



Proximal Junctional Kyphosis and Proximal Junctional Failure Following Adult Spinal Deformity Surgery

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The purpose of this review is the current understanding of proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) following adult spinal deformity (ASD) surgery. We carried out a systematic search of PubMed for literatures published up to September 2017 with “proximal junctional kyphosis,” “proximal junctional failure,” and “adult spinal deformity” as search terms. A total of 98 literatures were searched. The 37 articles were included in this review. PJK is multifactorial in origin and likely results from variable risk factors. PJF is a progressive form of the PJK spectrum including bony fracture, subluxation between UIV and UIV+1, failure of fixation, neurological deficit, which may require revision surgery for proximal extension of fusion. Soft tissue protections, adequate selection of the UIV, prophylactic rib fixation, hybrid instrumentation such as hooks, vertebral cement augmentation at UIV and UIV+1, adequate selection material of rods and age-appropriate spinopelvic alignment goals are strategies to minimize PJK and PJF. The ability to perform aggressive global realignment of spinal deformities has also led to the discovery of new complications such as the PJK and PJF. Continuous research on PJK and PJF should be proceeded in order to comprehend the pathophysiology of these complications.

Key Words: Proximal junctional kyphosis, Proximal junctional failure, Adult spinal deformity, Complications

INTRODUCTION

Proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) are recognized complications after long instrumented posterior fusion in adult spinal deformity (ASD) surgery^{22,34,51}. PJK is a radiologic phenomenon of adjacent segment pathology and ongoing adjacent segmental problems at the transition between fused and mobile motion segments^{4,22,39}. PJK has a spectrum of disease severities from no clinical symptom to causing clinical symptom which may require revision surgery. PJF is a progressive process in the spectrum of PJK with structural failures such as vertebral body fracture and/or posterior ligament complex, and vertebral subluxation. PJF may present higher morbidities including pain, neurologic deficit, and revision surgery^{16,38,48}. This study was designed to provide comprehensive background materials for PJK and PJF after ASD surgery from thorough review of current literatures.

MATERIALS AND METHODS

We carried out a systematic search of PubMed for literatures published up to September 2017

with “proximal junctional kyphosis,” “proximal junctional failure,” and “adult spinal deformity” as search terms. A total of 98 literatures were searched. Case reports and articles that did not focus on PJK and PJF were excluded. Finally, the 37 articles were included in this review.

DEFINITION OF PROXIMAL JUNCTIONAL KYPHOSIS

There is no confirmative consent on the definition of PJK at present. As suggested by the terminology, PJK was defined as a kyphotic deformity in the spinal motion segments immediately cephalad to the instrumented segments¹⁵. PJK was first defined in the literature by Bridwell and colleagues as a proximal junctional sagittal Cobb angle between the lower endplate of uppermost instrumented vertebra (UIV) and the upper endplate of 2 supra-adjacent vertebra $\geq 10^\circ$ or at least 10° greater than the preoperative measurement⁷.

Another researcher defined PJK as a proximal junctional sagittal Cobb angle between the lower endplate of UIV and the upper endplate of one supra-adjacent vertebra $\geq 15^\circ$ ¹⁵. They suggested that the arbitrary selection of 5° or 10° does not correlate with clinical symptoms

or adjacent level disease. Their criteria $\geq 15^\circ$ was based on the standard deviation of all postoperative patients in their study and the assumption that normal is within 2 standard deviations.

Bridwell et al.²⁾ and O'Shaughnessy et al.³⁹⁾ used 20° between UIV and 2 supra-adjacent vertebra as the cutoff for defining meaningful PJK. They suggested that PJK occurs with fairly high prevalence after adult deformity surgery and PJK $\geq 20^\circ$ does not lead to revision surgery but it can be a meaningful cutoff value for poor outcomes.

Hostin et al.¹⁶⁾ set a reference angle 15° between UIV and 2 supra-adjacent vertebra based on the results of a large multicenter and retrospective study. Many authors suggested that varied angulation from 5 to 20° ^{7,15,16,30,39)}. To date, the angulation of PJK which at least 10 degrees greater than preoperative measurement is the most repeatedly used definition of PJK in the articles^{4,7,12,40)}.

PJK is not a single disease but a spectrum having various severities of disease. In early time literatures, PJK has not been found to cause significant clinical symptoms or structure failures. In those studies, there are no significant differences between the groups with or without PJK in Scoliosis Research Society-22 scores and clinical symptoms^{7,18,25,49)}.

DEFINITION OF PROXIMAL JUNCTIONAL FAILURE

PJF is a progressive form of the PJK spectrum including verte-

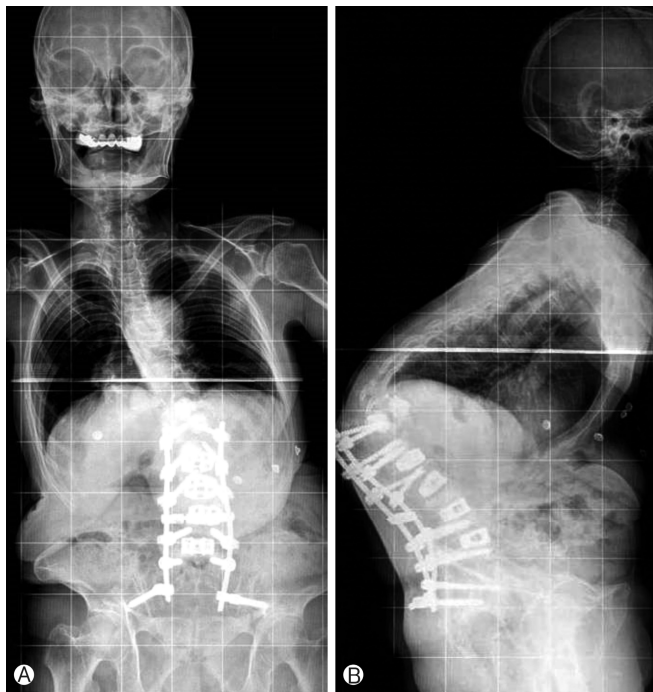


Fig. 1. Antero-posterior (A) and lateral (B) plain radiographs of the patient. The subluxation at the proximal level of uppermost instrumented vertebra caused severe thoracolumbar junction kyphosis and trunk shift to left side.

bral fracture of UIV or UIV+1, subluxation between UIV and UIV+1, failure of fixation, neurological deficit, which may require revision surgery for proximal extension of fusion^{16,40,44,49)}. Yagi et al.⁵²⁾ defined PJF as symptomatic PJK requiring any types of surgery. The structural failure that occurs with PJF can present as vertebral body fracture, implant pull-out or breakage, and/or disruption of the posterior osseoligamentous complex^{11,16)}. Patients with PJF have significantly worse clinical symptoms and Oswestry disability index scores^{24,51)}. Other terms used to describe PJF have included "topping off syndrome," "proximal junctional fracture," and "proximal junctional acute collapse." These terms highlight the associated structural failure and mechanical instability that distinguish this more severe form of proximal junctional pathologies from PJK³⁵⁾.

A case of catastrophic PJF is shown in Figs. 1 and 2. The subluxation at the proximal level of UIV caused severe thoracolumbar junction kyphosis, trunk shift to left side, disruption of posterior ligament complex, and rod protrusion penetrating the skin. Revision surgery for fusion extension to proximal upper thoracic level was performed (Fig. 3). The patient was well-tolerated without another PJK/PJF.

CLASSIFICATION OF PROXIMAL JUNCTIONAL KYPHOSIS

There is a lack of a standardized consensus to determine which patients with PJK need and will benefit most from revision surgery. Two separate classification systems have been proposed (Tables 1, 2). Boachie-Adjei and colleagues initially published their PJK classification in 2011 and subsequently revised it in 2014^{49,52)}. In their series, most failures were of type 2N (bony failure without spondylolisthesis) and most cases with neurologic abnormalities were type 2S (bony failure with spondylolisthesis). This classification has merits that it is simple and easy to describe the type and severity of PJK. It provides an objective means for clinicians to communicate the type of PJK²⁹⁾. However, it has

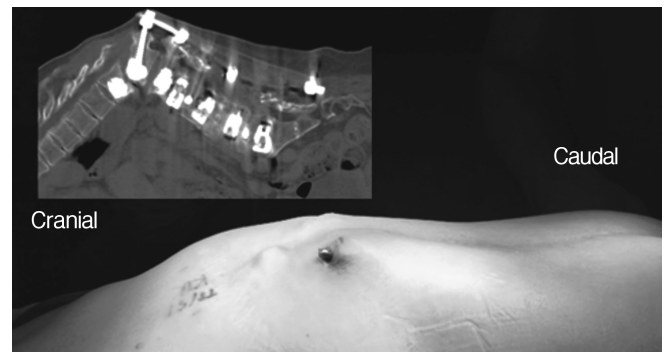


Fig. 2. Sagittal computerized tomography and intraoperative photo of the back of the patient. Severe thoracolumbar junction kyphosis and disruption of posterior ligament complex due to the subluxation at the proximal level of uppermost instrumented vertebra is observed. The proximal portion of rod penetrated the skin.

drawbacks that it lacks prognostic information and does not guide management. The classification scheme does demonstrate which patients tend to be symptomatic, but it does not provide information regarding the natural course and severity of disease. Thus, according to the classification, the clinicians have difficulty to determine which patients need a treatment including revision surgery. This classification has a limit with respect to patient management.

Hart et al.¹¹⁾ and the International Spine Study Group (ISSG) provided a new PJK classification to guide treatment and provide decision criteria for revision surgery. A proximal junctional kyphosis severity scale that assigns points to 6 different components thought to be important in the evaluation and management of PJK/PJF (Table 2). The 6 components include neurological deficit, focal pain, instrumentation problem, change in kyphosis/posterior ligament complex integrity, fracture location, and level of UIV. Each component is further categorized and assigned a certain number of points. The points are then summed for a total severity score. The proposed Hart-ISSG PJK severity scale has been shown to have good reliability and repeatability. Its score has been shown to strongly correlate with health-related quality of life outcome scores and indication for revision surgery. The score ≥ 7 indicates for revision surgery. A prospective study to evaluate its utility is under way.



Fig. 3. Postoperative 3 years anteroposterior (A) and lateral (B) plain radiographs of the patient. Revision surgery for fusion extension to upper thoracic level was performed and the patient was well-tolerated without another proximal junctional kyphosis/failure.

INCIDENCE

Several authors have analyzed the incidence of PJK following ASD surgery. It has been reported from 17% to 61.7%^{7,8,18,24,31,33,34,49,51)}. The incidence has wide range according to the study population and the period of follow-up (F/U). In the previous study, 42 of

Table 1. Classification of the grades and severity of proximal junctional kyphosis/proximal junctional failure by Boachie-Adjei et al.⁵²⁾

Type	Description
1	Disc and ligamentous failure
2	Bone failure
3	Implant/bone interface failure
Grade	
A	Proximal junctional increase 10°–19°
B	Proximal junctional increase 20°–29°
C	Proximal junctional increase 30°
Spondylolisthesis	
PJF-N	No obvious spondylolisthesis above UIV
PJF-S	Spondylolisthesis above UIV

PJF, proximal junctional failure; UIV, uppermost instrumented vertebra.

Table 2. The Hart-International Spine Study Group proximal junctional kyphosis severity scale

Parameter	Qualifier	Severity scale
Neurologic deficit	None	0
	Radicular pain	2
	Myelopathy/motor deficit	4
Focal pain	None	0
	VAS ≤ 4	1
	VAS ≥ 5	3
Instrumentation problem	None	0
	Partial fixation loss	1
	Prominence	1
Change in kyphosis/PLC integrity	Complete fixation loss	2
	0°–10°	0
	10°–20°	1
	>20°	2
UIV/UIV+1 fracture	PLC failure	2
	None	0
	Compression fracture	1
Level of UIV	Burst/chance fracture	2
	Translation	3
	Thoracolumbar junction	0
	Upper thoracic spine	1

VAS, visual analogue scale; PLC, posterior ligamentous complex; UIV, uppermost instrumented vertebra.

the 249 patients (17%) developed PJK during the F/U period²³. Another researcher investigated an incidence of 20% for 157 adult idiopathic scoliosis patients during 4.3 years F/U⁴⁹. Hyun and Rhim¹⁸ reported the incidence of PJK through a multicenter retrospective long-term F/U study. The incidence of PJK was 23% in patients with fixed sagittal imbalance who underwent pedicle subtraction osteotomy for average 6.1 years F/U. Kim et al.²⁴ investigated an incidence of PJK for 161 ASD patients. They reported 39% incidence of PJK with 7.8 years F/U. Maruo et al.³³ analyzed 90 ASD patients in long fusion to sacrum with an average 2.9-year F/U. They demonstrated 40% the incidence of PJK. Lee et al.³¹ reported 61% of PJK about 47 patients with lumbar degenerative kyphosis surgery during 3.8-year F/U. Whereas, the incidence of PJF was reported between 1.4% and 35%^{16,45,52}. Yagi et al.⁵² introduced that incidence of PJF was 1.4% in 23 of the 1,668 patients. According to another study, PJF was observed in 60 of the 173 patients (35%)⁴⁵.

RISK FACTORS

Variable risk factors for PJK and PJF have been described in the literatures. It can be categorized into surgical, radiographic, and patient-related risk factors. Surgical risk factors include injury of the posterior soft tissues, combined anterior and posterior approach, fusion to the sacrum/ilium, pedicle screw constructs, rod stiffness, selection of the UIV, the magnitude correction of deformity, and thoracoplasty. Damage of the posterior soft tissues (facet capsule, posterior tension band, etc.) has been suggested as a risk factor for PJK^{5,7,9,10,22,24,51,52}. The insufficiency of the posterior ligamentous complex by the surgical procedure is not a reversible factor. Previous investigators reasoned that ligamentous failure of the posterior interspinous ligament and paraspinous musculature damage may contribute to increasing of PJK⁵¹. Hyun et al.¹⁷ recently reported that preoperative insufficiency muscularity and fatty degeneration in the musculature of thoracolumbar area can cause PJK.

In patients with anteriorposterior spinal fusion, PJK is three times more likely to occur than patients with posterior fusion²². Fusion to the lower lumbar spine and sacrum also increase the incidence of PJK^{34,37,47,49,51}. After fusion to lower lumbar spine, trunk attempt to control balance by a change in the lumbar curves. However, the fused lumbar segment interfered with the adjustment and then PJK was increased⁴⁷.

Use of pedicle screw construct is one the risk factors^{15,25,26,47}. Helgeson et al.¹⁵ has shown that pedicle screw only construct compared with hook and hybrid significantly caused PJK after surgery. The high rigidity of vertebrae with pedicle screw increased adjacent segment kyphosis^{25,26}.

The PJK could occur because of increasing the rod stiffness. Han et al.¹⁰ explained that when cobalt chrome multiple-rod constructs (CoCr MRCs) and titanium alloy 2-rod constructs (Ti TRCs) are used, more PJK occurs in the group using CoCr MRCs (CoCr MRC: 60% vs. Ti TRC: 26.5%)¹⁰. In another literature, the cobalt chrome (CoCr) rod cause PJK more than titanium alloy (Ti) rod (CoCr: 46% vs. Ti: 18%)⁹.

The decision of the UIV may affect the occurrence of PJK⁷. The UIV at the upper and lower thoracic level have been related with PJK^{2,22}. The UIV at upper thoracic cause PJK by subluxation and soft tissue failure, whereas UIV at lower thoracic cause PJK secondary to vertebral body fractures^{16,33}. Bridwell et al.² reported that shorter fused levels (8 vs. 11 levels fused) and a UIV at the lower thoracic than upper thoracic spine were shown to cause the PJK more.

The greater intraoperative curvature correction cause a compensation by the trunk and formation proximal kyphosis⁴⁷. A magnitude correction of deformity is related with the occurrence of PJK^{21,33,34,51,52}. The greater correction of a sagittal vertical axis (SVA) and postoperative lumbar lordosis (LL) may contribute to the risk of PJK^{1,33}. Mauro et al.³³ reported that change in LL more than 30° was identified as a risk factor.

Wang et al.⁴⁷ pointed out that the thoracoplasty cause injury to anatomically stable structure of the sternum-rib-spine unit. This procedure will make more stress to spine and induce PJK.

Preoperative sagittal imbalance as radiologic factors has been shown to increase PJK^{16,26,30,33,40,47,51}. Park et al.⁴⁰ reported that degree of preoperative sagittal imbalance influenced the occurrence of PJK. Mauro et al.³³ had investigated spinopelvic parameter and reported that PJK was increased in patients who had higher preoperative thoracic kyphosis, proximal junction angulation, pelvic incidence (PI), and LL. Several authors reasoned that preoperative proximal junctional angle >5° increase the risk of junctional kyphosis and PJF^{5,11,30}.

Older age (>55 years), high body mass index (BMI), and osteoporosis as patient-specific factors for PJK and PJF have been suggested^{2,21,24}. Kim et al.²⁴ explained that degeneration and muscular atrophy by aging expressed more PJK. Low bone density and high BMI are potential risk factors^{2,38,51}. Several studies have reported that osteopenia was common in patients with complications, such as proximal vertebral fracture, subluxation and PJK^{16,20,48}. Yagi et al.⁵⁰ reported that low bone mineral density was a risk factor for PJF (T-score <-1.5; odd ratio, 6.4). Bridwell et al.² reported that BMI was related to the occurrence of PJK.

PREVENTION

The comprehension about patient characteristics is important to reduce PJK and PJF postoperatively. The risk factors should be enough considered for preventing PJK and PJF. There are several strategies to minimize PJK and PJF. Soft tissue protections, choice of a valid level and instrumentation at the UIV, prophylactic rib fixation, vertebral cement augmentation, adequate selection material of rods and age-appropriate spinopelvic alignment goals are worth consideration.

The soft tissue should be carefully dissected. Preservation of the interspinous ligaments, supraspinous ligaments, supra-adjacent facets, and their capsules at the UIV are considered to ease off the risk of PJK and PJF³. In the preparation for surgery, confirming the range of exposure to avoid overexposure and

soft tissue damage could be a method to alleviate the risk of PJK and PJF.

A choice of appropriate UIV requires careful consideration. Neutral and stable vertebra were selected as the UIV for decrease the incidence of revision²⁶⁾. The UIV at T8 or lower increased the PJK and the UIV at proximal level could cause perioperative complications^{2,6,39,42)}. Thoracic hyperkyphosis have been regarded as a risk factor of PJK and PJF^{25,26,30,33,47,49,51)}. Fusion extension to the upper thoracic level in patients with thoracic hyperkyphosis is considered to decrease the risk of PJK and PJF.

Instrumentation has been shown to be related with PJK^{15,25,26)}. Pedicle screws make rigid constructs and have a chance of facet violation¹⁵⁾. To avoid the injury of facet joint, various trials with hooks have been reported. Hassanzadeh et al.¹⁴⁾ reported that PJK did not occur in patients with transverse process hook and pedicle screws.

Hart et al.¹²⁾ reported the prophylactic rib fixation without fusion at the UIV+1. Vertical expandable prosthetic titanium rib (VEPTR) hook inserted at the medial posterior portion of the UIV+1 ribs through two longitudinal incisions. Then the VEPTR hooks are connected by titanium rods.

The vertebral cement augmentation at the UIV or UIV+1 has been proposed to be an effective method to prevent PJK and PJF^{8,13,46)}. Hart et al.¹³⁾ reasoned that prophylactic vertebral cement augmentation cranial to UIV is an effective method. They reported that the patients with vertebral cement augmentation had shown low incidence of PJF. Martin et al.³²⁾ reported that patients with vertebral cement augmentation at UIV and UIV+1 had shown lower incidence of PJF than historical data. In another study, cement augmentation at UIV and UIV+1 reduced proximal junctional fractures and associated revision surgeries⁴⁶⁾. Kebaish et al.¹⁹⁾ reported a cadaveric study that prophylactic vertebral cement augmentation at the UIV and UIV+1 reduced the risk of junctional fractures. However, cement augmentation at only the UIV showed no significant benefit for preventing proximal junctional fractures.

The spinopelvic parameters including SVA, thoracic kyphosis, LL, and PI must be analyzed^{41,49,51)}. Schwab et al.⁴³⁾ introduced the relations between LL and PI that they should be within 9° range ($PI=LL\pm 9^\circ$). Lafage et al.²⁸⁾ have demonstrated that normal range of the spinopelvic alignment in older patients is greater than younger patients. The age of patient has an influence on the decision of spinopelvic alignment goals. The age-appropriate alignment goals may reduce the risk of overcorrection and occurrence of PJK and PJF³⁵⁾.

Several studies have been suggested that fusion of the sacrum can increase the incidence of PJK^{2,24,49)}. L5 as the lowest instrumented vertebra promote the degeneration of the L5-S1 disc and the incidence of revision operation. Thus, we generally perform fusion down to the sacrum for avoiding additional surgery²⁷⁾.

The PJK and PJF could occur more frequently in patients with osteoporosis or osteopenia. Several reports suggested that bisphosphonates inhibit fusion, whereas the teriparatide could be used to reinforce fusion^{36,37)}. Recent studies suggested that the

use of CoCr rod and multiple rod construct can increase rod stiffness, strengthen the stability of the construct of the spinal column, prevent rod breakage and affect the occurrence and the time of PJK. The authors speculated that PJK may occur more frequently in CoCr systems than in Ti systems^{9,10)}. They strongly suggested that precise and personalized selection of rod should be considered and stiff rod such as stainless steel or CoCr is not always the best. The authors concluded that stiff rod may prevent rod fractures or pseudarthrosis but can cause PJK more frequently.

CONCLUSION

The advance of implants, surgical skills and basic knowledge for spinal deformity has permitted long-level spinal instrumentation and fusion. The ability to perform aggressive global realignment of spinal deformities has also led to the discovery of new complications such as PJK and PJF. Although several studies have reported incidence and risk factors for PJK, conclusive factors to lead PJK/PJF and solutions for prevention of the complication remain unsolved. Continuous research on PJK and PJF should be proceeded in order to comprehend the pathophysiology of these complications.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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