Neuromuscular scoliosis
	Ankylosing spondylitis
Prognostic factors	
Q1 and 3	
Patient factors	
Age, sex, BMI, BMD (osteoporosis)	
Behaviors, *e.g.*, smoking	
Radiographical measures	
Sagittal and coronal angles	
C7-sacral plumb line	
Others	
Index pathology treated	
e.g., degenerative scoliosis, osteoporosis	
Clinical factors	
Posterior ligament integrity	
e.g., complications, comorbidities	
Surgical factors	
e.g., UIV, instrumentation, approach	
Inclusion of pelvic fixation	
Magnitude of correction/sagittal imbalance correction	
Outcomes	
Q1	Distal junctional kyphosis
Description of criteria used to define/diagnoses: PJK was defined by 2 criteria: (1) proximal junction sagittal Cobb angle ≥10° and (2) proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement	Proximal junction fracture or collapse
Frequency of PJK	

(*Continued*)

TABLE 1. ***(Continued)***

Inclusion	Exclusion
Timing in the development of PJK	
Q2	
Functional and quality-of-life outcomes (*e.g.*, SRS, ODI measures)	
Study type	
Studies designed to evaluate risk factors and frequency for PJK	Cadaver studies
Studies evaluating associations between PJK and patient functional or quality-of-life outcomes	Case reports
	Studies of computer simulation, finite element analysis, or biomechanical aspects
	Studies with N < 10 for Q1, Q2

BMI indicates body mass index, BMD, bone mineral density; PJK, proximal junctional kyphosis; SRS, Scoliosis Research Society; ODI , Oswestery Disability Index.

defined PJK on the basis of the criteria outlined by Glattes *et al*,[2] namely, proximal junction sagittal Cobb angles between the lower endplate of the UIV and the upper endplate of the 2 supra-adjacent vertebrae 10° and more and at least 10° greater than the preoperative measurement. Studies not meeting this definition or not describing the number of surgically treated levels were excluded. In instances in which multiple reports published on the same underlying population existed, the report with the most complete data was selected. Studies that included more than 20% of patients with trauma, tumor, infection, neuromuscular scoliosis, or ankylosing spondylitis were excluded. Studies with fewer than 10 patients were excluded. Biomechanical, cadaver, and computer simulation studies were excluded.

Data Extraction

From the included articles, the following data were extracted: patient demographics, inclusion and exclusion criteria, follow-up duration and the rate of follow-up, risk (%) of PJK, potential risk factors and related effect sizes, and data comparing quality of life and function in those who developed PJK and those who did not (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703).

Study Quality and Overall Strength of Body of Literature

Level-of-evidence (LoE) ratings were assigned to each article independently by 2 reviewers using criteria set by *The Journal of Bone & Joint Surgery, American Volume*,[8] for prognostic studies and modified to delineate criteria associated with methodological quality and described elsewhere.[9] The overall strength of the body of evidence (SoE) with respect to each clinical question was determined on the basis of precepts outlined by the Grading of Recommendations Assessment, Development and Evaluation working group[10] and recommendations made by the Agency for Healthcare Research and Quality.[11] Risk of bias was evaluated during the individual study evaluation described earlier in the section "Study Quality and Overall Strength of Body of Literature." This system, which derives a strength-of-evidence grade of "high," "moderate," "low," or "insufficient" for each outcome or clinical question, is described in further detail in the methods article for this focus issue.[9] The supplemental digital material contains the details of how we arrived at the strength of evidence for each key question (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703).

Data Analysis

When data were provided, the risk (cumulative incidence) of PJK was reported. Data were summarized but were not pooled between studies because of the limited number of studies for specific populations available and the heterogeneity of patient populations and definitions for various factors.

Where authors provided effect sizes from multivariate analysis (*i.e.*, adjusted effect size estimates) and/or of significance based on adjustment for confounders, these were reported. In studies that did not use multivariate analysis, crude risk ratios (RRs) and 95% confidence intervals (95% CIs) or risk differences were calculated to provide an estimate of effect size where data were available. Calculations were performed using Stata 9.0.[12] Odds ratios (ORs), RRs, or hazard ratios whose CI included the value of 1 were not statistically significant. Values above 1 suggest increased risk and values below 1 suggest decreased risk for PJK. Wide CIs suggest greater variability in estimates and call into question the certainty of the effect estimate. For continuous data, the mean change and percent change relative to preoperative values were calculated if the data were not part of the multivariate analysis.

Clinical Recommendations and Consensus Statements

Clinical recommendations or consensus statements were made through a modified Delphi approach by applying the Grading of Recommendations Assessment, Development and Evaluation/Agency for Healthcare Research and Quality criteria that imparts a deliberate separation between the strength of evidence (*i.e.*, high, moderate, low, or insufficient) and the strength of recommendation. When appropriate, recommendations or statements "for" or "against" were given "strong" or "weak" designations based on the quality of evidence, the balance of benefits/harms, and the values and patient preferences. In some instances, costs may have been considered. A more thorough description of this process can be found in the Focus Issue methods article.[9]

TABLE 2. Characteristics of Included Studies

Authors	Study Design	Demographics	Disease/Case Definition	Study Population Characteristics	Follow-up: %
Adults					
Kim *et al*[4]	Retrospective prognostic study	N = 161 Female: 87% Mean age: 45.2 yr (range, 18.1–73.0)	Proximal junction sagittal Cobb angle of ≥10° and proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement.	Group 1: PJK (n = 62) Group 2: Non-PJK (n = 99) Scoliosis: n = 106 Sagittal imbalance syndrome: n = 55 Previous surgery: n = 67 Time-dependent changes in PJK: Preoperative: 3° ± 7.7° 8-wk postoperative: 14° ± 6.5° 8-wk postoperative − preoperative change: 10° ± 5.6° (59%) 2-yr postoperative: 15° ± 6.2° 2-yr postoperative − 8-wk postoperative change: 1° ± 5.4° (6%) 2-yr postoperative − preoperative change: 12° ± 6.2°(65%) Ultimate postoperative − preoperative change: 17° ± 6.5° (100%) Ultimate postoperative − 8-wk postoperative change: 17° ± 5.8° (41%) Ultimate postoperative − 2-yr postoperative change: 5° ± 5.8° (35%)	Mean 94 mo (range, 60–238): NR
Kim *et al*[3]	Retrospective prognostic study	N = 249 Female: 86% Mean age: 35 yr (range, 15–62)	Proximal junction sagittal Cobb angle of ≥10° and proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement.	Group 1: Non-PJK (n = 207) Group 2: PJK (n = 42) Normal bone quality: n = 156 Abnormal bone quality: n = 93 Osteopenia: n = 16 Osteoporosis: n = 77 Mean levels fused: 10.64 Fusion to S1: n = 57 Thoracoplasty: n = 75 Anterior surgery: n = 14 Posterior surgery: n = 147 Anteroposterior surgery: n = 88 Hook/hybrid: n = 182 Pedicle screw: n = 40 Vertebral body screws: n = 25 Wires: n = 2 UIV T1–T3: n = 83 UIV T4–T12: n = 163 UIV L1 or below: n = 3	Mean 48 mo (range, 18–108): 74%

(*Continued*)

TABLE 2. (*Continued*)

Authors	Study Design	Demographics	Disease/Case Definition	Study Population Characteristics	Follow-up: %
Mendoza-Lattes *et al*[6]	Retrospective prognostic study	N = 54 Female: 83% Mean age: 59.3 ± 10.3 yr	Proximal junction sagittal Cobb angle of ≥10° and proximal junction sagittal Cobb angle at least 10° greater than the preoperative measurement.	Group 1: Non-PJK (n = 35) Group 1: PJK (n = 19)	Mean 26.8 mo (range,12–42): NR
Scheuermann kyphosis					
Denis *et al*[1]	Retrospective prognostic study	N = 67 Female: NR Mean age: 37 yr (range, 16–51)	Proximal junctional angle of >10° and at least 10° greater than the corresponding preoperative measurement.	Group 1: PIV = PEV (n = 40) Group 2: PIV = Short of PEV (n = 27) Hyperextension of <50° treated with posterior-only surgery: n = 15 Anteroposterior surgery: n = 52 Scoliosis >20°: n = 11 Lumbosacral spondylolysis: n = 6 Thoracolumbar type Scheuermann kyphosis with apex at T10/T11: n = 6 T7/T9: n = 51	Mean 73 mo (range, 60–164): NR
Lonner *et al*[13]	Retrospective prognostic study	N = 78 Female: 32% Mean age: 16.7 yr (range, 9–27)	Kyphosis measured from 1 segment cephalad to the upper end instrumented vertebra to the proximal instrumented vertebra with an abnormal value defined as ≥10°.	Group 1: Anteroposterior surgery (n = 42) Group 2: Posterior arthrodesis (n = 36)	Mean 35 mo (range, 24–72): NR
Pediatric/adolescent					
Kim *et al*[5]	Retrospective prognostic study	N = 410 Female: 70% Mean age: 14.6 yr (range, 10.6–20)	Proximal junction sagittal Cobb angles between the lower endplate of the uppermost instrumented vertebra and the upper endplate of 2 supra-adjacent vertebrae ≥10° and at least 10° greater than the preoperative measurement at 2 yr postoperative.	Group 1: PJK (n = 111) Group 2: Non-PJK (n = 299) Mean levels fused: 11.7 Mean Risser sign: 2.9 Main thoracic: n = 195 Double thoracic: n = 76 Double major: n = 51 Triple major: n = 13 Thoracolumbar/lumbar major: n = 31 Major thoracolumbar/lumbar and minor thoracic structural: n = 44 Coronal lumbar A modifier: n = 141 Coronal lumbar B modifier: n = 85 Coronal lumbar C modifier: n = 184 Sagittal Normal thoracic kyphosis modifier: n = 285	24 mo: NR

(*Continued*)

TABLE 2. (*Continued*)

Authors	Study Design	Demographics	Disease/Case Definition	Study Population Characteristics	Follow-up: %
				Sagittal Thoracic hyperkyphosis modifier: n = 54	
				Sagittal Thoracic hypokyphosis modifier: n = 71	
				Thoracoplasty: n = 132	
				Posterior iliac crest graft: n = 278	
				Hooks: n = 210	
				Hybrid: n = 103	
				Pedicle screws: n = 97	
				Time-dependent changes in PJK:	
				Preoperative: 6° ± 5.7°	
				Immediate postoperative: 13° ± 6.2°	
				2 yr postoperative: 22° ± 6.9°	
				Preoperative − 2 yr postoperative change: 16.7° ± 6.2°	
Wang *et al*[7]	Retrospective prognostic study	N = 123	Measured Cobb angle >10° and compared with the preoperative angle of that region, the increase was more than 10°.	Group 1: Control (n = 88)	Mean 42 mo NR
		Female: 81%		Group 2: PJK (n = 35)	
		Mean age: 15 yr (range, 13–16)			

PJK indicates proximal junctional kyphosis; NR, not reported; UIV, upper instrumented vertebra; PIV, proximal instrumented vertebra; PEV, proximal end vertebra.

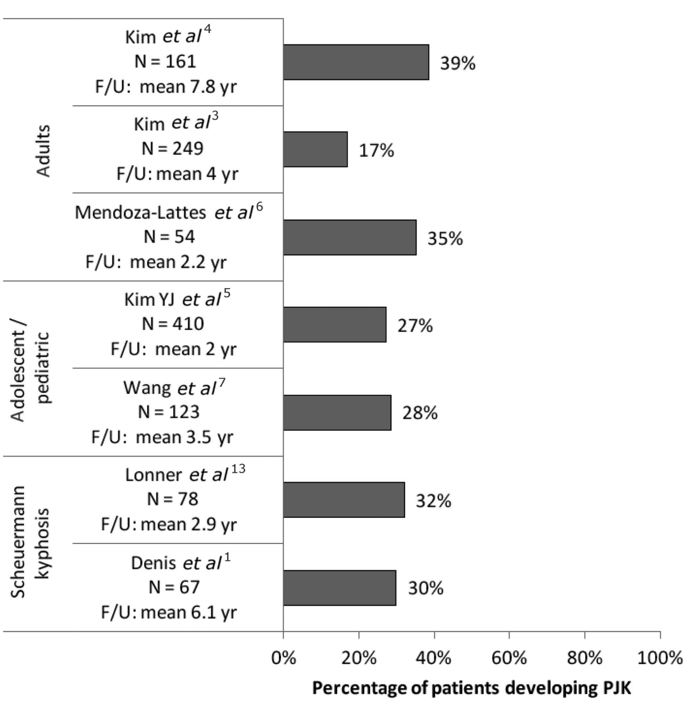

Figure 2. Summary of cumulative risk of PJK across included studies. PJK indicates proximal junctional kyphosis.

RESULTS

Study Selection

The systematic literature search yielded 85 potentially relevant citations that were evaluated against the inclusion/exclusion criteria set *a priori* (Figure 1 and Table 1). Two investigators independently considered the studies for inclusion. Discrepancies in selection were resolved by discussion and when necessary, evaluation of the manuscript. The majority of studies (n = 63) were excluded on the basis of title and abstract evaluation. The full text of 22 articles was reviewed, leading to exclusion of 15. Some studies provided data to answer more than 1 question. Seven studies were included, forming the basis of this report.[1,3–7,13] The cohort studies with data available to answer the key questions were graded as LoE III. A list of excluded studies, including definitions of PJK used in those studies, can be found in the supplemental digital material along with the details of LoE determination (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703).

Table 2 summarizes characteristics of included studies and their populations.

TABLE 3. PJK Findings Across Studies With Respect to Timing

Authors	Follow-up Length	Primary Results Related to Timing of PJK Development
Adults		
Kim *et al*[3]	Mean: 4 yr (range, 1.5–9.0)	• Cumulative risk: 16.9% (42/249)
		• 43% (18/42) of persons who developed PJK did so within the first year of follow-up
Kim *et al*[4]	Mean: 7.8 yr (range, 5–19.8)	• Cumulative risk: 39% (62/161)
		• Average proximal PJA increase at 8 wk postoperative accounted for 59% of the total increase at ultimate follow-up
		• Total proximal junctional increase after 2 yr demonstrated 35% of the total increase at ultimate follow-up
Mendoza-Lattes *et al*[6]	Mean: 2.2 yr (range, 1–3.5)	• Cumulative risk: 35% (19/54)
		• No information on timing reported
Adolescents		
Kim *et al*[5]	2 yr	• Cumulative risk: 27% (111/410)
		• Immediate postoperative PJA was 13° in the PJK group, increasing to 22° at 2 yr; average increase was 17°
Wang *et al*[7]	Mean: 3.5 yr	• Cumulative risk: 28% (35/123)
		• Mean kyphosis angles at the proximal junction in those with PJK were 8° (6.0°, 10.0°) at 2 wk, 9° (8.0°, 14.0°) at 6 mo, 16° (12.0°, 19.0°) at 1.5 yr, and 18° (16.0°, 21.0°) at final follow-up
Scheuermann kyphosis		
Denis *et al*[1]	Mean: 6.08 yr	• Cumulative risk: 30% (20/67)
		• No information on timing reported
Lonner *et al*[13]	Mean: 2.9 yr (range, 2–6)	• Cumulative risk: 32.1% (25/78)
		• No information on timing reported

PJK indicates proximal junctional kyphosis; PJA, proximal junctional angle.

Reported Risk and Timing of PJK Development

The risk of PJK ranged from 17% to 39% in patients with adult scoliosis,[3,4,6] 27% to 28% in patients with adolescent scoliosis,[5,7] and 30% to 32% in patients with Scheuermann kyphosis[1,13] (Figure 2).

The timing for the development of PJK was not uniformly reported across studies. In 1 study, 43% of adults who developed PJK did so within the first year of follow-up.[3] Furthermore, the average increase in the PJK angle by 8 weeks postoperative accounted for 59% of the total increase at final follow-up.[4] Among studies of adolescent scoliosis, the greatest increase in PJK angle occurred within 1.5 to 2.0 years. Neither of the studies in persons with Scheuermann kyphosis provided information on the timing of PJK development (Table 3).

What Factors Are Associated With PJK Development?

Potential risk factors were evaluated across multiple studies and are illustrated in Table 4. Tables 5 to 9 summarize these risk factors and provide additional information on effect sizes on the basis of available data. Some studies evaluated and adjusted for potential confounding factors with the use of multivariate analyses.[3,6]

Patient and Demographic Factors

Scoliosis

As reported in 2 studies that employed multivariate analysis,[3,6] age at surgery was not significantly associated with PJK although it was significant in the third study based on unadjusted estimates.[4] Sex, body mass index, and comorbidities were not statistically significant risk factors when adjusting for other confounding variables[3] (Table 5).

No statistical association between age and the occurrence of PJK was seen in studies of adolescent scoliosis.[5,7] Risser sign was used to grade skeletal maturity (scale range, 0–5, where 5 indicated completion of fusion). Lower grades were associated with PJK in multivariate analysis from 1 study,[7] but no association was found in the other.[5] In 1 study, males were at higher risk for PJK based on unadjusted RRs[5] but not significantly so in the other, which adjusted for other factors[7] (Table 6).

TABLE 4. Summary of Risk Factors for PJK Evaluated and Those Significantly Associated With PJK

Study	Potential Prognostic Factors Evaluated (as Reported by Authors)	Effect Sizes and Significant Results* (as Reported by Authors)
Adults		
Kim *et al*[4]	• Patient factors: Age, sex, comorbidities (osteoporosis; alcohol abuse; cigarette smoking; and cardiovascular, endocrine, neurological, gastrointestinal, or psychiatric disease), and osteotomy.	Age (unadjusted)
	• Radiographical factors: Global sagittal balance, proximal junctional angle, thoracic kyphosis, lumbar lordosis.	$P = 0.007$
	• Surgical factors: Instrumentation type.	>55 yr: $P < 0.0001$
		Age-adjusted estimates (no odds ratios or risk ratios reported)
		Lowest instrumented vertebra (S1)
		$P = 0.009$
		Combined anteroposterior approach
		$P = 0.032$
		Pedicle screw construct
		$P = 0.041$
Kim *et al*[3]	• Patient factors: Age, sex, osteoporosis, osteopenia.	*Multivariate analysis (adjusted)*
	• Radiographical factors: SSVL difference, PJK angle.	
	• Surgical factors: Instrumentation technique, surgical approach, UIV, levels fused, thoracoplasty, fusion to S1, length of fusion.	Sex (female)
		OR: 2.53 (0.67–9.65), CI: 95%, $P = 0.173$
		HR: 2.36 (0.72–7.81), CI: 95%, $P = 0.159$
		Age
		OR: 0.99 (0.95–1.03), CI: 95%, $P = 0.582$
		HR: NR
		Osteopenia/osteoporosis
		OR: 1.75 (0.68–4.46), CI: 95%, $P = 0.244$
		HR: 1.86 (0.98–3.55), CI: 95%, $P = 0.058$
		Upper instrumented level (T1–T3)
		OR: 2.34 (1.07–5.12), CI: 95%, $P = 0.034$
		HR: 1.98 (1.05–3.72), CI: 95%, $P = 0.034$
		Anteroposterior approach
		OR: 3.13 (1.08–9.05), CI: 95%, $P = 0.035$
		HR: 3.04 (1.56–5.93), CI: 95%, $P = 0.001$
		Fusion to S1
		OR: 1.52 (0.55–4.16), CI: 95%, $P = 0.419$

(*Continued*)

TABLE 4. (*Continued*)

Study	Potential Prognostic Factors Evaluated (as Reported by Authors)	Effect Sizes and Significant Results* (as Reported by Authors)
		HR: NR
		SSVL difference
		OR: 0.99 (0.98–1.00), CI: 95%, $P = 0.004$
		HR: 0.99 (0.98–1.00), CI: 95%, $P = 0.001$
Mendoza-Lattes *et al*[6]	• Patient factors: Age, sex, BMI.	*Multivariate analysis*
	• Radiological factors: Coronal Cobb angle, sagittal balance, thoracic kyphosis Cobb angle, coronal balance, sagittal alignment, pelvic incidence, sacral slope.	C7 Plumb line
		$P = 0.0055$
		Difference between lumbar lordosis and thoracic kyphosis
		$P = 0.0121$
Scheuermann kyphosis		
Denis *et al*[1]	• Patient factors: Age, sex, presence of pain (thoracic or low lumbar), previous treatment (bracing, physical therapy), smoking status.	*Estimates are unadjusted*
	• Radiographical factors: Cobb measurement of thoracic kyphosis (upper to lowermost tilted end vertebra including the total kyphosis) and lumbar lordosis (lower thoracic end vertebra to superior endplate of S1, location of apical vertebra, C7 sagittal plumb line [relative to sacral promontory]), location of neutral and first lordotic discs distal to thoracic kyphosis.	Fusion short of the proximal end vertebra
		Reported as significant
	• Pathologic factors: Presence of spondylolysis or spondylolisthesis.	
	• Clinical factors: Abnormal neurological findings, postoperative complications.	≥50% correction
		$P < 0.05$
	• Surgical factors: Operative approach (posterior-only), instrumentation system used, need for revision surgery.	
Lonner *et al*[13]	• Patient factors: Age, sex.	*Estimates are unadjusted*
	• Clinical factors: Complications, implant failure.	Kyphosis follow-up
	• Radiological factors: Thoracic kyphosis, lumbar lordosis, sagittal translation, distal junctional kyphosis, pelvic incidence, first lordotic disc, sagittal stable vertebra, lateral kyphosis, apical translation.	
		$P < 0.01$
	• Surgical factors: Surgeon, duration of surgery, estimated blood loss, blood products given, levels instrumented, instrumentation type, anchor type and levels, performance of anterior release, graft, posterior osteotomies.	Kyphosis percent change
		$P = 0.02$
Pediatric/adolescent		
Kim *et al*[5]	• Patient factors: Age, sex.	*Estimates are unadjusted*†
	• Clinical factors: Pre-existing segmental kyphosis, Risser sign.	Preoperative thoracic Cobb angle‡
	• Radiographical factors: Sagittal alignment, preoperative C7 sagittal plumb line, proximal thoracic Cobb angle, main thoracic Cobb angle, proximal junctional angle, T5–T12 sagittal Cobb angle.	
		$P < 0.0001$

(*Continued*)

TABLE 4. (*Continued*)

Study	Potential Prognostic Factors Evaluated (as Reported by Authors)	Effect Sizes and Significant Results* (as Reported by Authors)
	• Surgical factors: Level of UIV, number of fused vertebrae, type of instrumentation, thoracoplasty.	Postoperative thoracic Cobb angle change (T5–T12)‡
		$P < 0.0001$
		Thoracoplasty‡
		$P = 0.001$
		Sex‡
		$P = 0.007$
Wang *et al*[7]	• Patient factors: Age, sex.	*Multivariate analysis*
	• Clinical factors: Duration of usage of orthosis, Risser sign.	Age
	• Radiological factors: Cobb angle, postural curvature angle of thoracic vertebrae, kyphosis angle at proximal junction area, corrected angle of thoracic vertebrae, C7-SSVL distance in the sagittal plane.	OR: 0.94 (0.79–1.13), CI: 95%, $P = 0.518$
	• Surgical factors: Material of correction, grafting material, material used for fixation of upper vertebra, material of internal fixation, fused lumbar vertebrae, number of fused segments, location of upper vertebra.	Sex (male)
		OR: 1.07 (0.24–4.87), CI: 95%, $P = 0.929$
		Risser
		OR: 1.73 (1.06–2.81), CI: 95%, $P = 0.028$
		Preoperative postural curvature angle of thoracic vertebrae
		< 20° (referent)
		30°–40° OR: 0.84 (0.16–4.50), CI: 95%, $P = 0.838$
		> 40° OR: 4.49 (1.06–19.09), CI: 95%, $P = 0.042$
		Thoracoplasty
		OR: 11.31 (2.48–51.58), CI: 95%, $P = 0.002$
		Material of correction
		Rotating bar (referent)
		Distraction OR: 4.30 (1.22–15.19), CI: 95%, $P = 0.024$
		Grafting material
		Autogenous bone (referent)
		Allogeneic bone OR: 0.04 (0.01–0.27), CI: 95%, $P = 0.001$
		Biomaterials OR: 0.07 (0.01–0.45), CI: 95%, $P = 0.005$
		Material used in fixation of upper vertebra
		Hook (referent)
		Screw OR: 19.99 (3.54–112.98), CI: 95%, $P = 0.001$

(*Continued*)

TABLE 4. (*Continued*)

Study	Potential Prognostic Factors Evaluated (as Reported by Authors)	Effect Sizes and Significant Results* (as Reported by Authors)
		Fused lumbar vertebrae
		Above L2 (referent)
		Below L2 OR: 1.88 (0.54–6.50), CI: 95%, *P* = 0.320
		Number of fused segments
		< 6 (referent)
		6–8 OR: 0.56 (0.12–2.50), CI: 95%, *P* = 0.444
		≥ 8 OR: 0.95 (0.22–4.07), CI: 95%, *P* = 0.946

**Factors included as part of multivariate model are listed although they may not have remained statistically significant.*

†P values reported by authors on the basis of comparison of those with PJK with all patients in the sample.

‡Factors compared with PJK vs. total population rather than those without PJK.

SSLV indicates sagittal sacral vertical line; PJK, proximal junctional kyphosis; UIV, upper instrumented vertebra; OR, odds ratio; CI, confidence interval; HR, hazard ratio; NR, not reported; BMI, body mass index.

Kyphosis

None of the studies of Scheuermann kyphosis evaluated patient demographic factors or characteristics as risk factors.

Surgical Factors

Scoliosis

Two studies in adults evaluated fusion to S1 as a risk factor for PJK, but this association failed to reach significance in a multivariate analysis. Combined anteroposterior approach was associated with an increased risk of PJK in 2 studies based on adjusted estimates, and the UIV level at T1–T3 was associated with PJK in 1 study, which provided adjusted estimates.[3] Similarly, the UIV at T8 or below was not[4] based on univariate analysis. After adjustment for age, use of pedicle screws did not significantly increase PJK risk *versus* the use of hybrid constructs or hooks. Performing an osteotomy did not increase the risk for PJK in that same study (Table 5).

In the 2 studies of adolescents,[5,7] no significant association was found between the number of fused vertebrae and the risk of PJK. Increased risk of PJK was associated with performed thoracoplasty.[5,7] Both studies suggested that the use of screws might be associated with higher PJK risk than the use of hooks. However, the wide CI for the adjusted OR reported by Wang *et al*[7] suggested great variability in the estimate and calls its stability into question. The study by Wang *et al*[7] suggested that the use of distraction (*vs.* a rotating bar) increases PJK risk and the use of allogenic bone or biomaterials for fusion decreases the risk compared with autogenous bone for grafting. The proportions of persons who developed PJK and those who did not were similar with respect to the UIV in 1 study[5] (Table 6).

Kyphosis

Limited information on the influence of surgical factors on the risk of PJK from unadjusted estimates was found in the 2 Scheuermann kyphosis studies. In both, shorter fusions were associated with increased PJK risk. Lonner *et al*[13] evaluated the risk of PJK for levels fused in relation to the proximal Cobb end vertebra. An increase in PJK risk was associated with fusion levels caudal to and including the Cobb end vertebra compared with fusion cephalad to the Cobb end vertebra, but statistical significance was not achieved. Denis *et al*[1] described the "level of proximal instrumented vertebra" and the "proximal end vertebra (PEV)" and the risk associated with the proximal instrumented vertebra being short of the PEV. The PEV was determined by using the "best fit line" technique on the radiographs. Fusions short of the PEV were associated with a significant increase in PJK risk; however, the wide CI should be considered. In this study, correction of more than 50% was associated with increased risk of PJK. The authors state that this finding lost significance when PJK was related to failure to fuse to the actual upper end of the vertebra of the curve or when there was damage to the ligamentum flavum; however, they do not provide supportive data. Lonner *et al*[13] reported that there was no association with proximal anchor type (hook or screw) and PJK development ($P = 0.36$) but did not provide supportive data (Table 7).

Radiographical Factors: Angles

Scoliosis

Authors reported various measured angles from radiographs. Tables 8 and 9 summarize findings related to these

TABLE 5. Summary of Patient and Surgical Factors Evaluated in Included Studies of Adults

Risk Factors	Authors	PJK	No PJK	Effect Size (Significance)*
Patient factors				
Age	Kim *et al*[4]	49.2 ± 12.6	42.9 ± 15.2	$P = 0.007$
		≥55 yr old	42% (26/62)	RR_{crude} 1.92 (1.33–2.77)
		27% (44/161)		
	Kim *et al*[3]	Unknown	Unknown	OR_{adj} 0.99 (0.95–1.03)†
	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR_{adj} NS
Sex	Kim *et al*[3]	Unknown	Unknown	OR_{adj} 2.53 (0.67–9.65)
	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR NS‡
BMI	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR_{adj} NS
Osteopenia/porosis	Kim *et al*[3]	Unknown	Unknown	OR 1.75 (0.68–4.46)
Comorbidity present	Kim *et al*[4]	44% (27/62)	39% (39/99)	RR_{crude} 1.11 (0.75–1.64)
				$P = 0.6020$
Surgical factors				
Osteotomy	Kim *et al*[4]	31% (19/62)	33% (33/99)	RR_{crude} 0.93 (0.60–1.42)
Fusion to S1	Kim *et al*[3]	43% (18/42)	19% (39/207)	OR_{adj} 1.52 (0.55–4.16)
Fusion to S1	Kim *et al*[4]	53% (33/62)	32% (32/99)	RR_{crude} 1.68 (1.14–2.47)
Fusion ≥ L5		47% (29/62)	68% (67/99)	Referent
				$P_{adj} = 0.059$§
UIV T8 or below	Kim *et al*[4]	68% (42/62)	34% (34/99)	RR_{crude} 1.31 (0.89–1.94)
UIV T1-T3	Kim *et al*[3]	Unknown	Unknown	OR_{adj} 2.34 (1.07–5.12)
Pedicle screw, hook/ hybrid	Kim *et al*[4]	32% (20/62)	18% (18/99)	RR_{crude} 1.54 (1.04–2.27)
		68% (42/62)	82% (81/99)	Referent
				$P_{adj} = 0.33$§
Surgical approach:				
Anteroposterior	Kim *et al*[3]	Unknown	Unknown	OR_{adj} 3.13 (1.08–9.05)
Anteroposterior	Kim *et al*[4]	68% (42/62)	51% (50/99)	RR_{crude} 1.58 (1.02–2.42)
Posterior-only		32% (20/62)	49% (49/99)	Referent
				$P_{adj} = 0.041$§

**If available, results of multivariate analysis are reported here as the adjusted odds ratio (OR_{adj}) as reported by authors, and any univariate evaluations were not reported; for those studies not reporting multivariate analyses, crude risk ratios (RR_{crude}) and 95% confidence intervals were calculated as data were available. The percentages are the proportion of persons (with or without PJK) who have the risk factor.*

†Odds per year of age based on multivariate analysis.

‡Details not given, but the authors state that sex distribution is comparable between the 2 groups.

§P value adjusted for age older than 55 yr at the time of surgery as reported by authors.

PJK indicates proximal junctional kyphosis; RR, risk ratio; OR, odds ratio; NS, not significant; BMI, body mass index; UIV, upper instrumented vertebra.

measurements and additional data are available in the supplemental digital content (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703). Kim *et al*[5] found that preoperative thoracic kyphosis of more than 40° along with a postoperative decrease of thoracic kyphosis more than 5° demonstrated an increased risk of PJK development. It may be that if excessive kyphosis is removed during thoracic spinal deformity surgery, there is a risk of PJK developing to compensate for the kyphosis that has been removed.

Two studies of adults evaluated the PJK angle. It was not a significant risk factor in multivariate analysis in 1 study,[3] but the other, using unadjusted analyses, found significant

TABLE 6. Summary of Patient and Surgical Factors Evaluated in Included Studies of Adolescents

	Authors	PJK	No PJK	Effect Size (Significance)*
Patient factors				
Age	Kim *et al*[5]	14.5 ± 1.83	14.8 ± 2.03	*P* = 0.13
	Wang *et al*[7]	Unknown	Unknown	OR_{adj} 0.94 (0.79–1.13)
Male sex	Kim *et al*[5]	26% (29/111)	15% (44/299)	RR_{crude} 1.63 (1.16–2.29)
	Wang *et al*[7]	Unknown	Unknown	OR_{adj} 1.07 (0.24–4.87)
Risser sign	Kim *et al*[5]	2.8 ± 1.80	3.0 ± 1.88	*P* = 0.50
	Wang *et al*[7]	Unknown	Unknown	OR_{adj} 1.73 (1.06–2.81)
Pre-existing segmental kyphosis	Kim *et al*[5]	21% (23/111)	20% (61/299)	RR_{crude} 1.01 (0.69–1.50)
Surgical factors				
Number fused vertebrae	Kim *et al*[5]	12.1 ± 1.46	11.6 ± 1.62	*P* = 0.50
	>12	41% (45/111)	32% (96/299)	RR_{crude} 1.30 (0.95–1.79)
	6 to −12	59% (66/111)	68% (203/299)	Referent
	Wang *et al*[7]			
	≥ 8	Unknown	Unknown	OR_{adj} 0.95 (0.22–4.07)
	6 to −8			OR_{adj} 0.56 (0.12–2.50)
	<6			Referent
Fused lumbar vertebrae	Wang *et al*[7]			
	Below L2	Unknown	Unknown	OR_{adj} 1.88 (0.54–6.50)
	Above L2			Referent
Thoracoplasty	Kim *et al*[5]	42% (47/111)	28% (85/299)	RR_{crude} 1.55 (1.13–2.12)
	Wang *et al*[7]	Unknown	Unknown	OR_{adj} 11.31 (2.48–51.58)
Material of correction	Wang *et al*[7]			
	Distraction	Unknown	Unknown	OR_{adj} 4.30 (1.22–15.19)
	Rotating bar			Referent
Grafting material	Wang *et al*[7]			
	Allogeneic bone	Unknown	Unknown	OR_{adj} 0.04 (0.01–0.27)
	Biomaterials			OR_{adj} 0.07 (0.01–0.45)
	Autogenous bone			Referent
Fixation of upper vertebra	Wang *et al*[7]			
	Screw	Unknown	Unknown	OR_{adj} 20.0 (3.54–113)
	Hook			Referent
Instrumentation	Kim *et al*[5]			
	Screw *vs.* hook	31% (34/111)	21% (63/299)	RR_{crude} 1.57 (1.08–2.27)
	Hybrid *vs.* hook	27% (30/111)	24% (73/299)	RR_{crude} 1.30 (0.88–1.93)
	Hook	42% (47/111)	55% (163/299)	Referent
Upper instrumented vertebra	Kim *et al*[5]			
	T2	20% (22/111)	20% (61/299)	Difference 0%

(*Continued*)

TABLE 6. (*Continued*)

	Authors	PJK	No PJK	Effect Size (Significance)*
	T3	36% (40/111)	31% (94/299)	Difference 5%
	T4	32% (36/111)	36% (107/299)	Difference 4%
	T5	10% (11/111)	10% (31/299)	Difference 0%
	T6 and below	2% (2/111)	2% (6/299)	Difference 0%

*If available, results of multivariate analysis are reported here as the adjusted odds ratio (OR_{adj}) as reported by authors, and any univariate evaluations were not reported; for those studies not reporting multivariate analyses, crude risk ratios (RR_{crude}) and 95% confidence intervals were calculated as data were available, or the difference in proportion of persons with PJK who had the factor and those who did not are given for effect size. The percentages are the proportion of persons (with or without PJK) who have the risk factor.

PJK indicates proximal junctional kyphosis; OR, odds ratio; RR, risk ratio.

differences postoperatively between those who did and did not develop PJK[4] (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703). In studies using multivariate analyses, the sagittal sacral vertical line,[3] the thoracic kyphosis-lumbar lordosis Cobb angle, and the C7 plumb line[6] remained significantly different between groups (Table 8). Kim *et al*[4] also reported on the following measures: thoracic (T5–T12) kyphosis (significant differences at 8 wk and ultimate follow-up but not preoperatively), lumbar lordosis (no statistical differences at any time point), and sagittal vertical axis (no statistical differences at any time point); additional details can be found in the supplemental digital content (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703).

In the 2 studies of adolescents, increased preoperative thoracic Cobb angle and postural thoracic curvature angle were associated with increased risk of PJK[5,7] (Table 9). The multivariate analysis of Wang *et al*[7] included preoperative postural curvature of thoracic vertebrae: compared with those with less than 20°, those with more than 40° were at greater risk for PJK (the odds of >40° angle were 4 times greater for those who had PJK). On the contrary, Kim *et al*[5] reported no significant differences between those who did and did not develop PJK in the proximal thoracic Cobb angle, main thoracic Cobb angle, or C7 to the plumb line to the sacrum. In addition, Kim *et al*[5] examined radiographical factors (additional details available in the Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703), preoperatively, immediate postoperatively, and at 2 years postoperatively, comparing values for those who did and did not develop PJK.[5] In this study, no significant differences were found in the parameters addressed.

TABLE 7. Summary of Factors Reported in Included Studies in Persons With Scheuermann Kyphosis

Risk Factors	Authors	PJK	No PJK	Effect Size (Significance)*
Surgical				
Proximal level of fusion	Lonner *et al*[13]			
	C7 or T1	8% (2/25)	14% (7/50)	Difference 6%
	T2, T3, T4	88% (22/25)	80% (40/50)	Difference 8%
	T5, T6, T7	4% (1/25)	6% (3/50)	Difference 2%
Fusion levels caudal to and including CEV *versus* cephalad to the CEV	Lonner *et al*[13]	84% (21/25)	66% (33/50)	RR_{crude} 2.04 (0.79–5.24)
Proximal instrumented vertebra short of proximal end vertebra of the true kyphosis	Denis *et al*[1]	85% (17/20)	21% (10/47)	RR_{crude} 8.40 (2.72–25.89)
Correction more than 50%	Denis *et al*[1]	55% (11/20)	21% (10/47)	RR_{crude} 2.68 (1.13–5.47)
				$P = 0.0065$

*If available, results of multivariate analysis are reported here as the adjusted odds ratio (OR_{adj}) as reported by authors, and any univariate evaluations were not reported; for those studies not reporting multivariate analyses, crude risk ratios (RR_{crude}) and 95% confidence intervals were calculated as data were available, or the difference in proportion of persons with PJK who had the factor and those who did not are given for effect size. The percentages are the proportion of persons (with or without PJK) who have the risk factor.

PJK indicates proximal junctional kyphosis; CEV, Cobb end vertebra.

TABLE 8. Summary of Radiographical Measurements and Associations With PJK in Adults

Risk Factors	Authors	PJK	No PJK	Effect Size (Significance)*
Preoperative sagittal imbalance: Sagittal vertical axis ≥8 cm	Kim *et al*[4]	27% (17/62)	23% (23/99)	RR_{crude} 1.14 (0.74–1.75)
Sagittal sacral vertical line difference (mm)	Kim *et al*[3]	−20.98 ± 44.12	−1.03 ± 38.93	OR_{adj} 0.99 (0.98–1.90)
				P_{adj} = 0.004
Sacral slope	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR_{adj} NS
Ratio of C7 plumb line distance to sacral endplate/sacral femoral distance	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR_{adj} 0.972 (0.949–0.996)
Cobb angle differences: (magnitude of thoracic kyphosis) − (lumbar lordosis)	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR_{adj} 0.861 (0.771–0.961)
Pelvic incidence	Mendoza-Lattes *et al*[6]	Unknown	Unknown	OR_{adj} NS

**If available, results of multivariate analysis are reported here as the adjusted odds ratio (OR_{adj}) as reported by authors and any univariate evaluations were not reported; for those studies not reporting multivariate analyses, crude risk ratios (RR_{crude}) and 95% confidence intervals were calculated as data were available. The percentages are the proportion of persons (with or without PJK) who have the risk factor.*

PJK indicates proximal junctional kyphosis; NS, not significant.

TABLE 9. Summary of Radiographical Measurements and Associations With PJK in Adolescents

	Authors	PJK	No PJK	Effect Size (Significance)*
Preoperative thoracic Cobb angle	Kim *et al*[5]			
	Categorizations			
	<10°	9% (10/111)	20.4% (61/299)	Difference 11%
	10°–40°	68.5% (76/111)	69.9% (209/299)	Difference 1.4%
	>40°	22.5% (25/111)	9.7% (29/299)	Difference 12.8%
	Comparisons			
	>10° *vs.* <10°			RR_{crude} 2.11 (1.16–3.84)
	10°–40° *vs.* <10°			RR_{crude} 1.89 (1.03–3.47)
	>40° *vs.* 10°–40°			RR_{crude} 1.74 (1.23–2.45)
Postoperative thoracic Cobb changes (T5–T12)	Kim *et al*[5]			
	>5° increase	9% (10/111)	25% (76/299)	Difference 16%
	≤5° change	26% (29/111)	30% (91/299)	Difference 4%
	>5° decrease	65% (72/111)	44% (132/299)	Difference 23%
Preoperative postural curvature angle of thoracic vertebrae	Wang *et al*[7]			
	30°–40°	Unknown	Unknown	OR_{adj} 0.84 (0.16–4.50)
	>40°			OR_{adj} 4.49 (1.06–19.09)
	<20°			Referent

**If available, results of multivariate analysis are reported here as the adjusted odds ratio (OR_{adj}) as reported by authors and any univariate evaluations were not reported; for those studies not reporting multivariate analyses, crude risk ratios (RR_{crude}) and 95% confidence intervals were calculated as data were available, or the difference in proportion of persons with PJK who had the factor and those who did not are given for effect size. The percentages are the proportion of persons (with or without PJK) who have the risk factor.*

PJK indicates proximal junctional kyphosis.

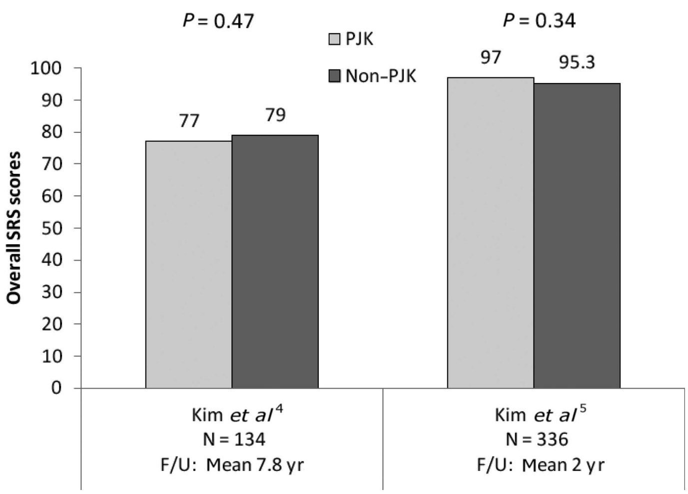

Figure 3. Comparison of SRS scores between patients with PJK and those without PJK. SRS indicates Scoliosis Research Society; PJK, proximal junctional kyphosis.

Kyphosis

Scheuermann kyphosis studies provided limited radiographical findings. Denis *et al*[1] did not compare thoracic kyphosis, lumbar lordosis, or C7 plumb line between those with and without PJK but did report that 10 patients overall had a residual kyphosis of more than 55° following surgery. Lonner *et al*[13] reported a preoperative kyphosis difference between groups ($P = 0.07$), a statistically significant difference in kyphosis at follow-up ($P < 0.001$) with the percent change also significant ($P = 0.02$) but no difference in pelvic incidence.

Do Patients With PJK Have Worse HRQOL Outcomes?

Scoliosis

Data from 3 studies[3–5] suggest that there is no difference in function between those who do and do not develop PJK, based on the Scoliosis Research Society (SRS) questionnaire scores at follow-up. Two studies, 1 in adults[4] and 1 in adolescents,[5] reported total SRS scores as well as those for the pain, self-image, function, and satisfaction. Kim *et al*[5] used the SRS-24 questionnaire, and the study by Kim *et al*[4] used 3 questionnaires, the SRS-24, 29, and 30, normalized to 100 for purposes of analysis.[4] The overall mean scores at follow-up were similar for those who did and did not develop PJK, and no differences between groups were seen when separate domain scores were compared (Figure 3 and Table 10).

The third study reported total SRS outcomes score differences from preoperative to postoperative for each group, with the note that for the score differences, comparison between the patients with PJK and non-PJK did not show a statistically significant difference.[3] However, there are certainly patients with PJK who are symptomatic and require either nonoperative or even operative management, but these facts are not quantified well in any current literature.

Kyphosis

Studies on Scheuermann kyphosis did not assess HRQOL outcomes.

Evidence Summary

The overall summary of the available evidence (Table 11) focuses on findings across multiple studies. The strength of evidence was rated as moderate for overall risk (cumulative incidence) of PJK, indicating that future research is likely to have an important impact on the confidence of the estimate and may change the estimate. The strength was upgraded from low to moderate on the basis of estimate size. A rating of low for all of the risk factors across studies of adolescents and adults suggests that future research is very likely to have an important impact on our confidence of the effect estimate and likely to change the estimate. The overall evidence for the majority of factors evaluated in persons with Scheuermann kyphosis was considered insufficient, indicating that any estimate is uncertain.

DISCUSSION

PJK is a form of ASP that occurs in 17% to 39% of cases after spinal deformity surgery. Although multifactorial in etiology, combined anteroposterior surgery, thoracoplasty, UIV at T1–T3, and those without anatomical restoration of thoracic kyphosis are at higher risk and should be followed closely. Interestingly, the occurrence of PJK had no effect on HRQOL outcomes, and there is a paucity of literature on methods for assessing PJK when it occurs.

TABLE 10. SRS Subscales: Mean Scores Reported by 2 Studies

	Kim *et al*[5] (Adolescent/Pediatric Patients)			Kim *et al*[4] (Adult Patients)		
	PJK	No PJK	*P*	PJK	No PJK	*P*
Pain	21.9 ± 3.5	21.1 ± 3.9	0.16	17 ± 5.9	18 ± 6	0.7
Self-image	21.3 ± 3.2	21 ± 3.5	0.54	19 ± 4	19 ± 4.3	0.74
Function	20.1 ± 3.5	20.5 ± 3.1	0.39	17 ± 5.2	18 ± 4.6	0.7
Satisfaction	9.2 ± 1.2	9 ± 1.4	0.2	9 ± 1.9	9 ± 1.5	0.84

**Scores of Kim et al[4] were normalized for the SRS 24, 29, and 30 to the SRS-24 standard point allocations.*

PJK indicates proximal junctional kyphosis; SRS, Scoliosis Research Society.

TABLE 11. Strength of Evidence Summary

	Strength of Evidence	Conclusions/Comments	Baseline	Upgrade (Levels)	Down-Grade (Levels)
Question 1: What is the reported risk and timing of PJK development?					
Risk (cumulative incidence)	Moderate	• Cumulative risk ranged from 17% to 39% across studies.	Low	Large effect (1)	No
Timing	Low (adult and adolescent scoliosis)	• Two studies in adults and 2 in adolescents suggest that most PJK development or greatest increases in PJA may occur relatively early in postoperative period.	Low (adult and adolescent scoliosis)	No	No
	Insufficient (Scheuermann kyphosis)	• Not reported in studies of Scheuermann kyphosis.	Insufficient (Scheuermann kyphosis)		
Question 2: What factors are associated with PJK development?					
Patient factors (age, sex, Risser sign)	Low (adult and adolescent scoliosis)	• Adults: In multivariate analysis (2 studies), neither age nor sex was significant; older age conferred higher risk of PJK based on crude estimates in 1 study.	Low (adult and adolescent scoliosis)	No	No
	Insufficient (Scheuermann kyphosis)	• Adolescents: No association with age in 2 studies. No association with sex in multivariate analysis but increased risk in males based on unadjusted risk ratio. In study using a multivariate model, Risser sign was associated with PJK but no association was found in second study.	Insufficient (Scheuermann kyphosis)		
		• Scheuermann kyphosis: Not reported in studies of Scheuermann kyphosis.			
Surgical factors	Low	• Adults: Fusion to S1 did not increase risk, but combined anterior and posterior approach was associated with increased risk based on adjusted estimates (2 studies).	Low	No	No
		• Adolescents: Number of fused vertebrae did not increase PJK risk. Thoracoplasty was associated with increased PJK risk as was the use of screws *vs*. hooks in both studies. Confidence intervals for adjusted estimates were wide, calling their stability into question.			
		• Scheuermann kyphosis: Two studies suggest increased risk of PJK with shorter fusions; results were statistically significant in 1. Wide confidence intervals suggest some instability in estimates. Neither adjusted for potential confounding factors.			
Radiographical findings	Low (adult and adolescent scoliosis)	• Adults: In multivariate analyses, none of the following were associated with PJK: SSVL, sacral slope, ratio of C7 plumb line: sacral femoral distance, difference between magnitude of thoracic kyphosis and lumbar lordosis Cobb angle measurement or pelvic incidence. Mean PJA significantly different between those who did and did not develop PJK postoperatively in 1 study.	Low (adult and adolescent scoliosis)	No	No

(*Continued*)

TABLE 11. (*Continued*)					
	Strength of Evidence	Conclusions/Comments	Baseline	Upgrade (Levels)	Down-Grade (Levels)
	Insufficient (Scheuermann kyphosis)	• Adolescents: Preoperative thoracic Cobb angle and postural thoracic curvature > 40° associated with PJK.	Insufficient (Scheuermann kyphosis)		
		• Scheuermann kyphosis: One study reported significant differences in kyphosis pre- and postoperatively.			
Question 3: Do persons with PJK experience decreased function or quality of life?					
SRS scores	Low (adult and adolescent scoliosis)	• Adults: Scores similar between those who did and did not develop PJK in 2 studies.	Low (adult and adolescent scoliosis)	No	No
	Insufficient (Scheuermann kyphosis)	• Adolescents: Scores similar between groups in 1 study.	Insufficient (Scheuermann kyphosis)		
		• Scheuermann kyphosis: No studies found.			

PJK indicates proximal junctional kyphosis; PJA, proximal junctional angle; SSVL, sagittal sacral vertical line; SRS, Scoliosis Research Society.

It seems that combined anteroposterior surgery, thoracoplasty, UIV at T1–T3, and those without anatomical restoration of thoracic kyphosis postoperatively demonstrated a higher risk for the development of PJK. We decided to concentrate on PJK, because this is the most distinct form of radiographical ASP that allowed a formal systematic review to be successfully carried out. These results should be considered within the context of the overall low (LoE III) quality of studies. Because of the multifactorial etiology of PJK and because of the potential for confounding variables, studies with multivariate analysis were initially considered more strongly in our risk factor assessment. Control for potential confounding factors was seen in several studies,[3,6,7] and 1 reported age-adjusted *P* values for some risk factors.[4] Studies that controlled for confounding factors are generally considered to provide the best estimates for determining the strength of association. Some risk factors (*i.e.*, age, fusions to the sacrum), which were identified on univariate analysis, were no longer significantly associated with PJK in multivariate analysis. However, due to the paucity of studies using multivariate analysis, some of these risk factors were still considered important on the basis of the unadjusted estimates and clinical differences in risk between groups.

Our primary focus was on factors that were reported across multiple studies. Risk factors identified in single studies included osteoporosis and obesity, but those that were not significant in our systematic review. Surgery-related risk factors described previously in the literature included those who have had significant corrections in the sagittal plane and pedicle screw instrumentation at the proximal end vertebra.

There are other risk factors that are well accepted by the spinal reconstructive surgical community that are not necessarily quantified in the literature, because these factors are either difficult to quantify or so complex that research to evaluate their effect is challenging. In addition, some of these risk factors may have implications for the development of radiographical or clinical ASP that is different from PJK, such as acute fractures at or directly above constructs with or without neurological sequelae. One such surgical issue is disruption of muscular/ligamentous/bony tissue at or cephalad to the upper instrumented/fused level during spinal reconstructive surgeries. Although all surgeons would agree that minor degrees of this occur in nearly every standard surgery performed, quantification of this disruption is difficult, making a scientific basis for our theory on this difficult to formulate. In addition, the type and degree of corrective forces used during actual rod placement that are a part of spinal deformity corrective surgery probably play an important role as well but are impossible to quantify currently. Thus, the load that the proximal portion of the implants and adjacent tissues is experiencing after a deformity correction can become nonphysiologic and may play a role in the alterations between a rigid/instrumented proximal region of the spine and the abrupt transition to the mobile/uninstrumented and fused immediate cephalad. These transitional forces are real, long lasting, and certainly a component of PJK development.

Quantifying the increase in the relative risk for PJK for various factors across included studies was problematic because a mixture of ORs and RRs is used in this review on the basis of data available in individual studies. ORs were reported in some studies.[3,6,7] Although these studies adjusted for potentially confounding factors, they may have overestimated the relative risk of PJK. (From a statistical standpoint, in which there is a high incidence of an outcome [>10%], the OR overestimates the relative risk, particularly with higher frequencies. The risk of PJK reported in the included studies ranged from 17% to 39%, which is not consistent with a

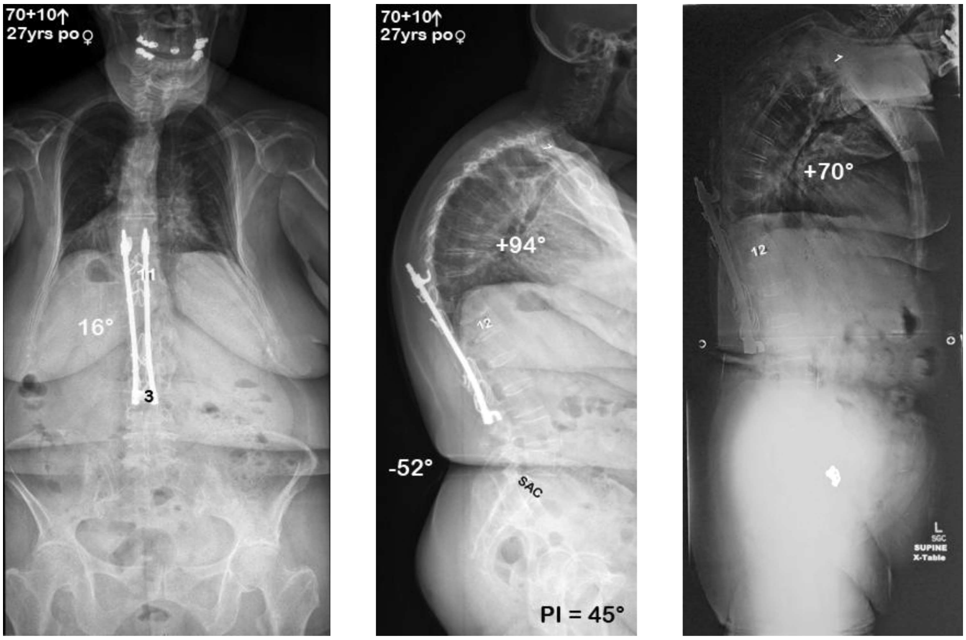

Figure 4. A 70+10-year-old woman with PJK 27 years after a posterior spinal fusion for a thoracolumbar fracture. She had + 94° of overall thoracic kyphosis, which corrected to +70° on hyperextension.

"rare" outcome.) Unadjusted RRs were calculated for studies that did not perform multivariate analyses.[1,4,5,13] Unfortunately, such estimates do not take into account the potential influence of confounding factors and therefore may be biased. Thus, neither measure may provide the true picture of the association between some factors and increased risk of PJK.

We excluded studies that did not define the PJK angle as the angle between the caudal endplate of the UIV to the cranial endplate of the 2 levels above with an angle of 10° or more and at least 10° greater than the preoperative measurement. Since its first description in the literature, the majority of studies have implemented this measurement. A handful of other studies that used different methods for measuring the PJK angle as well as those that defined PJK as an angle other than 10° were excluded from this study (see Supplemental Digital Content 1, available at http://links.lww.com/BRS/A703). Using a standardized definition for PJK allows for a uniform method of evaluating PJK and risk factors associated with its development across study populations.

From a radiographical perspective, few preoperative or postoperative risk factors were identified in this review. It is likely that there are obvious and subtle alterations in sagittal plane alignment and balance that will undoubtedly contribute to PJK development. The intricate interaction between spinal regional alignment (cervical lordosis, thoracic kyphosis, and lumbar lordosis) and the contributions from skull position

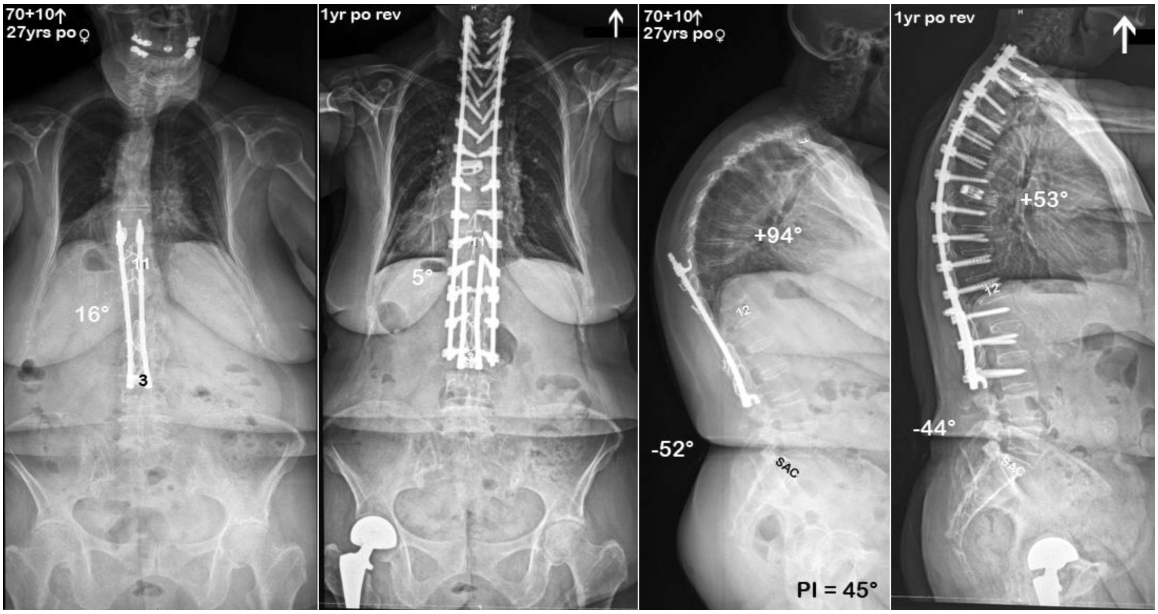

Figure 5. The patient underwent a posterior T8 vertebral column resection and posterior spinal fusion from C7 to L3 for correction of an overall kyphosis of +53°.

and sacropelvic parameters most likely play a role in optimal sagittal balance and for the prevention of things such as PJK. For example, all spinal reconstructive surgeons have experienced patients undergoing a major sagittal realignment procedure in the lumbar spine, such as a pedicle subtraction osteotomy, in order to increase lumbar lordosis and optimize global sagittal balance, where the patient developed PJK cephalad to the construct postoperatively. This can be seen very early postoperatively in those patients in whom the degree of lordosis produced was somewhat excessive for what the patient's regional and global balance required and is reflected by a reciprocal PJK mentioned above. Unfortunately, these types of common clinical scenarios are not well referenced in our current literature. However, the notion that there is a delicate balance among all spinal regions is becoming increasingly accepted, with important contributions from the sacropelvic unit below as well as less understood contributions from the brain/brainstem balance centers above that all together help establish the physiologic set point of global sagittal alignment and balance for each person. When spinal reconstructive surgery alters that dynamic balance, there may be many subtle as well as obvious manifestations, and the development of PJK is a true reflection of that.

PJK is a complication with a multifactorial etiology that, in our systematic review, occurred with increased frequency in those of advanced age, fusions to the sacrum, combined anteroposterior surgery, thoracoplasty, UIV at T1–T3, and those without anatomical restoration of thoracic kyphosis postoperatively. Other radiographical and surgical risk factors probably also play a role in PJK development but have not been adequately quantified in current literature. Patients with these risk factors should be monitored closely for the potential development of PJK. Although the majority of PJK cases do not necessitate revision surgery, those cases that are severe and progressive can lead to a devastating neurological compromise, so close monitoring of patients at high risk is warranted (Figures 4 and 5).

Future directions for research should aim toward stratifying different severities of PJK to delineate those of various radiographical severities, symptomatic *versus* asymptomatic, as well as those requiring revision surgery *versus* continued observation. Risk factor analysis should stress multivariate analysis for an etiology, which is multifactorial and further outcomes assessment needs to be performed after stratification into these different subgroups and etiologies.

Evidence Summary

The overall strength of evidence regarding the cumulative risk of PJK was considered moderate on the basis of the large proportions of persons reported to having developed it across studies, indicating that we have moderate confidence that the evidence reflects the true effect; however, future research may change this confidence as well as the estimate. With regard to the timing of PJK development, various risk factors described, and impact of PJK on HRQOL, the overall strength of evidence across studies of adults and adolescents was low. Additional research is likely to change the estimate as well as our confidence that this represents the true effect. With the exception of surgical risk factors, the evidence across studies of patients with Scheuermann kyphosis was deemed insufficient, indicating that we have low confidence that the evidence reflects the true effect. Further research is likely to change our confidence in the effect estimate and it is likely to change the estimate of effect given that the evidence either is unavailable or does not permit a conclusion (Table 11).

CONSENSUS STATEMENT

1. The risk of developing PJK above a spinal deformity fusion is 17% to 39%, with most noted by 2 years postoperative.
   Level of Evidence: Moderate
   Strength of Statement: Strong
2. The risk factors of PJK development include increased age, fusion to sacrum, combined ASF/PSF, thoracoplasty, UIV at T1–T3, and nonanatomic restoration of thoracic kyphosis.
   Level of Evidence: Low
   Strength of Statement: Weak
3. The development of PJK does not seem to have a detrimental effect on HRQOL outcomes, at least in milder/nonrevision forms.
   Level of Evidence: Moderate
   Strength of Statement: Weak

➢ Key Points

- ❑ The risk of developing PJK above a spinal deformity fusion is 17% to 39%, with most noted by 2 years postoperative.
- ❑ Surgery-related risk factors are combined anterior/posterior surgery, thoracoplasty, UIV at T1–T3, and those without anatomical restoration of thoracic kyphosis postoperatively.
- ❑ The use of hooks, wires, or pedicle screws at the proximal level did not have a consistent statistically significant association with PJK across studies.
- ❑ The presence of PJK did not result in differences in HRQOL outcomes.

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References

1. Denis F, Sun EC, Winter RB. Incidence and risk factors for proximal and distal junctional kyphosis following surgical treatment for Scheuermann kyphosis: minimum five-year follow-up. *Spine (Phila Pa 1976)* 2009;34:E729–34.
2. Glattes RC, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis. *Spine (Phila Pa 1976)* 2005;30:1643–9.
3. Kim HJ, Yagi M, Nyugen J, et al. Combined anterior-posterior surgery is the most important risk factor for developing proximal junctional kyphosis in idiopathic scoliosis. *Clin Orthop Relat Res* 2012;470:1633–9.
4. Kim YJ, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis in adult spinal deformity after segmental posterior spinal instrumentation and fusion: minimum five-year follow-up. *Spine (Phila Pa 1976)* 2008;33:2179–84.
5. Kim YJ, Lenke LG, Bridwell KH, et al. Proximal junctional kyphosis in adolescent idiopathic scoliosis after 3 different types of posterior segmental spinal instrumentation and fusions: incidence and risk factor analysis of 410 cases. *Spine (Phila Pa 1976)* 2007;32:2731–8.
6. Mendoza-Lattes S, Ries Z, Gao Y, et al. Proximal junctional kyphosis in adult reconstructive spine surgery results from incomplete restoration of the lumbar lordosis relative to the magnitude of the thoracic kyphosis. *Iowa Orthop J* 2011;31:199–206.
7. Wang J, Zhao Y, Shen B, et al. Risk factor analysis of proximal junctional kyphosis after posterior fusion in patients with idiopathic scoliosis. *Injury* 2010;41:415–20.
8. Wright JG, Swiontkowski MF, Heckman JD. Introducing levels of evidence to the journal. *J Bone Joint Surg Am* 2003;8:1–3.
9. Norvell DC, Dettori JR, Skelly AC, et al. Methodology for the systematic reviews on adjacent segment pathology. *Spine (Phila Pa 1976)* 2012;37:S10–7.
10. Atkins D, Best D, Briss PA, et al. Grading quality of evidence and strength of recommendations. *BMJ* 2004;328:1490.
11. West S, King V, Carey TS, et al. *Systems to Rate the Strength of Scientific Evidence*. Evidence Report/Technology Assessment No. 47 (Prepared by the Research Triangle Institute-University of North Carolina Evidence-based Practice Center, Contract No. 290-97-0011). Rockville, MD: *Agency for Healthcare Research and Quality*; 2002.
12. StataCorp. *Stata Statistical Software: Release* 9th ed. College Station, TX: StataCorp LP; 2005.
13. Lonner BS, Newton P, Betz R, et al. Operative management of Scheuermann's kyphosis in 78 patients: radiographic outcomes, complications, and technique. *Spine (Phila Pa 1976)* 2007;32:2644–52.