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ORIGINAL ARTICLE

Revision surgery in proximal junctional kyphosis

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Abstract

Introduction Proximal junctional kyphosis (PJK) is a relatively common complication following spinal deformity surgery that may require reoperation. Although isolating the incidence is highly variable, in part due to the inconsistency in how PJK is defined, previous studies have reported the incidence to be as high as 39% with revision surgery performed in up to 47% of those with PJK. Despite the discordance in reported incidence, PJK remains a constant challenge that can result in undesirable outcomes following adult spine deformity surgery.

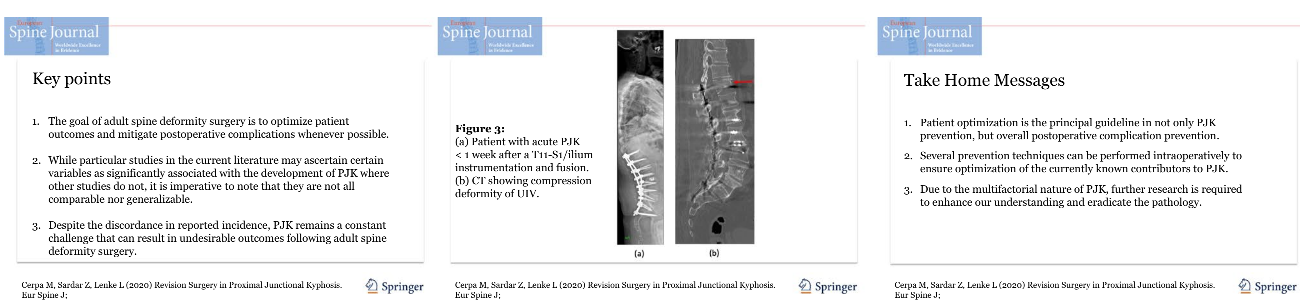
Methods A comprehensive literature review using Medline and PubMed was performed. Keywords included "proximal junctional kyphosis," "postoperative complications," "spine deformity surgery," "instrumentation failure," and "proximal junctional failure" used separately or in conjunction.

Results While the characterization of PJK is variable, a postoperative proximal junction sagittal Cobb angle at least 10°, 15°, or 20° greater than the measurement preoperatively, it is a consistent radiographic phenomenon that is well defined in the literature. While particular studies in the current literature may ascertain certain variables as significantly associated with the development of proximal junctional kyphosis where other studies do not, it is imperative to note that they are not all one in the same. Different patient populations, outcome variables assessed, statistical methodology, surgeon/surgical characteristics, etc. often make these analyses not completely comparable nor generalizable.

Conclusions The goal of adult spine deformity surgery is to optimize patient outcomes and mitigate postoperative complications whenever possible. Due to the multifactorial nature of this complication, further research is required to enhance our understanding and eradicate the pathology. Patient optimization is the principal guideline in not only PJK prevention, but overall postoperative complication prevention.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



Keywords Spine surgery · Spine deformity · Proximal junctional kyphosis · Postoperative complications

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Introduction

In today's aging society, spinal disorders are becoming increasingly prevalent and subsequently garnering a heightened amount of assiduity. While nonoperative management for spinal disorders is available depending on the severity of disease, nonoperative treatment may become exhausted thus requiring operative treatment. Complications following operative treatment adversely affect both patients and surgeons, and preventing complications is imperative. Proximal junctional kyphosis (PJK) is a relatively common complication following spinal deformity surgery that may require reoperation. Although isolating the incidence is highly variable, in part due to the inconsistency in how PJK is defined, previous studies have reported the incidence to be as high as 39% with revision surgery performed in up to 47% of those with PJK [1, 2]. Despite the discordance in reported incidence, PJK remains a constant challenge that can result in undesirable outcomes following adult spine deformity surgery.

Defining the problem

Lee et al. were the first to report PJK as an abnormal kyphosis with a sagittal plane Cobb angle greater than five degrees between T2 and the proximal level of the instrumented fusion in adolescent idiopathic scoliosis [3]. Following this first report, Glattes et al. sought to identify the incidence, risk factors, and patient outcomes associated with PJK in a study of 81 adult deformity patients treated with long posterior instrumentation and fusion [4]. They defined the proximal junction as the caudal endplate of the upper-instrumented vertebra (UIV) to the cephalad endplate two supra-adjacent vertebrae (Fig. 1), while abnormal PJK was defined by the presence of two criteria: (1) a proximal junction sagittal Cobb angle of ≥ 10° and (2) a postoperative proximal junction sagittal Cobb angle at least 10° greater than the measurement preoperatively [4]. They found that 26% (21/81) of patients developed PJK according to this definition, with an average junctional sagittal Cobb measurement of 19.4° (range 11–33°). When comparing the patients with PJK to those without PJK, they found no statistically significant difference in patient outcome scores (SRS-24), including pain and self-image subsets [4].

While the characterization of PJK is variable, a postoperative proximal junction sagittal Cobb angle at least 10°, 15°, or 20° greater than the measurement preoperatively, it is a consistent radiographic phenomenon that is well defined in the literature [1–8]. Regardless of the radiographic criteria, PJK can become pathologic and result in proximal junctional failure (PJF). PJF is present when PJK occurs with at least one of the following: fracture of the vertebral body of UIV or UIV + 1, pullout of instrumentation at the UIV, adjacent vertebral subluxation, neurological deficits related to the PJK, or revision surgery requiring extension of the proximal fusion within the first 6 months of the index procedure [2, 5] (Fig. 2). The distinction between PJK and PJF is important

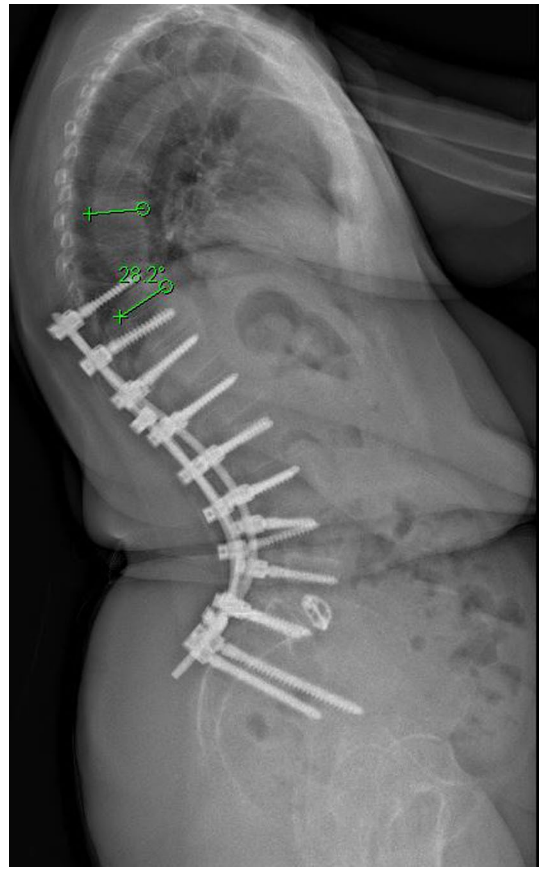

Fig. 1 Proximal junction sagittal Cobb angle measured from caudal end plate of UIV to cranial end plate of UIV + 2

to note when assessing reported incidences and prevalence across studies in the current literature. In a multicenter retrospective study, Hostin et al. reviewed 1218 adult spinal deformity cases and identified an incidence of acute proximal junctional failure (APJF) of 5.6% (68/1218) with a 41% revision rate [5]. While this series had a large population, the heterogeneity of the population may confound the reported incidence and mechanisms of PJF. Furthermore, APJF was considered present if there was ≥ 15° postoperative increase in the proximal sagittal angle, failure of UIV fixation, or revision surgery extending the proximal fusion [5]. Defining PJK as a minimum of a 15° postoperative increase in proximal junctional kyphosis likely underreports the true incidence and makes this study not generalizable to previous reports that cite PJK as a minimum of 10° postoperative increase. This analysis, however, did elucidate that the majority of APJF occurred in the thoracolumbar (TL) region (66%) as opposed to the upper thoracic region [5].

Bridwell et al. were the next to attempt to identify the critical angle of PJK that significantly affects patient-reported outcome scores as well as revision rates [7]. They

Fig. 2 **a** PJK with subluxation of UIV + 1 over UIV. **b** Revision surgery required extension of construct and 3-column osteotomy at PJK site

chose to assess the value of ≥ 20° postoperative increase in PJK in a homogenous population of adult spinal deformity patients based on previous studies that did not show any significant difference in SRS or ODI scores. Ultimately, 27.8% (90/25) of the patients demonstrated a ≥ 20° postoperative increase in PJK and only one patient required revision surgery. However, they did not find 20° to be a critical threshold when comparing the PJK group to the non-PJK group in any of the SRS outcome domains [7]. Interestingly, Yagi et al. found similar results when using 10° as a critical angle but after stratifying PJK into symptomatic versus non-symptomatic groups they were able to identify a significant difference between preoperative and postoperative ODI scores and SRS self-image domains ($p < 0.001$; $p = 0.03$) [9]. In this analysis, Yagi et al. classified PJK based on severity of the Cobb angles: grade A as 10°–14°, grade B as 15°–19°, and grade C as ≥ 20° [9, 10]. The average follow-up in this series was 7.3 years, and they identified a 22% prevalence of PJK [10]. The proximal junctional angle continued to increase at long-term follow-up, which demonstrates the importance of the 10° postoperative increase to identify early PJK.

Fig. 3 **a** Patient with acute PJK < 1 week after a T11-S1/ilium instrumentation and fusion. **b** CT showing compression deformity of UIV

Risk factors and prevention

Choosing an appropriate UIV is imperative; Hostin et al. found that APJF occurred more frequently in the TL region compared with the UT region with a significant difference in the mode of failures; fractures being more common in the TL-APJF group ($p = 0.00$) and soft-tissue failures more common in the UT-APJF group ($p < 0.02$) [5]. Similarly, Smith et al. observed a significant difference in APJF occurring less frequently when the UIV was in the UT spine compared to fusions with a UIV in the lower thoracic (LT) or lumbar spine ($p = 0.035$) and an overall APJF rate of 35% (60/173) [11]. While the most common mode of failure in the APJF LT and lumbar populations was UIV fracture (Fig. 3), a PJK angle of 15° or more was the most common in the UT group, but they were significantly less likely to undergo revision surgery ($p = 0.014$) [11]. In a 2-year follow-up study performed by Kim et al. assessing differences between UIV levels in patients with a lower instrumented vertebra (LIV) of L5 or S1, they found no significant difference between UIV levels of T9-T10, T11-T12, or L1-L2 [12].

Older age has been consistently identified as a significant risk factor for developing PJK in adult idiopathic scoliosis patients postoperatively [1, 2, 4, 5, 10–13]. Multiple reports have identified an age > 55 years as an increased risk factor for developing PJK, while others indicate an age > 60 years as a significant risk factor [1, 7, 12–15]. Osteoporosis and low bone mineral density (BMD) are more likely to occur in older patients, and as such have been a commonly reported risk factor for development of PJK [8, 12, 15]. Yagi et al. found that patients with a preexisting low BMD, including both osteoporosis and osteopenia, were significantly more likely to develop PJK at an increase of 30.9% ($p = 0.04$) compared to people with a normal BMD, although this analysis did not identify age (> 55) as a significant risk factor ($p = 0.33$) [9]. Likewise, Kim et al. identified osteoporosis ($p = 0.016$) and > 60 years (0.02) as significant risk factors in the PJK group compared to the non-PJK group [11]. Another analysis from the same institution examined the characteristics of patients that required revision surgery for PJK and identified that the mean age (60.1 years) and mean number of levels fused (14.1 levels) were significantly higher in the PJK group that had revision surgery ($p = 0.03$; $p = 0.02$), as well as a 75% prevalence of degenerative scoliosis in the PJK group requiring surgery [14]. Other multivariate analyses failed to identify increased patient age or BMD as a significant independent risk factor in PJK development, suggesting that PJK is multifactorial and varies on an individual basis [15–17]. A biomechanical study performed by Kebaish et al. [18] showed that cement augmentation of UIV and UIV + 1 significantly reduced the incidence of junctional vertebral body fractures in a posterior instrumentation construct from T10 to L5. They also reported on clinical results of this technique in 38 patients with a T-score of < − 1 [19]. At 6 months follow-up, they noted an 8% incidence of PJK and 5% incidence of PJF in this cohort. However, at 5 years follow-up the same group reported a PJK rate of 28.2% suggesting no clear benefit of cement augmentation with long-term follow-up [20]. While these particular factors become tricky when mitigating the onset of postoperative PJK, it is advisable to have patients start osteoporosis treatment prior to undergoing a spinal instrumentation and fusion, and perform proper preoperative counseling to inform patients of the risk of developing PJK.

Surgical characteristics have also been recognized to increase the likelihood of PJK progression following surgical intervention. For example, Kim et al. sought to identify the relative risks in multivariate analyses for PJK development in idiopathic scoliosis and found that compared to posterior- or anterior-only surgery combined anterior and posterior surgery was the most important risk factor (OR = 3.13; 95% CI = 1.08, 9.05) and the only other significant factor was a UIV of T1-T3 UIV (OR = 2.34; 95% CI = 1.07, 5.12) [15]. Interestingly, BMD, age, and fusion to the sacrum were not independent risk factors in this multivariate analysis [15]. In contrast, Yagi et al. demonstrated that a posterior instrumentation and fusion was a significant risk factor for PJK compared to anterior instrumentation and fusions, with a 27% increase in PJK in the posterior group ($p < 0.001$) [8]. However, this analysis only had a total of four anterior-only fusions in the study population where only one of these patients was in the PJK group, and therefore most likely lacks a sufficient sample size to definitively affirm that posterior-only fusions are a significant risk factor for PJK. In addition, long spinal instrumented fusions to the sacrum have been suggested as an increased risk factor for PJK although other studies maintain that there is no association [13, 15, 17]. Disruption of interspinous and supraspinous ligaments at the cranial end of the construct are thought to contribute to the development of PJK. Finite element analyses have shown increased pressure in the nucleus by > 50% and increased angular displacement of 19–26% with disruption of these ligaments [21]. However, the current literature lacks sufficient clinical data to definitively suggest ligamentous disruption as a risk factor for PJK.

Perhaps the most important risk factor when analyzing the development of PJK is the global spinal alignment. Multiple studies have touched on how the sagittal plane dictates the necessary amount of sagittal correction required for each individual patient and how that relates to PJK. Yagi et al. found that an SVA change of greater than 50 mm was associated with a significantly increased rate of PJK, while Liu et al. published a preoperative TK > 40° as a risk factor for the development of PJK in a comprehensive meta-analysis [9, 22]. Similar to Yagi et al., Smith et al. identified that a postoperative SVA of less than 50 mm was significantly associated with the occurrence of APJF ($p = 0.009$) [13]. Maruo et al. identified preoperative proximal junctional angle more than 10°, preoperative thoracic kyphosis > 30°, > 30° change in lumbar lordosis, and a pelvic incidence > 55° as significant predictive factors for the onset of postoperative PJK [16]. One study describes an "ideal" spinal alignment as an SVA < 50 mm, pelvic tilt < 20°, and pelvic incidence-LL (PI-LL) < ±10° even though Kim et al. described that overcorrection, even within these parameters, can also lead to PJK, especially in older patients [14, 16]. These are all important concepts that highlight the necessity of achieving appropriate alignment parameters that are specific to what is necessary for each individual patient and can explain why there are multiple studies that contradict one another in regard to which variables are considered significant predictors of PJK.

A recent popular concept that has gained a lot of attention is the postoperative Global Alignment and Proportion (GAP) Score that predicts the likelihood of mechanical complications, including PJK [23]. GAP score parameters include relative lumbar lordosis (measured LL minus the ideal LL), relative pelvic version (measured sacral slope [SS] minus the ideal SS), relative spinopelvic alignment (measured global tilt [GT] minus the ideal GT), lordosis distribution index (L4-S1 lordosis divided by the L1-S1 lordosis multiplied by 100), and an age factor [23]. They explain how alignment characteristics can be broken down into proportionate, moderately disproportionate, and severely disproportionate. These corresponding alignment categories demonstrated mechanical complication rates of 6% in patients with proportionate alignment, versus 47% in patients with moderate disproportion, and 95% in patients with severe disproportionate alignment [23]. However, external validation of the GAP score has not consistently demonstrated a significant association between the proportional alignment categories and development of mechanical failure [24]. Additionally, this is a retrospective analysis that is performed postoperatively; therefore, there is not a reliable way to apply this principle preoperatively, and its ability to prevent PJK along with other mechanical complications remains undetermined.

At our institution, the prevention of PJK starts with the preoperative optimization of patients. We routinely assess the patient's nutritional status and bone mineral density. Patients with significant osteopenia or osteoporosis requiring instrumentation and fusion are referred to endocrinology for bone density optimization prior to surgery. The selection of fusion levels is based on the location of the structural curves, presence of a structural fractional lumbosacral curve, the condition of the L5-S1 disk and facets, the presence of thoracolumbar or thoracic kyphosis, and overall global sagittal and coronal alignment. Several steps are performed intraoperatively to ensure optimization of the currently known contributors to PJK. These steps include:

1. Careful dissection at the proximal end of the construct. We do not disrupt the interspinous ligaments between UIV and UIV − 1. We perform a meticulous muscle dissection at the UIV to avoid disruption of the facet joint between UIV and UIV + 1. We often utilize a hybrid open muscle sparing approach to insert the pedicle screws at UIV, especially when the UIV is in the lower thoracic spine or the upper lumbar spine. This "Wiltse" muscle splitting approach between the multifidus and longissimus muscles allows for retention of all midline ligamentous and muscle attachments.
2. We carefully assess the patient's alignment preoperatively to set appropriate alignment goals which we strive to achieve intraoperatively. Ideally, we want to achieve a global sagittal alignment where the cranial vertical axis (CrSVA) falls bisecting the hip joints (CrSVA-H) to provide optimal global sagittal alignment (Fig. 4).
3. In older patients, we devote extra attention to the amount of correction required so as to avoid overcorrection in this patient population. For patients with a sagittal

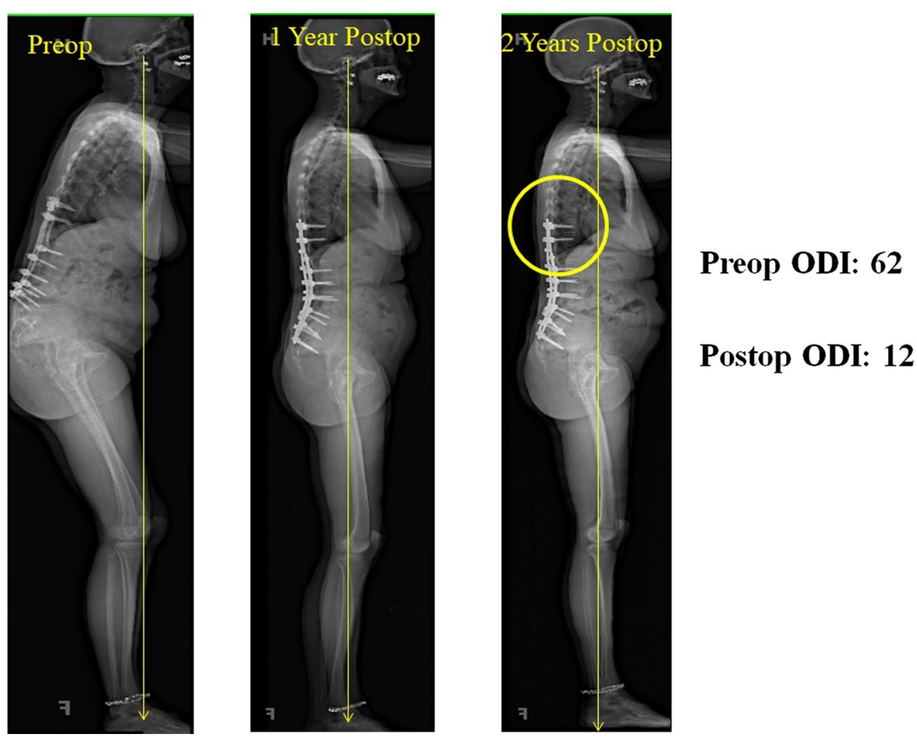

Fig. 4 Preop and postop images of a patient showing ideal Cranial Sagittal Vertical Axis bisecting the Hips (CrSVA-H axis) without PJK at 2 years postop

plane deformity, we aim for a lumbar lordosis closer to PI-10 in order to avoid creating hyperlordosis of the lumbar spine. Additionally, after the rods are in place, our practice is to perform full-length imaging in the AP and lateral planes to determine whether proper global alignment has been achieved. Based on the intraoperative images, we may adjust the deformity correction when needed. For adult patients undergoing surgery for scoliosis but with a preserved long-standing preoperative sagittal balance, our aim is to mimic the SVA and lumbar lordosis they had preoperatively to maintain appropriate patient-specific alignment.

4. Transition rods are used to transition from a 6.0 diameter to a 5.5 diameter at the cranially instrumented levels in order to create a "soft landing."
5. The use of reduction screws, or other reduction tools and techniques, is avoided at the cranially instrumented levels to avoid increased stress at the proximal end of the construct.
6. The most cranial part of the rod is contoured into a gentle kyphosis to allow for a smoother transition from the instrumented spine to the uninstrumented spine. Postoperatively, to avoid increased junctional stress that occurs with constructs extending to the proximal thoracic region due to the weight of the skull, we strive to have a vertical line extending along the most distal aspect of the skull fall to be touching or ideally, posterior to the most cephalad implants (Figure 5).

While the use of bracing to prevent PJK has not been studied, we do use cervical semi-rigid collars in our patients for 3 months postoperatively if the UIV is located in the upper thoracic spine. We believe that following this systematic approach helps lower the risk of PJK development. However, due to the multifactorial nature of this complication, further research is required to enhance our understanding and eradicate the pathology.

Revision surgery for PJK: strategies and technical considerations

Revision surgery is not required for every patient that presents with PJK, and often can be monitored for severity progression and managed nonoperatively. Surgery for PJK is typically discussed if there is severe deformity, progressive deformity, ongoing or severe pain, or risk to the neural elements. Delaying treatment in the presence of neurologic deficits or subluxation at the proximal levels can lead to catastrophic outcomes; therefore, urgent surgical treatment in these cases is

Fig. 5 Development of PJK in a patient with posterior skull line anterior to the proximal instrumentation. Image on the right shows revision surgery with instrumentation extension and posterior skull line posterior to proximal instrumentation

warranted. However, the timing of intervention is not well defined in the literature. In our practice, our preference is to perform an emergent surgical revision if there is subluxation between UIV and UIV − 1 and/or if there is presence of neurologic deficits. In most other non-urgent cases when PJK is first identified, a discussion with the patient is warranted. Once the nature and epidemiology of PJK are explained, the clinical presentation should be evaluated. If PJK is significantly adversely affecting the patient's quality of life (i.e., causing pain, discomfort, radiculopathy), surgical options can be considered and discussed.

Selection of levels when preparing for revision surgery in case of PJK is based on multiple factors. The UIV is chosen to be at least 2 or 3 levels proximal to the level of junctional kyphosis. However, often a longer proximal extension of the construct may be required. In general, we avoid having a UIV close to the apex on the main thoracic or proximal thoracic kyphosis. We prefer to include areas of increased kyphosis in the revision fusion construct. We also choose our UIV such that the new preoperative junctional angle is either neutral or lordotic.

The amount of correction required during a revision surgery for PJK is also determined on a case-by-case basis. The need for osteotomies, and which type of osteotomies, is determined based on the patient's current alignment, the alignment goals, and the rigidity of the spine where the correction needs to be performed. In patients with PJK due to overcorrection or hyperlordosis, we attempt to decrease the lumbar lordosis by performing posterior column osteotomies, when possible, and performing distraction across those sites to reduce the lordosis and achieve a more balanced spine. If there is circumferential fusion, then a 3-column osteotomy is needed to decrease the lordosis. Similarly, patients that lack adequate lordosis may need posterior column or 3-column osteotomies to improve the lordosis.

If a patient is treated acutely with surgery after development of PJK, simple posterior column osteotomies at the site of PJK may suffice to achieve adequate correction. However, in rigid PJK or in patients with neurological compromise, a 3-column osteotomy may be needed to correct the deformity and to achieve adequate decompression of the neural elements.

Realignment goals in revision surgery for PJK are similar to the goals for primary surgery in adult spinal deformity patients. Every effort is made to identify the etiology that may have led to development of PJK in order to optimize those factors during the revision procedure.

Conclusions

The goal of adult spine deformity surgery is to optimize patient outcomes and mitigate postoperative complications whenever possible. While particular studies in the current literature may ascertain certain variables as significantly associated with the development of proximal junctional kyphosis where other studies do not, it is imperative to note that they are not all one in the same. Different patient populations, outcome variables assessed, statistical methodology, surgeon/surgical characteristics, etc. often make these analyses not completely comparable nor generalizable. Patient optimization is the principal guideline in not only PJK prevention, but overall postoperative complication prevention.

Compliance with ethical standards

Conflict of interest LGL has received royalties, travel/meeting accommodations, and consultancy fees from Medtronic.

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