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Proximal Junctional Kyphosis Prevention Strategies: A Video Technique Guide

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BACKGROUND: Proximal junctional kyphosis (PJK) is a well-recognized complication in patients undergoing posterior instrumented fusion procedures for adult spinal deformity. Strategies that reduce rates of PJK have the potential to improve the safety of these operations and decrease cost by eliminating the need for revision surgery.

OBJECTIVE: To present a set of surgical techniques that can decrease rates of PJK in adults undergoing surgery for spinal deformity.

METHODS: We summarize the use of vertebroplasty, transverse process hooks, terminal rod contouring, and ligament augmentation as means to reduce rates of PJK.

RESULTS: We present PJK prevention strategies and a video technique guide that are safe, technically feasible, and add minimal operative time to these surgical procedures. When applied to appropriate high-risk patients, these techniques have the potential to dramatically reduce rates of PJK, which improves quality of life and decreases the cost associated with this treating adult spinal deformity.

CONCLUSION: PJK prevention strategies represent a critical area for improvement in surgery for adult spinal deformity. We present a summary of techniques that are safe, feasible, and add minimal time to the overall procedure. These techniques warrant investigation in a thoughtful, prospective manner, but are supported by existing data and compelling biomechanical rationale. Our hope is that these strategies can be applied, particularly in high-risk patients, to help reduce rates of PJK.

KEY WORDS: Spine, Deformity, Proximal junctional kyphosis, Prevention strategies, Vertebroplasty, Ligament augmentation

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Proximal junctional kyphosis (PJK) is a well-recognized, yet incompletely defined complication in patients undergoing posterior instrumented fusion for spinal deformity. It presents with abnormal kyphosis immediately above the uppermost instrumented vertebrae (UIV), which is measured using the sagittal Cobb angle between the inferior endplate of the UIV and superior endplate of the second vertebral body above the UIV (UIV+2). Definitions for PJK varies in the literature and some suggest it represents a spectrum that ranges from asymptomatic radiographic findings to the most severe form of proximal junctional failure (PJF), which includes radiographic evidence of PJK as well as clinical sequela such as pain, neurological deficit, and impaired quality of life requiring reoperation.[1,2] Radiographic definitions for PJK generally require kyphosis greater than 10° to 20° compared to the preoperative baseline but there is no standardized definition.[3,4] Furthermore, in cases where 3-column vertebral resections are applied to the thoracic and lumbar spine to correct sagittal malalignment, there are reciprocal changes in unfused segments that result in spontaneous increase thoracic kyphosis, which require consideration when using purely radiographic parameters to define PJK.[5,6] Several attempts have been made to grade and classify the severity of PJK including the Boachie-Adjei classification scheme, which is based on the type of structural failure, degree of kyphosis, and

ABBREVIATIONS: cMIS, circumferential minimally invasive surgery; **LL,** lumbar lordosis; **PI,** pelvic incidence; **PJF,** proximal junctional failure; **PJK,** proximal junctional kyphosis; **SVA,** sagittal vertical axis; **UIV,** uppermost instrumented vertebrae

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presence of spondylolisthesis.[7] The PJF Severity Scale incorporates neurological deficit, presence of focal pain, failures of instrumentation, change in kyphosis, UIV/UIV+1 fracture, and level of UIV.[6]

The causes of PJK are not fully understood, but are believed to include one or more of the following factors: age-related degeneration and deformity, disruption of the posterior ligamentous complex, vertebral fractures, instrumentation failure, degenerative disc disease, and facet violation.[1,3,8-10] Risk factors include old age,[11-14] increased preoperative sagittal imbalance,[15-21] use of pedicle screws,[4,17,19,21] greater curvature correction,[17,19,21] disruption of posterior intervertebral elements,[12,13,16,19] and fusion to lower lumbar vertebrae or the sacrum.[15,17,18,22-24] Rates of PJK vary by the reported definition, however, most range from 17% to 39%.[3,11,15,18,22,23,25] Interestingly, most cases of PJK occur relatively early in the postoperative course; 66% are observed in the first 3 months and 80% within the first 18 months.[17,18]

The most common causes for revision in adult spinal deformity surgery include worsening deformity, PJK/PJF, pseudarthrosis, implant failure, and infection.[26,27] PJK rates in adult spinal deformity vary from 17% to 40% depending on patient risk factors, study design, and defining criteria. In a retrospective study of 160 patients with long-segment fusions, Park et al[28] reported PJK developing at a median of 17 months and PJF at a median of 3 months. Body mass index was a risk factor for PJK, while age, osteoporosis, preoperative sagittal vertical axis (SVA), and UIV were risk factors for PJF.[28] Readmissions cost an average of $65 000 to $80 000 per patient, with admissions for revision surgery estimated between $100 000 to over $170 000.[29,30] Alekos et al[31] report average direct cost of revision operation for PJF at $55 547 (range $22 263-$97 883) and a total of 12.1% of the total direct costs of the index operation.[31] Developing strategies for PJK prevention will reduce the morbidity and cost of adult spinal deformity, but to date there are no well-established technical guides for PJK prevention. Vertebral cement augmentation[32,33] and hook fixation[4,19,34] have been shown to reduce PJK rates and when applied with novel strategies such as ligament augmentation and terminal rod contouring may decrease rates even further. Each of these prevention strategies are safe and do not dramatically increase operative time. Applying them to high-risk patients, who can be identified using advanced techniques in predictive modeling,[35] may help improve outcomes and decrease cost. In this manuscript, we present a summary of PJK prevention strategies and a technical video guide (**Video**, **Supplemental Digital Content**).

METHODS

We summarize the use of vertebroplasty, transverse process hooks, terminal rod contouring, and ligament augmentation. These strategies can be used in appropriately selected patients individually or in combination. Our institutional practice is to utilize Cortoss cement (Stryker, Kalamazoo, Michigan) for vertebroplasty and ligapass sublaminar cable (Medicrea, Rillieux-la-Pape, France) for ligament augmentation. Informed consent for use of each technique is obtained prior to surgery.

Technique

The patient is positioned prone on a Jackson table then prepped and draped in the usual sterile fashion. Fluoroscopy is used to confirm the appropriate level and an incision is made from the UIV-1 to pelvis. The spine is dissected out in a subperiosteal fashion to expose the spinous processes, lamina, facets, and transverse processes. A Midas Rex bur (Medtronic, Dublin, Ireland) is used to initiate pedicle screw entry sites, which are then palpated, tapped, and repalpated. Pedicle screws are placed at all levels except the UIV and UIV-1 where a gearshift probe is used to cannulate these levels followed by placement of pedicle markers. Intraoperative computed tomography is used to confirm proper screw placement, bony purchase, and exclude medial, lateral, or foraminal breaches.

Vertebroplasty

The UIV and UIV-1 are now prepared for vertebroplasty by decorticating the pedicle entrance points, tapping the cannulated sites, then filling them with thrombin-containing hemostatic matrix to occlude venous channels. Cement is injected into the vertebral bodies to complete the vertebroplasty at the UIV and UIV-1 with a volume of 3 mL at each entry site (6 mL per vertebral body). A pedicle screw is then introduced to the UIV only. We generally limit vertebroplasty to the thoracolumbar junction since failures at this level are generally due to fractures, while failure at the upper thoracic spine is generally secondary to ligament fatigue.

Hook Fixation

For constructs terminating in the upper thoracic spine, transverse process hook fixation is used instead of pedicle screw fixation since it provides a softer stress transition to the UIV. Hook fixation also allows for less dissection of the surrounding muscle and facet since these implants can be applied under muscle and around the transverse process without subperiosteal exposure.

Terminal Rod Contouring

After pedicle screws and hooks have been placed, osteotomies are performed if needed and the final rod is contoured according to the desired sagittal curve and locked into place. For rods terminating in the upper thoracic spine, we introduce terminal kyphosis so the rod is never forced into place. This prevents any additional loading forces to the construct and minimizes the risk for screw pullout or junctional stress. X-rays are obtained to confirm good alignment prior to final torqueing of set screws.

Ligament Augmentation

Attention is then turned to ligament augmentation at the UIV-1, UIV, and UIV+1. We have utilized this technique based on preliminary data suggesting that it can reduce PJK rates beyond vertebroplasty and transverse process hooks. The goal is to provide strength to the UIV-1, UIV, and UIV+1 and decrease junctional stress at these levels. A matchstick burr is used to drill through the center of the spinous processes and a soft sublaminar cable is looped through these holes in a mirrored fashion. The cable is pulled tight on each side by hand to allow testing of the exact tension desired, then fixed to the rod under tension using supplied connectors. Spinous processes at these levels are loaded in slight extension to resist flexion at the terminal construct.

DISCUSSION

We present a combination of techniques as a strategy for PJK prevention. Although the techniques presented in this manuscript have all been described individually, we believe the application of multimodal PJK prevention provides redundant layers of security that are especially valuable in high-risk patients. In addition to vertebroplasty, terminal rod contouring, hook fixation, and ligament augmentation, there are many other factors believed to play a role in PJK prevention including extending fusion constructs to include levels with baseline segmental kyphosis of more than 5°, use of composite metals and greater flexibility, less destruction of soft tissue at the UIV, achievement of optimal spinal balance and alignment, and use of transition rods.[3,8,16,20,36,37]

Failure to respect soft tissues around the UIV is considered a risk factor for PJK. Preserving interspinous ligaments, supraspinous ligaments, and the adjacent facet and its associated capsule are all believed to decrease the risk of PJK.[8,37] Unfortunately, in patients with multiple prior surgeries, careful dissection cannot always mitigate the effects of atrophic and degenerated soft tissue. Proper selection of the UIV is important; for example, the presence of thoracic hyperkyphosis has important implications for surgical planning as it is a well-known risk factor for the development of PJK.[2,15-18,20,21,38,39] Therefore, in patients with thoracic hyperkyphosis, extending the fusion and instrumentation to the upper thoracic levels is considered desirable to minimize the risk of PJK and to achieve appropriate sagittal realignment. The growth of minimally invasive surgical techniques has also led some to postulate that percutaneous fixation at the upper construct may result in less soft tissue disruption and lower rates of PJK. Mummaneni et al[40] compared PJK rates in circumferential minimally invasive surgery (cMIS) vs a hybrid approach for adult spinal deformity and found overall lower rates of PJK in the cMIS group, but no difference when controlling for number of levels fused.[40] The study was limited by selection bias, but further work is needed to compare long-term PJK rates in patients where only the uppermost levels undergo percutaneous fixation vs traditional open procedures.

The importance of correcting underlying pelvic incidence (PI) and lumbar lordosis (LL) mismatch is a well-recognized tenet of adult spinal deformity surgery, with a goal mismatch of less than 10°.[41] There are, however, at least 2 circumstances in which exceptions can be made. First, patients with extremely high PI (greater than 70°) require slightly less LL, while those with a low PI (less than 40°) require slightly more LL. The second situation where deviation from the typical PI-LL mismatch is the goal is in the elderly. The International Spine Study Group showed that spinopelvic parameters corresponding with health-related quality of life scores (eg, pelvic tilt, PI-LL mismatch, SVA) are substantially greater at baseline in the elderly; therefore, these authors advocate for incorporating consideration of the patient's age into the determination of optimal postoperative spinopelvic parameter alignment.[40] There is also data suggesting that patients with higher postoperative LL and larger sagittal balance change are associated with higher rates of PJK requiring revision surgery.[12] Adjusting for age-appropriate alignment goals and avoiding overly strict adherence to PI-LL mismatch correction at the extremes of anatomic variability may reduce the risk of under- and overcorrection and subsequent development of PJK.

Transverse process hook fixation has been used in an attempt to reduce rates of PJK, particularly in the upper thoracic spine since failure at these levels is often caused by ligamentous fatigue. Hook fixation requires less subperiosteal dissection in the surrounding muscle and facets, resulting in less compromise of the facet joint and improved dynamic fixation at the top of the construct by reducing the stress transition to the UIV.[4,19,42] There is modest data showing reduced PJK in patients who receive hook fixation vs pedicle screws at the UIV, with rates of 0% to 30% and 30 to 35%, respectively.[4,19] While there is more consistent data supporting hook or hybrid fixation at the proximal construct in the adolescent scoliosis literature,[4,14,19] the evidence in the adult population is inconclusive at best. Cammarata et al[37] performed biomechanical analysis of adult spine models and showed that hooks used with transition rods at the UIV were effective at reducing the biomechanical stress thought to play a role in the pathogenesis of PJK, but without significant clinical benefit. The current evidence is mixed; however, the reduced subperiosteal dissection and preservation of adjacent facet joints combined with compelling biomechanical rationale makes this a promising adjunct that is an area of active investigation.[3,13,24,25,34]

Vertebroplasty has been thoroughly investigated as an adjunct for PJK prevention. Kebaish et al[32] showed that vertebroplasty of the UIV/UIV+1 reduced rates of junctional fractures following long-segment instrumentation in a cadaveric model. Kayanja et al[43] enhanced up to 3 vertebral bodies with cement and assessed the effects on the stiffness and strength of the final construct. They found that the integrity of the construct was contingent on bone mineral density, thus concluding that vertebroplasty should be performed on vertebral bodies with highest risk for fracture. In a clinical study, Hart et al[33] reported that prophylactic vertebroplasty of the UIV and UIV+1 levels not only reduced the risk of PJF but was also cost-effective when compared to the cost of a revision procedure.[33] There are limitations and concerns associated with this procedure as it can accelerate degenerative disc disease by restricting blood supply to the discs adjacent to the cemented vertebra[44] and increase the risk of fractures at adjacent levels by virtue of altering spinal load mechanics.[45,46]

Techniques aimed at reinforcing the posterior tension band may prove to be effective as disruption of the posterior ligamentous complex is thought to play an important role in the pathogenesis of PJK and PJF. The goal of ligament augmentation is to provide additional support to the proximal construct, reduce junctional stress at these levels, and reinforce the ligamentous complex. This technique creates a tension band loop encompassing the involved levels and adds strength to the upper construct while also providing a smooth transition from rigid fused levels to the more mobile segments above. We have preliminary results showing dramatic reductions in early PJK, but long-term data are needed.

Summary

Strategies for decreasing rates of PJK will be essential moving forward. We present surgical techniques that are safe and add minimal operative time. Vertebroplasty provides strength to constructs terminating at the thoracolumbar junction, where failure is often due to fracture. Transverse process hooks are valuable for constructs terminating in the upper thoracic spine since they provide a softer stress transition to the UIV and can be applied with minimal muscular dissection and preservation of the facets. Our technique for terminal rod bending prevents additional loading and has the potential to minimize forces causing screw pullout or junctional stress. Ligament augmentation provides strength to the upper construct and reinforces the ligamentous complex, which is a common site of failure at these levels. It also allows for the upper construct to be placed in slight extension to help resist flexion forces. In addition to reducing PJK/PJF, these techniques, when used together in appropriately selected high-risk patients, have the potential to improve safety and reduce the cost and morbidity of surgery for adult spinal deformity.

CONCLUSION

PJK prevention strategies represent a critical area for improvement in surgery for adult spinal deformity. Surgical adjuncts that can prevent PJK/PJF and abrogate the need for readmission and revision surgeries are necessary to reduce both cost and morbidity. We present a summary of techniques that are safe and add minimal operative time. These techniques warrant future investigation in a thoughtful, prospective manner, but are supported by existing data and compelling biomechanical rationale. Our hope is that these strategies can be applied, particularly in high-risk patients, to help reduce rates of PJK.

Disclosures

Dr Bess is a consultant for K2 and Allosource, receives research grants from Medtronic, K2, Innovasis, Stryker, and DePuy, and holds patents with Innovasis and K2. Dr Shaffrey is a consultant for, receives royalties from, and holds patents with Medtronic, Zimmer-Biomet, and NuVasive, has stock in and teaching arrangements with NuVasive, received travel funding from Medtronic, and consults for K2M; he receives research support from NIH and the Department of Defense; he is on the Board of Directors of the American Board of Neurological Surgery, American Board of Neurological Surgeons, and Cervical Spine Research Society; he receives fellowship support from AO and NREF. Dr Hart is a consultant for DePuy Synthes and Globus, receives royalties from Seaspine and DePuy Synthes, received honoraria from DePuy Synthes and Globus, has grants from Medtronic and the International Spine Study Group Foundation; he has unpaid Board positions with CSRS, ILLSL, and ISSG. Dr Ames is a consultant for DePuy Synthes, Medtronic, and Stryker, receives royalties from Biomet Spine and Stryker, holds a patent with Fish & Richardson, and has stock in Doctor's Research Group and Visualase; he receives grants from DePuy Synthes Spine and AOSpine North America. The other authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article. Dr Smith is a consultant for Zimmer Biomet, NuVasive, and Cerapedics, receives honoraria from Zimmer Biomet, NuVasive and K2M, and receives royalties from Zimmer Biomet; he has fellowship funding from NREF and AOSpine; he has research study group grant funding from DePuy Synthes.

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COMMENT

This is a well-timed manuscript and video. PJK is a ubiquitous problem in spine deformity surgery that affects surgeons performing both open and MIS corrections. The techniques described in the video are useful and the discussion of the different methods is a valuable review. I suspect, however, that this problem is inherent to human anatomy and normal aging and the problem will never be completely eliminated. Overall an excellent video and manuscript and the authors should be commended.

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