Proximal Junctional Kyphosis and Failure: Strategies for Prevention

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KEYWORDS

• Adult spinal deformity • Proximal junctional kyphosis • Prevention • Kyphoplasty • Vertebroplasty • Tethers • Ligamentoplasty

KEY POINTS

- Proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) are common complications following long-segment posterior instrumented fusions for adult spinal deformity (ASD).
- Failures at the thoracolumbar junction are generally secondary to fractures, whereas those in the upper thoracic spine are typically caused by ligamentous failure.
- Ligamentous banding and use of transition rods may present cost-effective options that have potential to reduce PJF secondary to ligamentous failure.
- Two-level cement augmentation of the upper instrumented vertebra (UIV) and supra-adjacent vertebra to the UIV (UIV+1) may also benefit patients by reducing the incidence of PJF.
- Regional implant-focused strategies combined with careful planning and correction of the sagittal profile are important for minimizing the development of PJK and PJF and ensuring financial viability of ASD surgery.

INTRODUCTION

Balanced and patient-specific harmonious spinal alignment is important for upright posture maintenance, biomechanical stability, and to decrease energy used to stand and ambulate.[1,2] Deviations in alignment can be secondary to idiopathic, congenital neuromuscular, degenerative changes, and iatrogenic causes, which may manifest as sagittal malalignment, scoliosis, kyphosis, rotatory subluxation, and spondylolisthesis.[1,3] Such pathologies are categorized under the umbrella term, "Adult Spinal Deformity" (ASD).[3,4] These deformities are common and current prevalence data likely underestimate the true burden of disease due to mixed diagnoses and multiple subclassifications.[5] The prevalence of adult scoliosis has been estimated to be as high as 68% in elderly individuals.[6–10] As the global population ages, it is likely that the incidence of ASD will continue to increase, as will the economic burden associated with its surgical and nonsurgical management.

In an evolving value driven health care economy, there is increasing focus on defining the benefits of complex spine surgery.[11] Clinical outcome assessment via health-related quality of life (HRQOL) outcome scores is critical in defining the value and role for surgery in treating ASD. These outcome measures should incorporate measures of overall quality of life, functional measurements, pain levels, and disability.[12] Given the high prevalence and severity of complications following operations for

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Neurosurg Clin N Am 34 (2023) 573–584
https://doi.org/10.1016/j.nec.2023.06.004

ASD (ie, >70%), quantifying the benefits of surgery in this patient population is important in justifying its value proposition.[13] Importantly, multiple investigations have demonstrated the utility of operative intervention for ASD. Specifically, in a study of 427 ASD patients with 4-year mean follow-up, patients reported significant improvements in terms of pain, activity, appearance, mental status and SF-36.[14] In addition to improved patient-reported outcomes, the benefits of surgery are tangible in terms of increased productivity and decreased absenteeism from school and work, as demonstrated in a cohort of 1188 patients who underwent operative intervention to address ASD.[15] Even in patients who undergo the most complex ASD surgeries, including three column osteotomies, clinically relevant improvement in Scoliosis Research Society-22r (SRS-22r) HRQOL scores are achievable.[11] High postoperative satisfaction is reported in patients undergoing ASD surgery regardless of the approach used.[16]

Despite good outcomes, high satisfaction, and increased productivity after ASD surgery, complications can jeopardize outcomes and negatively affect quality of life. Included in these complications are surgical complications of which proximal junctional kyphosis (PJK) and proximal junctional failure (PJF) often require revision procedures. As PJK and PJF can be devastating complications for patients and vexing problems for surgeons, the authors present a detailed outline of PJK and PJF with a focus on surgical strategies aimed at preventing their occurrence.

DEFINITION, PREVALENCE, AND CLASSIFICATION OF PROXIMAL JUNCTIONAL KYPHOSIS AND PROXIMAL JUNCTIONAL FAILURE

PJK is defined by a postoperative proximal junction sagittal cobb angle $\geq$ 10° between the lower end plate of the upper instrumented vertebra (UIV) and the upper end plate of the two supra-adjacent vertebrae (UIV+2).[17] The prevalence of PJK following posterior fusion for ASD has been reported to range between 17% and 46%, with two-thirds of cases occurring within the 3-month postoperative period.[18–20] Many patients with PJK do not require revisions and may have equivalent functional outcomes when compared with those without PJK.[17,21–23] However, the progression of PJK to failure that necessitates revision is termed PJF and is clinically important (**Fig. 1**), as it can result in catastrophic neural compromise, severe disability, and challenging and costly revision operations.[24] Hostin and colleagues and the International Spine Study Group specifically defined PJF as occurring due to $\geq$ 15° postoperative increase in PJK, vertebral fracture of UIV or UIV+1, failure of UIV fixation, new onset of myelopathy, and/or other causes that require revision surgery (see **Fig. 1**; **Fig. 2**).[25] Revision operations for PJF typically consist of proximal extension of instrumented fusion with or without neural decompression and deformity correction via osteotomies, as they are commonly indicated for clinical symptoms of pain, spinal instability, neurologic deficits, significant kyphosis, ambulatory difficulties, and/or inability to maintain a horizontal gaze.[21,23,26–28]

The occurrence of PJK and PJF following surgery varies in time. In a cohort of 150 patients, Wang and colleagues reported that 80% of PJK cases are diagnosed within 18 months postoperatively, whereas Yagi and colleagues found that 66% of PJK cases were present at the 3-month mark in a study of 76 patients with 5-year follow-up.[23,29] In a series of 1218 posterior segmental instrumented fusions for ASD, Hostin and colleagues noted 5.6% of patients had PJF, with a mean time to failure occurring at 11.4 weeks.[25] The study reported that fractures were significantly more common for thoracolumbar PJF, whereas whole soft-tissue failures were more common in constructs that terminated in the upper thoracic spine.[25] Risk factors associated with PJF included older age, fewer fusion levels, worse postoperative sagittal vertical axis, fusion to the sacrum, and posterior spine fusion.[25] Even in cases where clinically irrelevant PJK is present at the 3-month mark, PJK may continuously progress and result in more extensive kyphosis within the 5-year postoperative period.[23]

Two categories of PJK/PJF include ligamentous failure and osseous fracture (see **Figs. 1** and **2**; Figs. **3** and **4**).[23] Ligamentous failure comprises greater than 70% of PJK cases and is hypothesized to occur due to surgical interventions that alter the integrity of the posterior supraspinous and interspinous ligaments, spinous process, and paraspinal musculature (see **Fig. 4**).[23] The insufficiency of the posterior ligamentous complex secondary to surgery may not be reversible.[23] Alternatively, PJK/PJF due to fractures present a differing presentation, of which there are two modalities (see **Figs. 1**, **3**, and **4**).[23] One type is where the supra-adjacent vertebrae above the UIV (UIV+1) undergoes a compression fracture with kyphosis (see **Figs. 1** and **3**), whereas the second is UIV collapse and subluxation of UIV+1 (see **Fig. 4**). Although the former may not be symptomatic, the latter is often clinically significant and produces myelopathy that necessitates a revision.

Fig. 1. A 73-year-old woman with osteoporosis underwent a T10 to pelvis posterior instrumented fusion (PSIF) with L4–S1 transforaminal lumbar interbody fusions (TLIF). Two years after operation, she reported worsening mid-thoracic back pain, progressively more difficulty standing upright, and subjective weakness of the lower extremities. Radiographs and CT scan demonstrated proximal junctional kyphosis (PJK) and a compression fracture at T10 (*A*, *B*). Note the risk for developing PJK and PJF was the undercorrection of her lumbar lordosis resulting in persistent lumbopelvic mismatch (*A*). No preventative strategies were used at the proximal junction. After undergoing an L3–S1 anterior lumbar interbody fusion (ALIF) and revision of T4 to pelvis PSIF, her back pain and posture were greatly improved (*C*).

COSTS OF PROXIMAL JUNCTIONAL KYPHOSIS AND PROXIMAL JUNCTIONAL FAILURE

The high costs associated with revision surgeries for PJF may undermine the ultimate utility of ASD surgery. The average direct costs associated with readmissions for PJF are among the largest and only second to pseudoarthrosis.[30] In a study of deformity patients, Yeramaneni and colleagues reported the average direct costs associated with readmission for PJF to be $55,516 while the average direct costs for revisions for any other cause to be $38,754.[30] Although available literature indicates direct costs associated with PJF revision operations to range from $20,000 to $120,000, estimations are likely underapproximations due to the lack of accounting for indirect costs. As for reasons PJF accounts for high expenditures, Theologis and colleagues noted that PJF revisions are of high complexity and require intensive postoperative care.[31,32] In the study, patients required the following average metrics: 6.3 posterior levels of instrumented fusion, blood loss of 1.2 L, operative time of 5.3 hours, and length of stay of 7.2 days.[32] Although surgical intervention for ASD may confer quality of life improvement for patients, overall utility depends on the associated costs and potential for revision surgery. As PJF presents a highly prevalent occurrence after posterior thoracolumbar instrumented spinal fusions with costs that are unsustainable for health care systems, preventative strategies to minimize the occurrence of PJF are of tremendous importance.

TECHNIQUES FOR PREVENTION OF LIGAMENTOUS FAILURE

Ligamentous failures afflict long posterior instrumented fusions that end cranially at the thoracolumbar junction and at the upper thoracic spine,

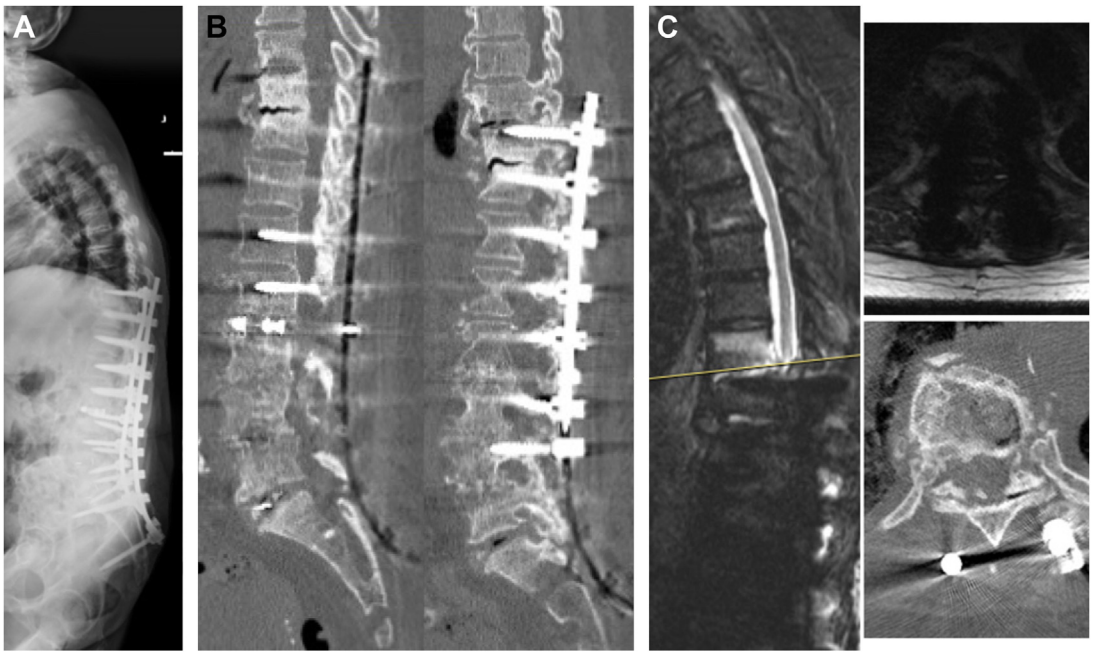

Fig. 2. A 79-year-old woman with osteoporosis presented with worsening back pain, gait instability, and lower extremity weakness after multiple prior spine operations, the last of which included a T10 to pelvis posterior instrumented fusion (PSIF) (*A*). Radiographs and CT scan demonstrated advanced disc degeneration and collapse at the proximal junction associated with loosening of the upper instrumented vertebral level's screws (*B*). An MRI also demonstrated high-grade spinal cord compression at this proximal junction (*C*). Note the risk for developing PJK and PJF was the undercorrection of her lumbar lordosis resulting in persistent lumbopelvic mismatch (*A*). No preventative strategies were used at the proximal junction.

although the latter constitutes a larger percentage. Techniques aimed at preventing ligamentous failure include implant focused solutions that dampen proximal forces. Such techniques use an approach known as "topping-off," implementing semi-rigid fixation at the proximal end of a rigid construct and thereby mitigating focal peak stresses at junctional levels.[33] Techniques to be discussed include the following: transverse process hooks (TPHs), ligamentous banding, multilevel stabilization screws (MLSSs), and flexible transition rods.

Transverse Process Hooks

TPHs may be used for constructs terminating in the upper thoracic spine, especially because failure at such levels is commonly due to ligamentous fatigue (Fig. 5). The benefits of hook fixation stem from the fact that it requires less dissection of surrounding muscle and facet and does not require subperiosteal exposure.[34] Although the use of TPHs at the proximal end of constructs has been suggested, their demonstrated clinical utility in reducing PJK/PJF risk in adults is limited. Although Kim and colleagues found no significant difference in incidences of PJK in ASD patients undergoing posterior spinal fusion using TPHs, pedicle screws, or hybrid constructs, the TPH group did have lower average proximal level kyphosis.[35,36] In terms of PJF incidence, Line and colleagues and Matsumura and colleagues also found no significant reduction with the use of TPH.[37,38] Only one study by Hassanzadeh and colleagues with 47 ASD patients found that PJK/PJF rates were lower when compared with a pedicle screw control group, though the TPH group had a shorter mean follow-up time compared with the pedicle screw group (2.8 vs 5.7 years).[39] Although TPH has shown clinical benefit in adolescents with scoliosis, limited evidence exists for adult deformity patients.[35,36,40]

Ligamentous Banding

Ligamentous banding at the UIV-1, UIV, and/or UIV+1 may provide a cornerstone method of reducing PJK rates that is superior to TPH. Implantation involves drill holes in the center of the spinous processes and weaving of a cable composed of allograft tendon or Mersilene tape through the holes in a variety of configurations. The cable is placed under tension so that the spinous processes are loaded into slight extension

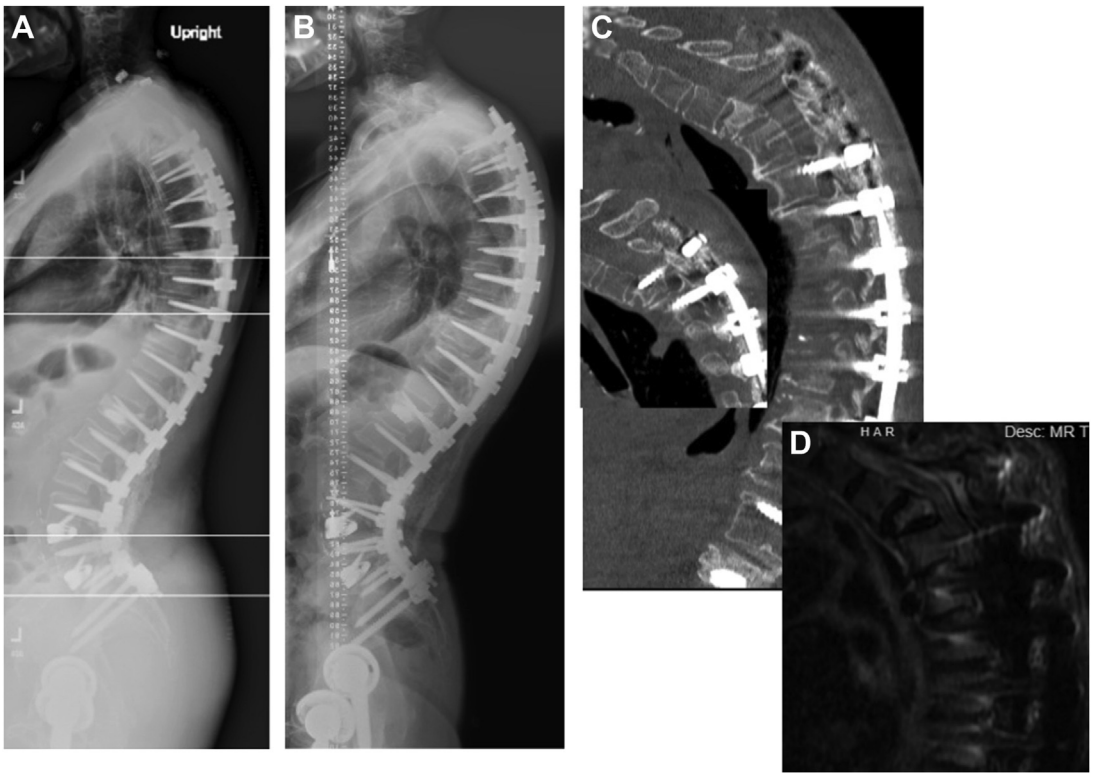

Fig. 3. A 68-year-old woman with osteoporosis with a degenerative lumbar scoliosis and adult Scheuermann's kyphosis underwent an L4–S1 ALIF and T3 to pelvis PSIF (*A*). Within 3 months of the index operation, she reported progressive difficulty maintaining horizontal gaze and decompensation of her neck posture. Radiographs and CT scan demonstrated PJK secondary to a UIV compression fracture and translation of the UIV+1 on the UIV (*B*, *C*) despite having ligament banding with mersilene tape at the UIV+1, UIV, and UIV-1. Although there was ventral spinal cord compression at the level of the UIV, she was neurologically intact (*D*).

and resist flexion at the UIV.[34] Each configuration (see **Fig. 5**) is associated with its own respective efficacy in preventing PJK/PJF.

Tether Connector Configuration

The tether connector configuration (see **Fig. 5**) was studied by Alluri and colleagues and Safaee and colleagues, who both found PJF to be significantly less common in tether connector groups than in patients with no posterior ligamentous augmentation.[41,42] Of note, the former study used a semitendinosus allograft,[41] whereas the latter used polyethylene tape.[42] No studies have compared whether one material is better than the other but the semitendinosus allograft may be a more cost-effective option. The tether connector configuration presents moderate efficacy in preventing progression of PKJ to failure.

Tether-Only and Tether-Crosslink

The tether-only (see **Fig. 5**) and tether-crosslink (see **Fig. 5**) configurations show less promise than the tether connector configuration. The tether-only configuration involves hand-tightening the band through the spinous processes of UIV+1 and UIV-1, whereas the tether-crosslink configuration involves the tape threaded through the spinous process of UIV-1 and tensioned by a cross-link between UIV-1 and UIV-2. No difference in PJF incidences was found by Buell and colleagues and Line and colleagues for either configuration when compared with pedicle screws without these ligamentous augmentation techniques.[37,43]

Tether-Pedicle Loop Configuration

The tether-pedicle loop configuration involves threading the band through the spinous process of UIV+1 and then tensioned and looped underneath the UIV pedicle screws, with the same process applied to the UIV and UIV-1 (see **Fig. 5**). There is limited scientific evidence to support this technique, as only one retrospective series has investigated this tether-pedicle loop configuration.[44] In this study of 108 patients, Iyer and

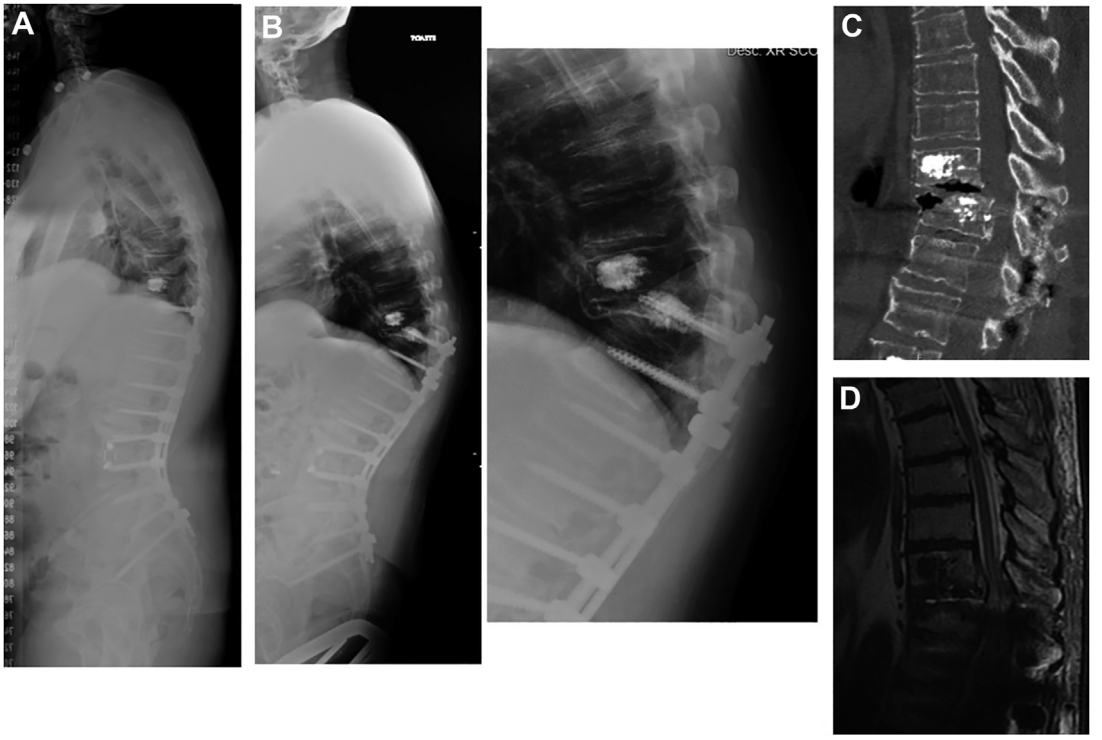

Fig. 4. A 56-year-old man underwent a T10 to pelvis posterior instrumented fusion including two-level cement augmentation of the UIV+1 and UIV (*A*). Six weeks postoperatively, he presented with progressive motor weakness of the lower extremities following a fall at home. Radiographs demonstrated an unstable three-column fracture with bilateral perched facets between the UIV and UIV+1 secondary to a ligamentous failure at the UIV and UIV+1 (*B*). A CT scan demonstrated a fracture of the anterior-superior endplate of the UIV and partial reducibility of the fracture-dislocation (*C*). At the proximal junction, MRI demonstrated severe central stenosis with cord signal change from a thoracic disc herniation and a dorsal epidural hematoma (*D*).

colleagues found no impact on PJK/PJF rates in patients with or without banding after controlling for sagittal correction.[44]

Figure-of-8 Tether

The figure-of 8 tether configuration consists of passing the band through the spinous process of UIV+1 and looping the band in a figure-of-8 pattern around the spinous process of UIV (see **Fig. 5**). In a study of 80 patients, Rodriguez-Fontan and colleagues found mersilene tape in the figure-of-8 configuration significantly decreased the risk of PJK following posterior instrumented fusions for ASD when matched to patients with this augmentation technique for sagittal cobb angle, lumbar lordosis, pelvic tilt, sacral slope, and pelvic incidence.[45]

Multilevel Stabilization Screws

MLSSs present a promising approach for reducing PJK and PJF incidence (see **Fig. 5**). In a cohort analysis, Kaufmann and colleagues demonstrated a significant independent association between MLSS and PJF rates, with an odds ratio of 0.11 when compared with patients with no MLSS.[46] In a separate case series of 15 patients, Sandquist and colleagues confirmed the possible clinical utility of LSS, finding that no patients with MLSS developed PJK/PJF.[47]

Flexible Transition Rods

Flexible transition rods over the UIV have shown promise in biomechanical studies but remain to be evaluated clinically (see **Fig. 5**). In a finite-element analysis, Cahill and colleagues found that the use of titanium transition rods may reduce disc nucleus pressure by 23% and angular displacement by 18% to 19% at the UIV.[48] Although Lee and colleagues found that the use of flexible titanium rods allowed 15° flexion and 10° extension at the proximal junction and produced a significantly lower PJK incidence when compared with pedicle screws (15% vs 38%), the follow-up duration of the pedicle screw group was longer.[49] The rod material favored in the

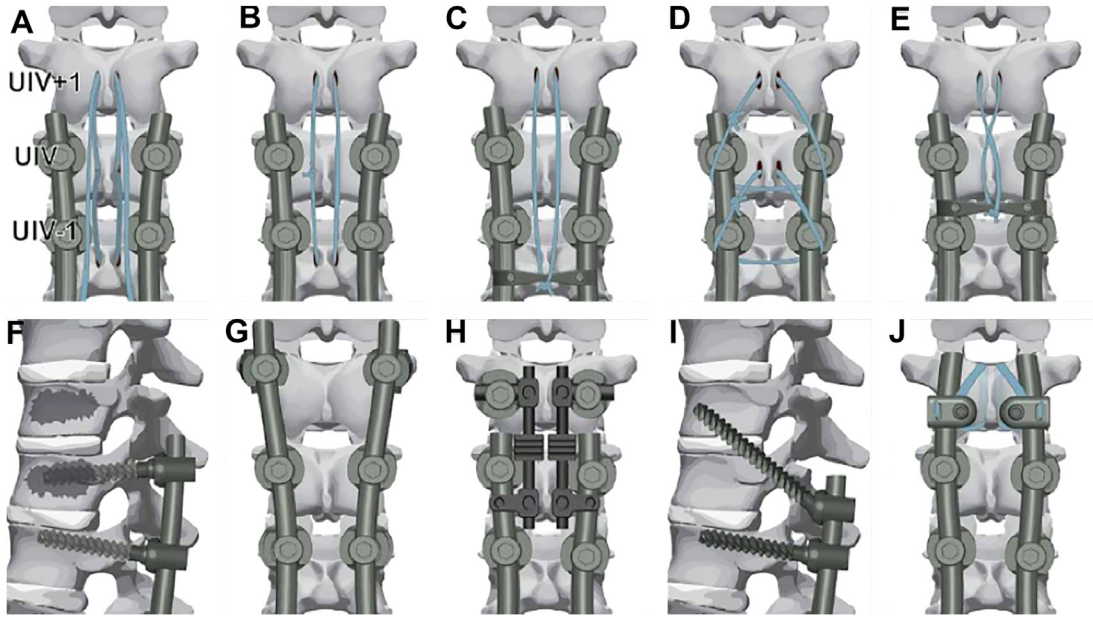

Fig. 5. Surgical prophylactic techniques for proximal junctional kyphosis and proximal junctional failure (*A*) tether-connectors, (*B*) tether-only, (*C*) tether-crosslink, (*D*) tether-pedicle loop, (*E*) tether in a figure-8 configuration, (*F*) prophylactic two-level vertebroplasty, (*G*) transverse process hooks, (*H*) flexible rods, (*I*) multilevel stabilization screw (MLSS) 44, and (*J*) sublaminar tapes. Adapted with permission from Vercoulen and colleagues.[33]

literature is titanium, with Han and colleagues reporting that PJK occurred much later for patients with titanium rods compared with cobalt rods (mean of 26.3 months postop vs 3.6 months postop, respectively).[50] However, the same study found that titanium transition rods had a significantly higher rate of rod fracture compared with cobalt-chrome rods (32.4% vs 0%).[50]

TECHNIQUES FOR PREVENTION OF FRACTURES

PJFs due to fractures most commonly occur at the thoracolumbar junction but may also occur in constructs that extend to the upper thoracic spine (see **Figs. 1**, **3** and **4**). The primary method for prevention of fractures is cement augmentation (**Fig. 6**).

Cement Augmentation

Cement augmentation may be performed when the UIV is at any thoracic and lumbar spinal level (see **Fig. 6**). There are numerous ways by which cement augmentation can be accomplished in regard to exposure technique, cement delivery method, and number of levels augmented.[34] For example, cement augmentation may be performed via an open exposure, through an all percutaneous method, or through a hybrid open and percutaneous method. In addition, there can be variation in cement deliver, including performing a vertebroplasty or a kyphoplasty, or both if two levels are involved.

Regarding level selection for cement augmentation, prior *in* vitro and clinical studies have demonstrated that cement augmentation of both the UIV and UIV+1 provides a stronger construct more apt at the prevention of fractures than no cement or only one-level cement augmentation of the UIV or UIV+1 (see **Fig. 6**). In a biomechanical study, Kebaish and colleagues found that 67% of specimens treated with one-level vertebroplasty and 100% of specimens without cement augmentation had a PJF, whereas only one of six cadavers with two-level cement augmentation (UIV and UIV+1) sustained a PJF.[51] Certain studies have found significant reduction in PJK/PJF rates when two-level cement is applied, whereas others have found that the two-level cement plays a role in delaying progression to PJK/PJF.[50,52–54] For example, in a retrospective study with minimum 6-month follow-up, Theologis and colleagues demonstrated that two-level cement augmentation resulted in significantly fewer revision operations for PJF compared with patients with no augmentation or augmentation at only one level.[54] In a separate prospective study of 39 ASD surgical patients with two-level cement, Raman and colleagues determined that cement augmentation minimized

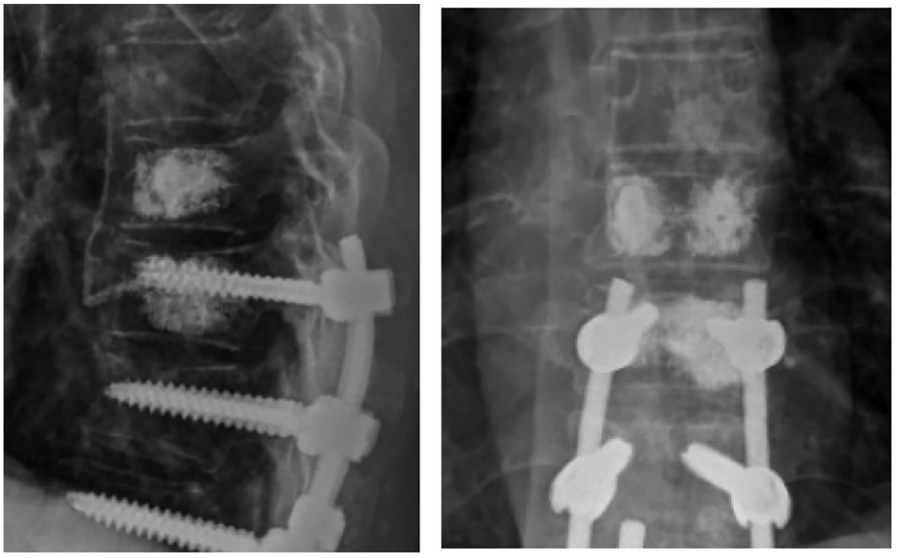

Fig. 6. Example of prophylactic two-level cement augmentation at the UIV and UIV+1 for prevention of proximal junctional fracture.

risk of PJF in the early postoperative period but had no decrease in incidence at 5-years.[55] Most patients in the study who developed PJK did so at 2 to 5 years, a follow-up duration that few other studies adhere toward. Hence, although PJF and PJF are typically early findings, two-level cement augmentation may delay the time course of the condition. Although rates reported in the literature for PJF in patients with cement augmentation are likely underestimated due to follow-up less than 2 years, patients may still functionally benefit from cement augmentation, with Martin and colleagues and Theologis and colleagues noting that patients receiving two-level cement augmentation had less disability, as assessed by the Oswestry Disability Index.[54,56]

Cement augmentation may also be cost-effective when compared with costs of revision operations for PJF. In a study of 28 ASD patients, Hart and colleagues noted that none of the 15 patients with two-level cement augmentation at the UIV and UIV+1 incurred PJF, whereas PJF occurred in the remaining 2/13 patients with constructs extending to the thoracolumbar junction.[24] The study determined that the cost of revision instrumented fusion (average $77,432) outweighed the costs of prophylactic two-level cement augmentation (average of $47,240).[24]

Potential negative effects of cement augmentation include cement embolization to the lungs, cement leakage to the adjacent surround tissues, including the spinal canal, acceleration of degenerative disc disease at the UIV, UIV+1, and UIV+2, and increased adjacent vertebral level fracture risk, which all may lead to future disability and costs.[24,57,58]

THE IMPORTANCE OF ALIGNMENT IN PREVENTING PROXIMAL JUNCTIONAL KYPHOSIS/PROXIMAL JUNCTIONAL FAILURE

Although the aforementioned text has focused on focal surgical strategies aimed at preventing PJK/PJF by augmenting the anterior column with cement and/or reinforcing the posterior ligamentous structures at the proximal junction of long thoracolumbar constructs, it is also important to take into consideration spinal alignment as a tool for minimizing the occurrence of PJK/PJF. Striking a balance between ideal correction of spinal alignment and avoiding overcorrection and under correction of the sagittal plane is important in preventing PJK/PJF (see **Figs. 1** and **2**; **Fig. 7**).[59–61] Although the "ideal" sagittal alignment parameters remain debatable and under continued investigation, the degree of sagittal plane correction is also important, as alignment measurements even within ideal postoperative ranges have been implicated with increased rates of PJK/PJF in older patients. In a retrospective review, Mauro and colleagues reported that changes in lumbar lordosis greater than 30° and thoracic kyphosis greater than 30° were significant risk factors for PJK.[59] On a similar note, Kim and colleagues determined that patients with PJF requiring revisions were older and had larger sagittal balance corrections in a case-control study of 206 ASD.[62] Specifically, older patients with "ideal alignment" (ie, postoperative

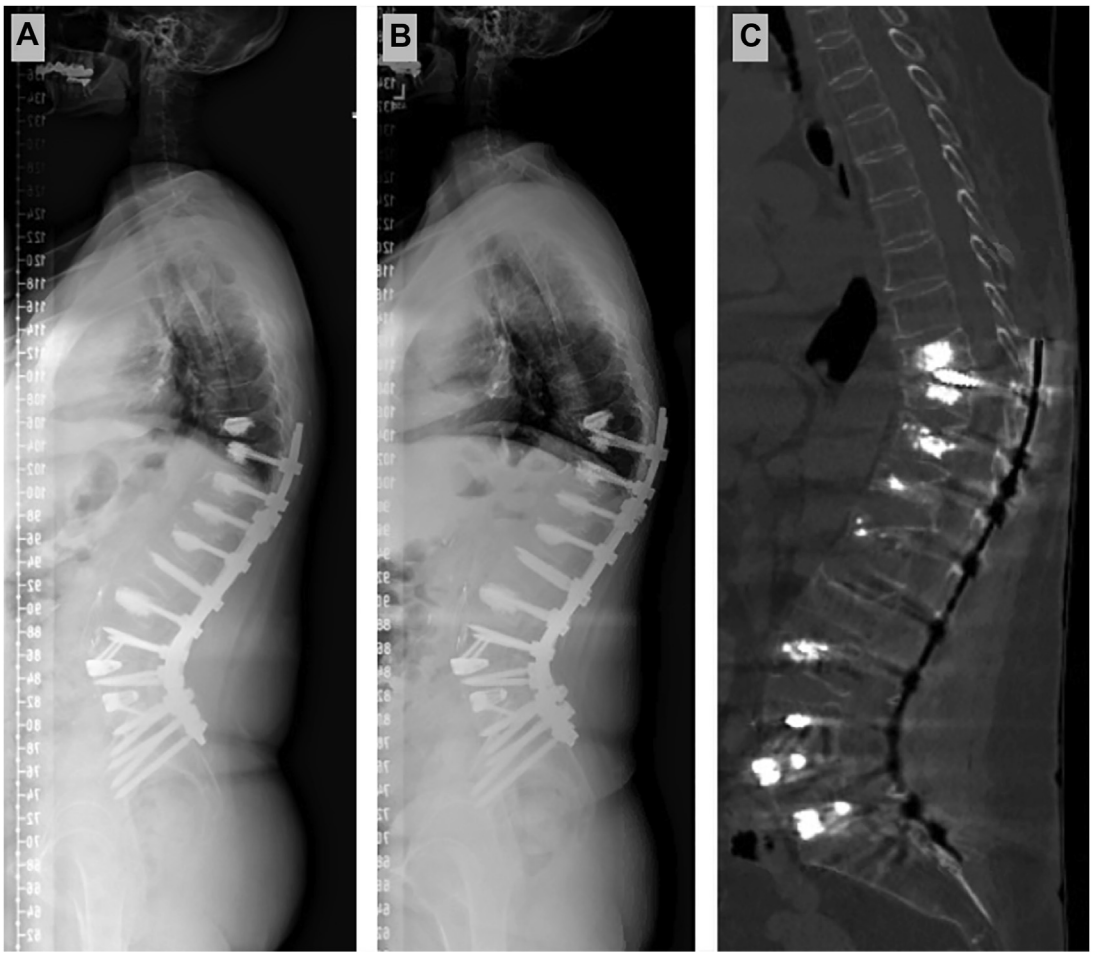

Fig. 7. A 56-year-old obese woman with osteoporosis underwent an L4–S1 ALIF and T10 to pelvis PSIF with two-level cement augmentation at the UIV and UIV+1 (*A*). At the 6-month postoperative visit, radiographs and CT scan demonstrated PJK from a compression fracture the UIV and cut out of the proximal screws into the disc space between the UIV and UIV+1 (*B*, *C*). Note the risk factors for development of PJK/PJF were obesity, osteoporosis, and likely overcorrection of the deformity with a posteriorly displaced L1 relative to the gravity line (*A*).

sagittal vertical axis [SVA] near 0 mm and lumbar lordosis [LL] approximating the pelvic incidence [PI]) were at an elevated risk of PJF compared with those patients with "non-ideal alignment" (ie, SVA nearer to 40 mm and LL closer to PI-10°).[62] Additional reports have verified corrections in SVA beyond 50 mm to be associated with PJK.[16,28,63] As such, a combination of implant-based solutions and avoidance of overcorrection and undercorrection of sagittal alignment represents the best path forward in mitigating PJK risk.

SUMMARY

PJK and PJF are common complications following long-segment posterior instrumented fusions for ASD. Progression to PJF involves clinical consequences for patients and requires costly revisions that may undermine the utility of surgery. Failures at the thoracolumbar junction are generally due to fractures, whereas those in the upper thoracic spine are typically caused by ligamentous failure. Ligamentous banding and use of transition rods may present cost-effective options that have potential to reduce PJF secondary to ligamentous failure. Two-level cement augmentation of the UIV and UIV+1 may also benefit patients by reducing the incidence of PJF and/or offering a delayed progression of PJK to PJF. These regional implant-focused strategies combined with careful planning and correction of the sagittal profile are important for minimizing the development of PJK and PJF and ensuring financial viability of ASD surgery.

CLINICS CARE POINTS

- Ligamentous banding and use of transition rods may present cost-effective options that have potential to reduce PJF secondary to ligamentous failure.
- Two-level cement augmentation of the upper instrumented vertebra (UIV) and supra-adjacent vertebra to the UIV (UIV+1) may also benefit patients by reducing the incidence of PJF.
- Regional implant-focused strategies combined with careful planning and correction of the sagittal profile are important for minimizing the development of PJK andPJF and ensuring financial viability of ASD surgery.

FUNDING

No funding was obtained for the submitted work.

DISCLOSURE

None of the authors have any relevant disclosures related to the submitted work.

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