



Realignment surgery in adult spinal deformity

Prevalence and risk factors for proximal junctional kyphosis

Introduction

Surgical realignment of adult spinal deformity (ASD) has advanced significantly over the last decade [17, 61, 64] but proximal junctional kyphosis (PJK) is a complication that continues to challenge clinicians [17, 59]. Proximal junctional kyphosis impacts health related quality of life and poses a socioeconomic burden, as evidenced by the 3.2 million US\$ incurred by a major center, direct costs for revisions due to proximal junctional failure, a more severe and clinically relevant form of PJK [53, 55, 59, 68]. We aim to augment understanding and provide current evidence regarding prevalence and risk factors of PJK to guide clinicians in accounting for this post-operative phenomenon in the setting of ASD.

Epidemiology

Definition

Traditionally, PJK has been defined as a change of at least 10° in the proximal junctional sagittal Cobb angle from the preoperative value (■ Fig. 1). Most authors have radiographically identified PJK when observing a kyphosis of ≥10° develop between the inferior endplate of the upper instrumented vertebra (UIV) and the superior endplate of the two supra-adjacent vertebrae [32]. Recent efforts by Lafage et al. [40] to redefine the thresholds of proximal junctional pathologies call for expansion of radio-

graphic PJK criteria. By also accounting for sagittal listhesis (from UIV to first supra-adjacent vertebra) and grouping by UIV (T8 and above; T9 and below), the new criteria were able to identify 20% of patients who underwent revision for proximal junctional pathologies (vs. 7% identified by classic criteria), enhancing the utility of radiographic PJK criteria for predicting future revision (■ Fig. 2; [40]).

Incidence and prevalence

The incidence and prevalence rates of PJK are widely variable in the literature. Reported incidence rates range from 5% up to 61%, although many authors reported rates between 20% and 40% [9, 18, 21, 26, 57, 59]. Prevalence has been determined to fall between 29% [58] and 39% [36]. Gupta et al. [20] identified a bimodal incidence and temporal pattern of PJK. Early PJK, which manifests within 6 weeks of surgery, is associated with an increased likelihood of future revision and was found to have an incidence of 40.3%. In contrast, delayed PJK occurs more than 1 year following surgery and was found to have an incidence of 22% ([20]; ■ Fig. 3).

Risk factors

While a variety of risk factors have been linked to the development of PJK in the literature, a simple method of stratifying these is by whether they are modifiable or non-modifiable by the surgeon.

Abbreviations

<i>ASD</i>	Adult spinal deformity
<i>ASD-FI</i>	Adult spinal deformity frailty index
<i>BMD</i>	Bone mineral density
<i>BMI</i>	Body mass index
<i>CoCrMRC</i>	Cobalt chromium multi-rod construct
<i>HRT</i>	Head repositioning test
<i>LL</i>	Lumbar lordosis
<i>mFI</i>	Modified frailty index
<i>miniBESTest</i>	Mini-balance evaluation systems test
<i>NIS</i>	Nationwide Inpatient Sample
<i>NSQIP</i>	National surgical quality improvement program
<i>PI</i>	Pelvic incidence
<i>PI-LL</i>	Pelvic incidence minus lumbar lordosis
<i>PJF</i>	Proximal junction failure
<i>PJK</i>	Proximal junctional kyphosis
<i>PT</i>	Pelvic tilt
<i>ROM</i>	Range of motion
<i>SRA</i>	Scoliosis Research Society
<i>SVA</i>	Sagittal vertical axis
<i>TiTRC</i>	Titanium two-rod construct
<i>TK</i>	Thoracic kyphosis
<i>TUG test</i>	Timed Up and Go test
<i>UIV</i>	Upper instrumented vertebra
<i>VAS</i>	Visual analog scale

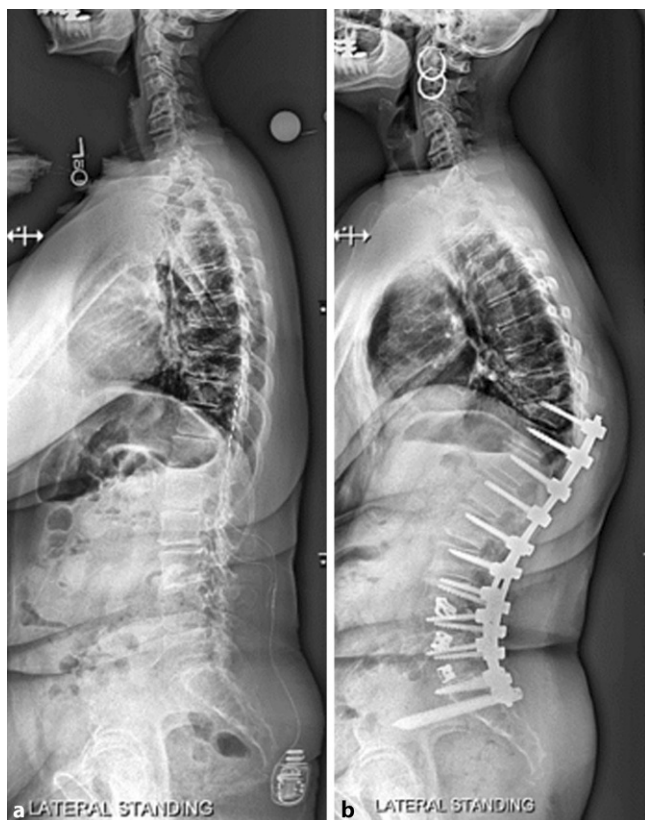


Fig. 1 ◀ Preoperative (a) and postoperative (b) sagittal radiographs of a patient with radiographically identified PJK per traditional criteria, with $\geq 10^\circ$ change in the proximal junctional sagittal Cobb angle from the preoperative value

Non-Modifiable/Patient-Specific Risk Factors

Age and magnitude of deformity

Older age at time of surgery is a well-documented risk factor associated with PJK and recent data suggest that patients older than 55 years are at increased risk of sustaining PJK [21, 36, 41, 46]; however, Lafage et al. [39] found that PJK in these patients is likely driven by sagittal plane overcorrection. In addition, preoperative presence of substantial sagittal malalignment and magnitude of deformity are also considered risk factors for PJK and proximal junctional failure. High preoperative sagittal vertical axis (SVA) and thoracic kyphosis are parameters of particular note [34, 65]. This emphasizes the necessity for patient-specific treatment, especially for older patients whose age and magnitude of deformity may require different alignment goals than younger patients [39].

Body mass index (BMI) and bone mineral density (BMD)

Strong consensus exists regarding the role of BMI in PJK onset [40, 41]. The under-

lying mechanism of progression to PJK may be related to the increased biomechanical stress placed on the UIV in patients with high BMIs [32]. At present, no investigation has quantified a BMI cut-off value at which PJK risk increases.

» Multiple studies support low bone mineral density as a risk factor for PJK

Multiple studies also support the consideration of low bone mineral density (BMD) as a risk factor for PJK [32, 46]. With respect to bone quality, osteoporotic patients possess a weaker bone-to-screw interface, increasing the risk of screw pull-out post-instrumentation. The risk of adjacent segment disease following spinal fusion due to low BMD is well-documented. Osteoporosis is also associated with muscle atrophy and coupling lower BMD with reduced thoracolumbar musculature has the potential to cause skeletal instability and expedite development of PJK [32, 66].

Neuromuscular envelope

Fatty infiltration of the muscular envelope can contribute to the development of spino-pelvic muscular asymmetry and has been implicated in PJK development [2, 9]. Moal et al. [51] identified how patterns and mechanisms of fatty infiltration vary between muscle groups involved in sagittal posture; the greatest effects were on spine and hip extensors, which may promote sagittal spinopelvic malalignment in the setting of ASD and contribute to the development of PJK [27–29, 51]. In addition, Hyun et al. [24] demonstrated that PJK might result from reduced preoperative muscularity and increased fatty degeneration within the thoracolumbar musculature. Their findings strongly encourage spine surgeons to assess thoracolumbar muscularity and degree of fatty degeneration at the junctional area of the UIV of choice.

Comorbidities and risk stratification

The presence of comorbidities is a well-documented risk factor for PJK following ASD realignment surgery [7, 55, 70]. Diebo et al. [10] developed a novel index to quantify collective morbidity risk of ASD realignment surgery, utilizing preoperative comorbidities among several parameters from the Nationwide Inpatient Sample (NIS). Pulmonary circulation and neurological disorders, among others, were identified as contributors to ASD risk. Further study of the roles played by individual comorbidities in development of PJK is warranted. Such indices will help augment preoperative risk stratification for ASD patients. Frailty has also been reported to predispose to PJK. Miller et al. [50] created a deformity-specific frailty index (ASD-FI), clearly demonstrating the increased likelihood of PJK in patients with frailty and severe frailty (0.3–0.5; >0.5, respectively), offering surgeons another useful tool for treatment optimization. Leven et al. [45] showed how higher modified Frailty Index (mFI) scores correlated with increased postoperative complication and re-operation rates (mFI > 0.27, 60% and 15% respectively), validating mFI use for ASD patient risk stratification. Scheer et al. [59] developed a model

that predicted either clinically significant PJK or proximal junction failure (PJF) with 86% accuracy. These tools may help surgeons to identify patients at risk for developing PJK/PJF in real-time in order to individualize risk-reduction approaches.

Risk stratification and mitigation of PJK is a top priority of ASD surgeons at present. In light of how the American College of Surgeons utilized the National Surgical Quality Improvement Program (NSQIP) database to generate a risk calculator, the Scoliosis Research Society (SRS) Risk Stratification Task Force is calling for strengthening of current risk stratification tools [16]. The 2016 SRS annual meeting dedicated a full day to a course aimed at identifying outcome predictors to improve care plans and optimizing cost-effectiveness of services provided [1]. Rigorous dual surgeon and multidisciplinary collaborative efforts in ASD during preoperative, perioperative, and postoperative phases has been demonstrated to produce substantial mitigation of perioperative complication rates [62]. The potential for these efforts to reduce PJK rates, enhance PJK prevention, and increase the standard of care appears promising.

Modifiable surgeon-controlled factors

Prevalent risk factors pertaining to surgical intervention include those related to operative approach, magnitude of sagittal realignment correction, and the characteristics of constructs.

Surgical approach

Several cadaver and biomechanical studies suggest that development of PJK is associated with posterior soft tissue and intervertebral elements disruption [34]. The combined anteroposterior approach has also been suggested as a risk factor for PJK [35, 55]; however, Liu et al. [46] have refuted this claim.

Sagittal realignment

Larger magnitude of deformity corrections is also associated with increased PJK incidence [55]. Multiple studies concluded that overcorrection of lumbar lordosis (LL) and SVA both contribute to

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Realignment surgery in adult spinal deformity. Prevalence and risk factors for proximal junctional kyphosis

Abstract

Although surgical techniques pertaining to adult spinal deformity (ASD) have advanced over the last decade, proximal junctional kyphosis (PJK) is still a complication following surgery for ASD that continues to significantly challenge clinicians. This article aimed to report on the prevalence of PJK as well as enhance understanding of surgically modifiable and non-modifiable risk factors of PJK to guide management of this postoperative complication of ASD. As the understanding of the pathogenesis as well

as surgical modifications aimed at reducing the incidence of PJK have advanced, so too should clinicians' ability to implement more patient-specific operative plans and improve outcomes following realignment surgery for ASD.

Keywords

Epidemiology · Patient-specific factors · Surgically-modifiable factors · Risk stratification · Outcomes

Operative Korrektur von Wirbelsäulendeformitäten des Erwachsenen. Prävalenz und Risikofaktoren der proximalen junktionalen Kyphose

Zusammenfassung

Obwohl sich die chirurgischen Techniken in Bezug auf die Behandlung von Wirbelsäulendeformitäten des Erwachsenen („adult spinal deformities“, ASD) in den letzten Dekaden weiterentwickelt haben, stellt die proximale junktional Kyphose (PJK) als Komplikation nach operativer Versorgung der ASD eine große Herausforderung für den Wirbelsäulenchirurgen dar. Ziel dieser Übersichtsarbeit ist es, die Prävalenz der PJK darzustellen und das Verständnis für chirurgisch beeinflussbare sowie chirurgisch nicht beeinflussbare Risikofaktoren der PJK zu erhöhen, damit diese relevante postoperative Komplikation der ASD besser eingeordnet und behandelt werden kann.

Da das Verständnis für die Pathogenese der PJK wie auch die chirurgischen Strategien mit dem Ziel, die Häufigkeit der postoperativen PJK zu reduzieren, fortgeschritten sind, muss nun auch die Fähigkeit der Kliniker gefordert werden, die patientenspezifische operative Planung in der Behandlung zu implementieren, um das postoperative Ergebnis nach der Wiederherstellung des sagittalen Profils bei ASD zu verbessern.

Schlüsselwörter

Epidemiologie · Patientenspezifische Faktoren · Chirurgisch beeinflussbare Faktoren · Risikostratifizierung · Ergebnisse

PJK onset [33, 34, 47, 55]. Dubouset's cone of economy helps explain this: sagittal alignment overcorrection disrupts the equilibrium between SVA and the natural line of gravity. The body tries to self-correct to an optimal position but is restricted to the remaining unfused segments following extensive fusion. This serves as the probable driving force behind the magnitude of reciprocal change in the proximal unfused thoracic spine, underscoring the importance of operative planning with respect to individual patient profiles [37]. Subsequently, the one-size-fits-all approach to determining realignment goals is ceding ground

to patient-specific planning. Lafage et al. [39] adjusted for age and found that all age groups of patients who developed PJK demonstrated global alignment overcorrection, revealing a connection between overcorrection and PJK magnitude. Overcorrection was once favored for older patients to gradually counter alignment degeneration, yet it does not account for age and patient-specific alignment goals. Thus, more comprehensive preoperative planning may mitigate PJK risk and establish patient sustainable realignment [39].

The extent of correction can also modify PJK risk. Gupta et al. [20] found that

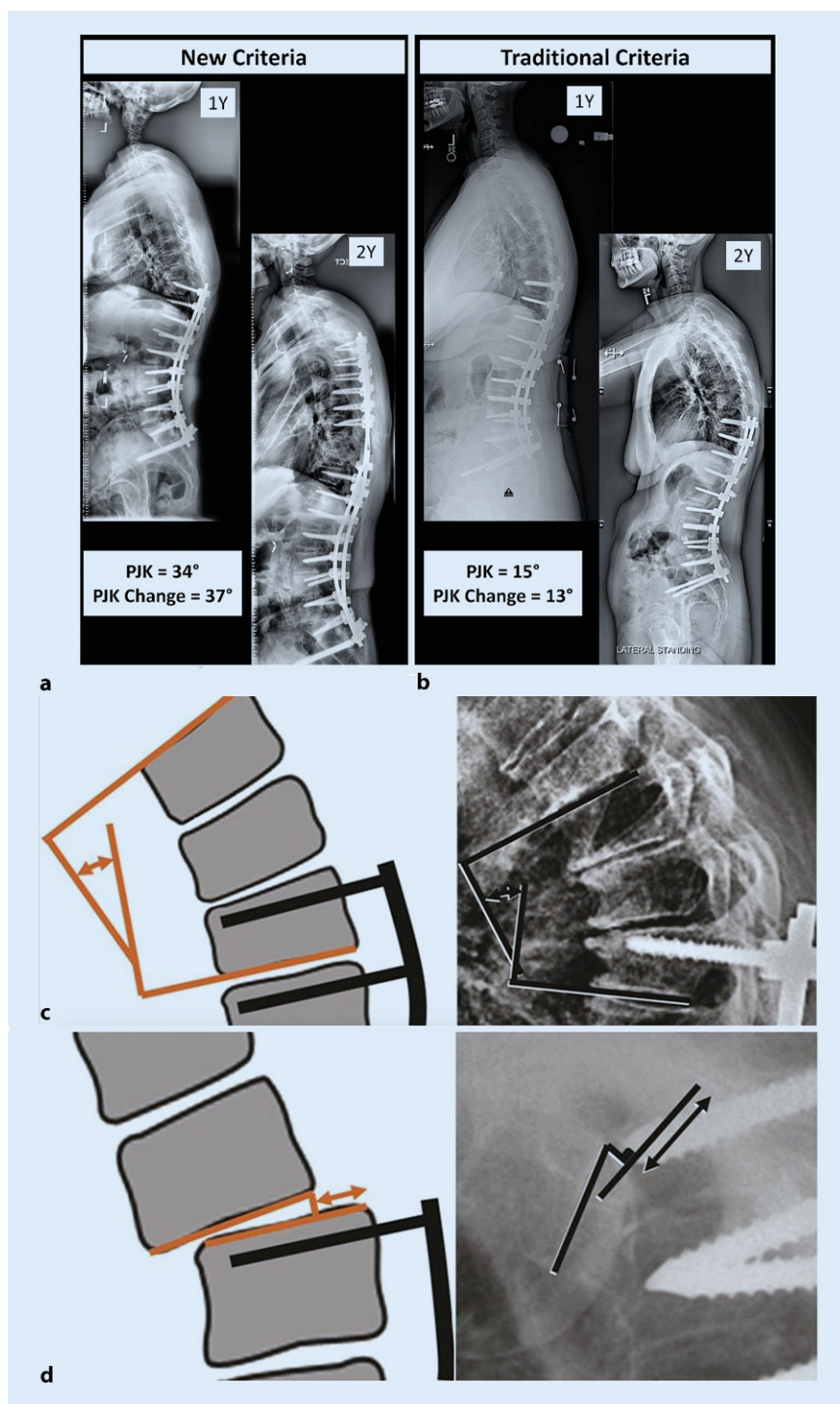


Fig. 2 ▲ Sagittal views of patients with radiographic proximal junctional kyphosis (PJK) at 1 and 2 years (Y; left and right, respectively) postoperatively. **a** A change in PJK of 3° from 1–2 years postoperatively in a patient who underwent revision surgery and was identified by redefined criteria accounting for sagittal listhesis. **b** A similarly small change in PJK of 2° from 1–2 years postoperatively evaluated per traditional criteria. Novel criteria, proposed by Lafage et al. [40], account for proximal junctional (PJ) angle between the UIV and UIV +2 (c) as well as sagittal listhesis (d). The new criteria groups patients into lower thoracic (UIV 3 mm and change in PJ listhesis >3 mm) or upper thoracic (UIV >T8 with PJ listhesis >8 mm and change in PJ listhesis >8 mm)

in contrast to delayed PJK, patients with early PJK had a higher rate of upper lumbar apex corrections, with a lesser extent of caudal correction. Durrani et al. [12] also determined that risk of PJK is best mitigated following implementation of posterior dynamic stabilization at caudal-most levels. Another consideration in realignment surgery is comprehensive evaluation of parameters that contribute to sagittal malalignment [42]. Currently, full spine standing radiographs in the coronal and sagittal planes are the gold standard for assessing spinopelvic parameters and global alignment [3]; however, a significant proportion of the population spends the majority of their time at work in the sitting position [13, 15].

» Larger magnitude of deformity corrections is also associated with increased PJK incidence

Therefore, assessment of sagittal trunk alignment cannot be restricted to standing posture only. Posture when sitting activates adaptive mechanisms that are modulated by pelvic incidence (PI) and that modify pelvic tilt (PT) and LL [42]. Endo et al. [13] showed how asymptomatic adults demonstrated nearly 50% reduction in LL angle and 285% increase in PT in the sitting position when compared to standing. Lee et al. [43] showed that not only did LL decrease as subjects went from standing to sitting, but these differences were more prominent in older subjects; specifically, these changes were highly concentrated in the lower lumbar region while sitting. Investigation of postural changes to the lumbar spine by Meakin et al. [48] showed small and non-significant changes in the lumbar spine shape between standing and supine positioning, yet they showed how the effect of positional change was markedly different for various spine shapes. Hey et al. [23] further explored this by radiographic evaluation of ROM, via sagittal global and segmental Cobb angles, in six common postures (slump sitting, forward bending, supine, half squatting, standing, and backward bending). They

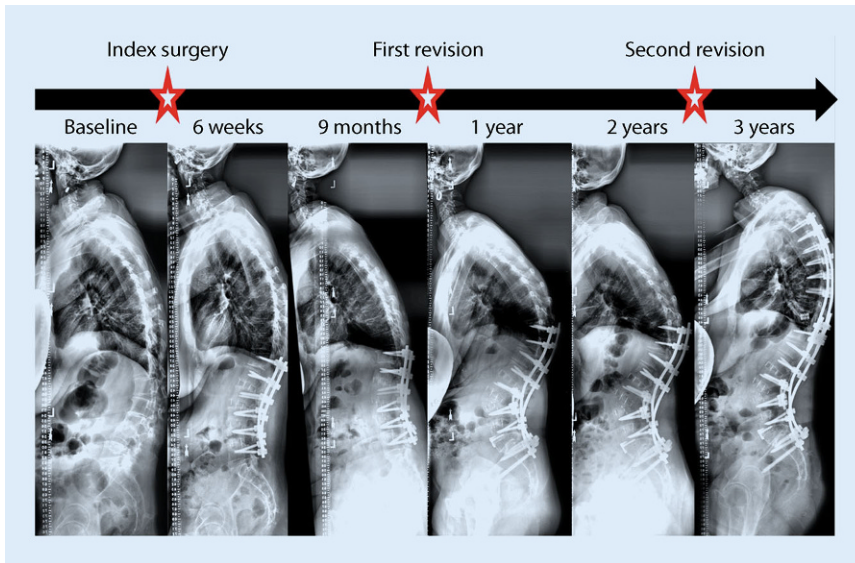


Fig. 3 ▲ A patient with delayed proximal junctional kyphosis (PJK) requiring multiple revision surgeries. Initial development of radiographic PJK following index surgery for adult spinal deformity (ASD) occurred 1 year postoperatively followed by revision surgery at 3 years postoperatively (from left to right)

showed that lordosis persisted at L4–L5 and L5–S1 across all postures, and that L4–L5 had the greatest ROM among lumbar spinal functional units. Recently, Patel et al. [56] highlighted the superior performance of preoperative supine radiographs over standing radiographs for predicting alignment changes in unfused segments following thoracolumbar fusion for ASD. Evaluation of sagittal alignment in more than one position may provide a better understanding of the true flexibility of the spine, account for the patient’s daily activities that require positional changes and improve overall outcomes by allowing achievement of a more optimal postoperative alignment.

Junctional zone

The literature consistently reports that UIV selection at the thoracolumbar junction, specifically between T11 and L1, is associated with PJK. This is likely due to the transition from the more inflexible thoracic spine and ribs to the more mobile lumbar spine [32, 55]. Beyond this, in-depth knowledge of the implications of UIV selection is limited. Lafage et al. [38] confirmed a significantly increased rate and risk of PJK in patients with UIV at a lower thoracic level. They also identified another potential risk factor: further review of the UIV zone,

while controlling for the compensatory impact of post-PJK increase in PT, revealed that patients who developed PJK demonstrated a more posterior construct inclination, suggesting that risk may decrease with suitable rod contouring [38]. The nature of the construct and instrumentation selected has also been examined. Utilization of hooks over pedicle screws has been associated with lower proximal junctional angle. Metzger et al. [49] concluded that placement of bilateral supralaminar hooks at the UIV was superior to all other hook and/or pedicle screw combinations, producing reduced hypermobility at the supra-adjacent noninstrumented segment. Han et al. [21] investigated spinal construct stiffness and found that cobalt chromium multi-rod constructs (CoCrMRC), in comparison to titanium two-rod constructs (TiTRCs), demonstrated improved rod stiffness, construct stability, and potential to reduce rod breakage; however, increasing rod stiffness with CoCr MRCs increased the risk of PJK occurrence and impacted the time-frame within which PJK develops. Whereas TiTRC patients developed PJK between 2 and 84 months, all PJK cases related to CoCrMRC occurred within 7 postoperative months [21].



Fig. 4 ▲ Anteroposterior (a) and lateral (b) stereoradiography of a 69-year-old female patient with osteopenia evaluated for proximal junctional kyphosis (PJK)

Disruption of the balance in forces at the junctional area is also thought to play a role in development of PJK. Utilizing finite element analysis, Bess et al. [4] demonstrated that the distribution of forces across and supra-adjacent to the UIV via posterior polyester tethers could allay the risk of PJK. Use of multi-level instrumented constructs with posterior tethers can produce a more gradual progression from instrumented to noninstrumented segments in ROM and forces on pedicle screws and posterior spinal ligaments, potentially mitigating the biomechanical risk of PJK.

» Disruption of balance in forces at the junctional area is thought to play a role in PJK

A PJK related to the junctional zone is also frequently associated with vertebral compression fractures [8]. Kebaish

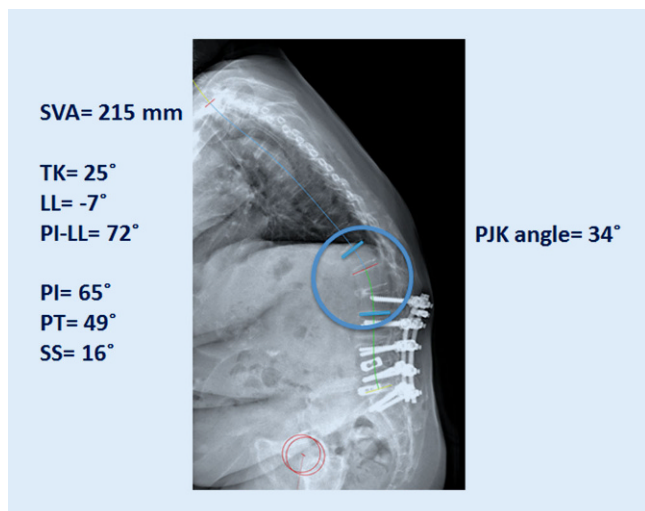


Fig. 5 ▲ Sagittal radiographic evaluation of the 69-year-old woman with radiographic proximal junctional kyphosis (PJK; blue circle) and severe sagittal malalignment (PI-LL = 72°). SVA sagittal vertical axis, TK thoracic kyphosis, LL lumbar lordosis; PI-LL pelvic incidence minus lumbar lordosis, PI pelvic incidence, PT pelvic tilt, SS sacral slope



Fig. 6 ▲ Severe fatty infiltration of the back musculature (outlined in red) on MRI of the lumbar spine in this 69-year-old female patient

et al. [31] demonstrated that a novel method of two-level prophylactic vertebral plasty (UIV + 1) substantially reduced incidence (17%) of vertebral compression fractures in cadaveric models, compared with no (100%) or one-level (67%) vertebral plasty. While cadaveric models preclude direct predictions of clinical PJK incidence, these findings warrant in vivo investigation. Theologis and Burch [67] evaluated two-level cement augmentation (UIV + 1) in patients with ASD, which yielded a significantly reduced revision rate for proximal junctional failure secondary to vertebral compression fracture. Moreover, they found an increased likelihood of revision surgery for PJK in patients undergoing no cement or any non-two-level cement augmentation technique (9.2-fold and 13.1-fold, respectively).

Clinical case presentation

A 69-year-old female patient with osteopenia and 3 previous spinal surgeries was evaluated for PJK, reporting non-radiating back pain and a decline in activities of daily living (Fig. 4).

Preoperatively, the patient had developed a PJK angle of 34°, with evidence of severe sagittal malalignment (thoracic kyphosis [TK] of 25°, SVA of 215 mm, and pelvic incidence minus lumbar lordosis

[PI-LL] of 72°). With advanced age and preoperative presence of significant sagittal malalignment, this patient has several risk factors for PJK and PJF (Fig. 5), as well as substantial fatty infiltration of the back musculature (Fig. 6).

Accounting for the age-adjusted goals of this older patient (age > 55 years) with severe sagittal malalignment (PI-LL = 72°), osteopenia, previous surgery, PJK (34°), and weak back musculature, she was indicated for a less ambitious, age-specific realignment. The patient underwent Ponte osteotomy at T12-L1 and L1-L2, with pedicle subtraction osteotomy at L3 and fusion from T5-S1 (Fig. 7).

The patient was observed to have no PJK and significant reduction in sagittal malalignment (PI-LL = 26° and SVA = 73 mm) 9 months postoperatively, demonstrating the clinical benefit of utilizing patient-specific planning in the context of PJK (Fig. 8).

Future directions: what is next?

Further investigation into several preoperative dynamic patient factors may provide a novel framework within which surgeons can work with patients to reduce risk of PJK. Innovations in technology have allowed measurement of body kinematics, which previously required

specialized equipment and laboratories, via wearable inertia sensors. Stabilometry, which relies on a single triaxial accelerometer, allows assessment of standing balance and has been widely used in patients with Parkinson's disease. This demonstrated ability to detect postural abnormalities suggests potential for providing biofeedback on ASD patients undergoing realignment surgery [25].

Somatosensory, visual, and vestibular systems play a role in impacting erect postural alignment. Older adults with ASD have an impaired perception of upright vertical alignment that worsens with age-related impairment of proprioceptive and vibratory input from the lower extremities. Assessment of these impairments prior to surgical realignment procedures for ASD may provide a deeper understanding of patient needs and ability to maintain the new alignment [6, 19, 30, 60]. A practical method of assessing balance and sensory input in the setting of ASD is the new Dubouset Functional Test. Completing this series of four simple timed tests (5 min walk: from a sitting position, stand, walk 5 m forward and backward, and return to a seated position; Stairs: climb up and down 3 stairs; Squat: squat up and down; Telephone: walk while speaking on the phone) was found to be feasible and safe for ASD patients [69]. Lemay et al. [44] re-

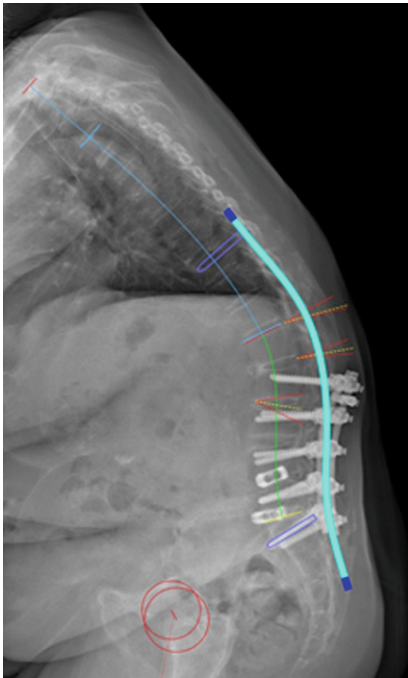


Fig. 7 ▲ Surgical planning for the patient, including Ponte osteotomy at T12-L1 and L1-L2, pedicle subtraction osteotomy at L3, and fusion from T5-S1

ported similar findings in patients with spinal cord injury utilizing the Mini-Balance Evaluation Systems Test (Mini-BESTest), a 14-item shortened clinical outcome score used to assess dynamic balance. This assessment method includes items evaluating sensory inputs, underscoring their role in maintaining static postural balance. Other such studies have been carried out to evaluate the utility of performance-based tests in assessing changes in balance, posture, or sensory function and their impact on postural alignment. Dugailly et al. [11] demonstrated the utility of the head repositioning test (HRT) in tracking management and progression of proprioceptive cervical deficits in patients with and without neck pain. In comparing patients with and without chronic lower back pain, da Silva et al. [63] validated the use of balance assessment during one-legged and semi-tandem stance in identifying deficiency in postural control in patients with chronic lower back pain, potentially revealing a tool to guide balance re-training for clinicians. Gautschi et al. [14] and Hartmann et al. [22] used the Timed Up and Go (TUG) test in patients

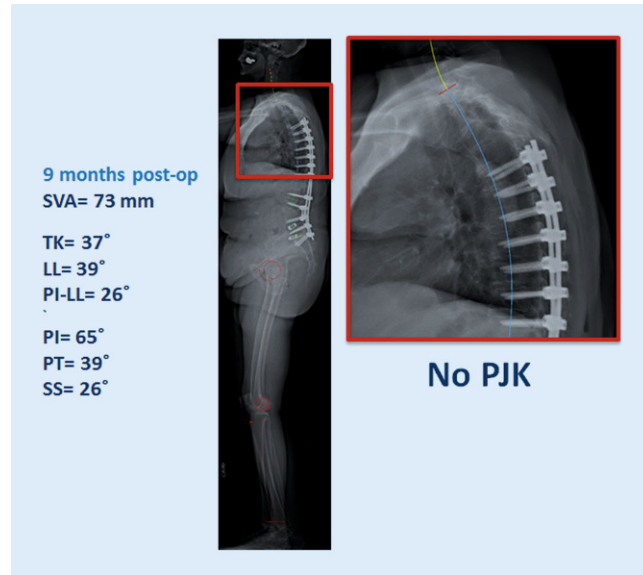


Fig. 8 ▲ Postoperative standing stereoradiography (9 months) of this 69-year-old patient following surgery, demonstrating resolution of proximal junctional kyphosis (PJK) and significant reduction in sagittal malalignment following age-adjusted goals for surgical correction (*insert is close up view*). SVA sagittal vertical axis, TK thoracic kyphosis, LL lumbar lordosis; PI-LL pelvic incidence minus lumbar lordosis, PI pelvic incidence, PT pelvic tilt, SS sacral slope

with lumbar degenerative disc disease, showing that the TUG test was a more sensitive and accurate tool for assessing the preoperative status and postoperative course than patient-reported outcomes, including the Visual Analog Scale (VAS) and EuroQol5D (EQ5D). Preoperative TUG test scores have been shown to predict the necessity of an assistive device 6 months following total hip arthroplasty [52], emphasizing the potential that such assessments may have in optimizing postoperative outcomes for patients with ASD. Moreover, current preoperative assessment and planning with respect to surgery for ASD is based on static radiographic imaging [5]. Lacking from the literature is a three-dimensional gait assessment of ASD patients preoperatively and postoperatively to identify dynamic factors related to the development of PJK. The kinematic and temporospatial data obtained could improve our understanding of the role of dynamic forces in the development of PJK and other complications following realignment surgery.

Conclusion

While surgical realignment for ASD has undergone significant advancement and improvement over the last decade, PJK remains a significant postoperative complication that challenges surgeons. In reviewing the literature, we have covered evidence-based discussion of prevalence and risk factors, both non-modifiable and surgeon-controlled. With an augmented understanding of all of the relevant factors in play, clinicians should be able to account for this phenomenon better and implement more patient-specific operative plans to optimize outcomes following realignment surgery for ASD.

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Compliance with ethical guidelines

Conflict of interest. C.B. Paulino is a paid presenter or speaker for DePuy, A Johnson & Johnson Company. F.J. Schwab receives research support from DePuy, is a paid consultant, presenter or speaker for K2M, Medtronic, Medtronic Sofamor Danek, Nuvasive, and Zimmer, owns stock or stock options in Nemaris INC, and is a board or committee member of the Scoliosis Research Society, Spine Deformity, and International Spine Society Group (Vice President). V. Lafage is a paid presenter or speaker for DePuy and Medtronic, receives research support from DePuy, is a board or committee member of the International Spine Study Group, Scoliosis Research Society, and Nemaris INC, and owns stock or stock options in Nemaris INC. B.G. Diebo, N.V. Shah and S.G. Stroud declare that they have no competing interests.

This article represents a review of the literature, including original studies of human or animal subjects performed by their respective authors, in order to complete this article. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Where applicable, informed consent was obtained from all individual participants included in the respective studies.

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Wie aus Knochen chirurgische Schrauben werden

Wenn Knochen mit medizinischer Unterstützung wieder zusammenheilen müssen, sind das chirurgische Mittel der Wahl meist Schrauben aus Titan oder Edelstahl. Während und nach dem Heilungsprozess werden diese Metallschrauben als störende Fremdkörper wahrgenommen und müssen oft in einem weiteren operativen Eingriff entfernt werden.

Österreichische Wissenschaftler entwickelten deshalb eine Alternative in der Orthopädie und Unfallchirurgie: eine Schraube, hergestellt aus dem besonders kompakten und harten Mittelteil des menschlichen Femur. Die Vorteile der Schraube aus Spenderknochen: Die Metallentfernung und damit eine zweite OP entfallen, da das Spendermaterial vollständig in den Knochen einheilt. So gut, dass das Transplantat nach etwa einem Jahr nicht mehr im Röntgen sichtbar ist. Zudem werden Infektionsgefahr und Komplikationen auf ein Minimum reduziert, da der Körper die Knochenschrauben als körpereigen erkennt.

Entscheidend ist dabei das Ausgangsmaterial: Die Spenderknochen stammen von Organ Spendern und dürfen erst nach strengen Selektionsverfahren und serologischen Screenings verwendet werden. Nicht jeder Spenderknochen eignet sich für die Herstellung jeder Knochenschraube. Ausschlaggebend ist die Größe der Havers-Kanäle, jener Kanäle, die Blutgefäße und Nervenbahnen der Knochenmitte entlang führen.

Derzeit entwickeln die Forscher die Schraube für die Anwendung in der Fuß- und Kieferchirurgie weiter, Bereiche, in denen die Knochen großen Belastungen standhalten müssen.

**Quelle: Technische Universität Graz,
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