INTERNATIONAL JOURNAL of SPINE SURGERY

Proximal Junctional Kyphosis Prevention Strategies Focused on Alignment

Mariah Balmaceno-Criss, Daniel Alsoof, Renaud Lafage, Bassel G. Diebo, Alan H. Daniels, Frank Schwab and Virginie Lafage

Int J Spine Surg published online 26 June 2023
https://www.ijssurgery.com/content/early/2023/06/22/8513

This information is current as of July 27, 2024.

The International Journal of Spine Surgery
2397 Waterbury Circle, Suite 1,
Aurora, IL 60504, Phone: +1-630-375-1432

International Journal of Spine Surgery, Vol. 00, No. 0, 2023, pp. 1–9
https://doi.org/10.14444/8513

Proximal Junctional Kyphosis Prevention Strategies Focused on Alignment

MARIAH BALMACENO-CRISS, BS[1]; DANIEL ALSOOF, MBBS[1]; RENAUD LAFAGE, MS[2]; BASSEL G. DIEBO, MD[1]; ALAN H. DANIELS, MD[1]; FRANK SCHWAB, MD[2]; AND VIRGINIE LAFAGE, PhD[2]

[1]*Department of Orthopedics, Brown University Warren Alpert Medical School, Providence, RI, USA;* [2]*Department of Orthopedics, Lenox Hill Hospital, Northwell Health, New York, NY, USA*

ABSTRACT

Adult spinal deformity (ASD) is a complex pathology associated with spinal malalignment in the coronal, sagittal, and axial planes. Proximal junction kyphosis (PJK) is a complication of ASD surgery, affecting 10%–48% of patients, and can result in pain and neurological deficit. It is defined radiographically as a greater than 10° Cobb angle between the upper instrumented vertebrae and the 2 vertebrae proximal to the superior endplate. Risk factors are classified according to the patient, surgery, and overall alignment, but it is important to consider the interplay between various factors. This article reviews the risk factors of PJK and considers alignment-focused prevention strategies.

Focus Issue Article

Keywords: adult spinal deformity, proximal junctional kyphosis, prevention, alignment

INTRODUCTION

Adult spinal deformity (ASD) is a complex pathology encompassing multiple conditions associated with spinal malalignment in the coronal, sagittal, and axial planes. Surgical management of ASD can improve a patient's health-related quality of life, with potential benefits compared with nonoperative treatment with a 5-year follow-up.[1–3] While there is a demonstrated benefit for surgical management in ASD, the risk of postoperative complications is high, affecting up to 70% of patients.[4] Despite the high complication rate, complications leading to prolonged hospitalization, invasive intervention, or increased morbidity and mortality contribute to only half of the overall rate.[4] One such complication is proximal junctional kyphosis (PJK), which affects 10% to 48% of patients who undergo ASD surgery, with reoperation rates ranging between 10% and 25%.[5–8]

Glattes et al define PJK radiographically in the sagittal plane using 2 criteria: (1) a ≥10° Cobb angle between the upper instrumented vertebrae (UIV) and the superior endplate 2 vertebrae proximal (UIV +2) and (2) a >10° change from the preoperative measurement.[9] PJK occurs early, with approximately 66% and 80% of PJK occurrences identified by 3 and 18 months after the operation, respectively.[10] Although PJK can present early, it also has a progressive component that can lead to late presentations, as demonstrated by Kim et al, who reported that patients continued to have kyphotic change beyond 2 years postoperatively.[11] Although PJK is common radiographically, ongoing debate remains over when PJK is a clinically significant finding. Multiple studies have shown that PJK may not significantly impact patient-reported outcome measurements (PROMs) by Scoliosis Research Society (SRS) and Oswestry Disability Index (ODI) scores.[9,12] Nevertheless, a previous study found a significant difference in the pain subcomponent of the SRS score despite no overall difference in SRS total score.[13] These findings support the notion that PJK has various degrees of severity ranging from a benign radiographic finding to proximal junctional failure (PJF) requiring surgical treatment (Figure 1).[14]

PJF is estimated to occur in 1.4% to 5.6% of patients following ASD surgery and is associated with neurological deficits, pain, and reduced functional outcomes.[14,15] PJF has been defined both radiographically and clinically. Radiographically, PJF is defined by Lafage et al as a proximal junctional angle (PJA) >28° or a change in PJA >22°.[16] Clinically, Yagi et al define PJF as symptomatic PJK requiring any type of revision surgery.[14] To evaluate PJK and determine when revision is recommended, the Hart-ISSG PJK Severity Scale can be utilized, with a retrospective analysis correlating higher HART scores to patients with more disability by ODI who ultimately underwent revision surgery.[15] In addition to the substantial morbidity associated with PJF, revision surgery has severe economic costs, with a direct cost of $3.2 million for only 57 cases in a previous study.[17] Given the progressive nature of PJK and the significant morbidity and cost associated with PJF, many studies

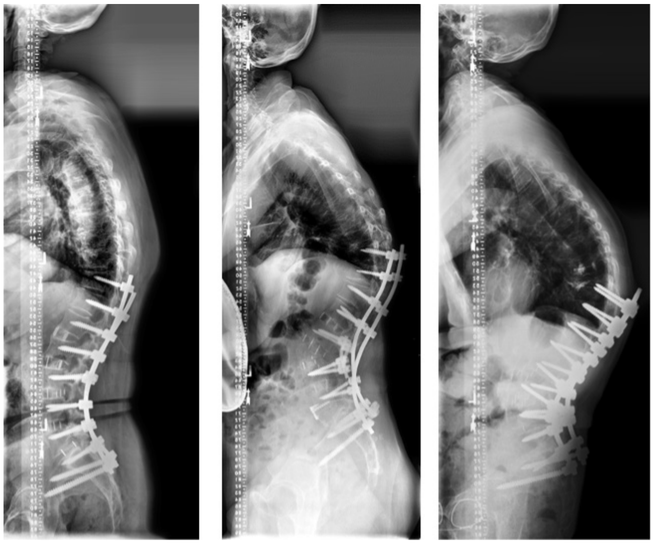

Figure 1. Example of different severity of junctional pathology from the radiographic finding on the left to catastrophic failure on the right.

and meta-analyses have investigated the risk factors for PJK development in order to pursue prevention.

While there has been significant research into PJK, a minimal number of risk factors have been consistently identified. The risk factors can be classified into categories related to the patient, the surgery, and overall alignment; however, citing any risk factor independently would be an oversimplification of PJK. For example, the patient-related risk factors most cited are low bone mineral density (BMD) and older age.[7,8] Since normal aging is marked by age-dependent degenerative changes in paraspinal muscle mass and bone quality, some of the risk associated with age is attributable to low BMD.[7,8] Fusion to the pelvis, an often-identified surgical risk factor, is another example because pelvic fusion can impact overall alignment.[7,8,18,19] Although a study by Yang et al identified that factors related to alignment play a greater role in predicting the risk of PJK than surgical factors, it is important to consider the interplay between various risk factors.[20] The focus of this article is to summarize the field's current understanding of alignment-related risk factors with an exploration of patient and surgery-related risks as they pertain to overall alignment.

ALIGNMENT-RELATED RISK FACTORS FOR PJK

Global sagittal alignment allows individuals to stand upright without pain or recruitment of compensatory mechanisms and requires concordance between the spine, pelvis, and lower extremities. It can be radiographically assessed using the sagittal vertical axis (SVA) or the T1 pelvic angle (TPA) and is influenced by the following spinopelvic parameters: thoracic kyphosis (TK), lumbar lordosis (LL), pelvic incidence (PI), and pelvic tilt (PT).

Postoperative Global Sagittal Alignment and Risk of PJK

Global sagittal malalignment has been cited many times as a risk factor for PJK development. For example, Kim et al found PJK patients postoperatively had a greater correction in SVA, and restoration of SVA to <1 cm was associated with revision surgery.[18] While data from Yagi et al corroborated that PJK patients had a greater correction in SVA, they found restoration of SVA to <1 cm to be protective against PJK development.[19] Perhaps the divergence in these study results, as well as others, can be explained by differences in patient demographics and the variable interconnection between the spinopelvic parameters to achieve a given global alignment. Despite the differences, both studies demonstrated that patients with PJK had greater deformity correction.

Overcorrection in ASD may in part be a result of applying a one-size fits all approach to restoring spinopelvic parameters to alignment based on SRS-Schwab classification without accounting for patient demographics. To investigate the impact of age on alignment, Lafage et al utilized regression analysis to generate spinopelvic parameters based on age-specific PROMs.[21,22] The study demonstrated greater spinopelvic parameter values with increased age.[23] Lafage et al performed a retrospective analysis using offsets between actual and age-adjusted (AA) ideal alignment and found that PJK patients had overcorrections in PI-LL mismatch and SVA. Furthermore, the study revealed a positive correlation between the magnitude of the PJK angle and the amount of sagittal parameter overcorrection. Retrospective application of AA alignment parameters to another subset of patients lowered the odds of PJK by 55% and the odds of PJF by 60.4%.[21,22]

On the other hand, undercorrection of spinal deformity was also found to be associated with the development of PJK in some studies. Im et al further demonstrated that, compared with overcorrected patients, those undercorrected had larger SVA and worse ODI but similar PJK rates.[24] Similar findings were proposed by Rothenfluh et al in the setting of degenerative lumbar disease. They found that patients with a spinopelvic mismatch (PI-LL >10°) had a 10-fold higher risk of developing junctional segment disease.[25] However, Byun et al and Sebaaly et al found that undercorrection led to significantly less PJK than overcorrection.[26,27]

Assessing postoperative SVA in PJK patients is difficult since the occurrence of PJK will affect the overall alignment and increase SVA. As such, it is more relevant to assess the alignment of the fused segment. Lafage et al investigated the pattern of fused lumbar alignment and shape in 50 patients requiring revision surgery for PJK.[28] An unsupervised cluster analysis was performed and revealed 2 distinct patterns: under- and overcorrected cohorts. Undercorrected patients had an anterior alignment of the lumbar spine with a larger PI-LL mismatch. Overcorrected patients had a posterior alignment of the lumbar spine with a negative PI-LL. Despite the differences in lumbar alignment, both groups underwent similar revision surgeries. This study further demonstrated that the etiology of PJK may vary according to the alignment of the fused segment. PJF following undercorrection may be due to excessive loading in an unfavorable position, whereas PJK in overcorrection may be a pathological compensation to achieve acceptable global alignment.

Classification Systems to Guide Operative Alignment Targets

Both SRS-Schwab (SRS) and AA classification systems attempt to define "normative alignment" with thresholds for PI-LL mismatch, SVA, and PT derived from patient-reported outcomes targets. However, these approaches do not account for the extremes of PI. In individuals with large PI values, higher PT values are required for physiologic alignment and may be outside what is considered "normative." To address this limitation of the SRS and AA classification systems, the Global Alignment and Proportion (GAP) score was developed (Figure 2). The GAP score provides a patient-specific assessment of disproportion normalized to PI. Yiglor et

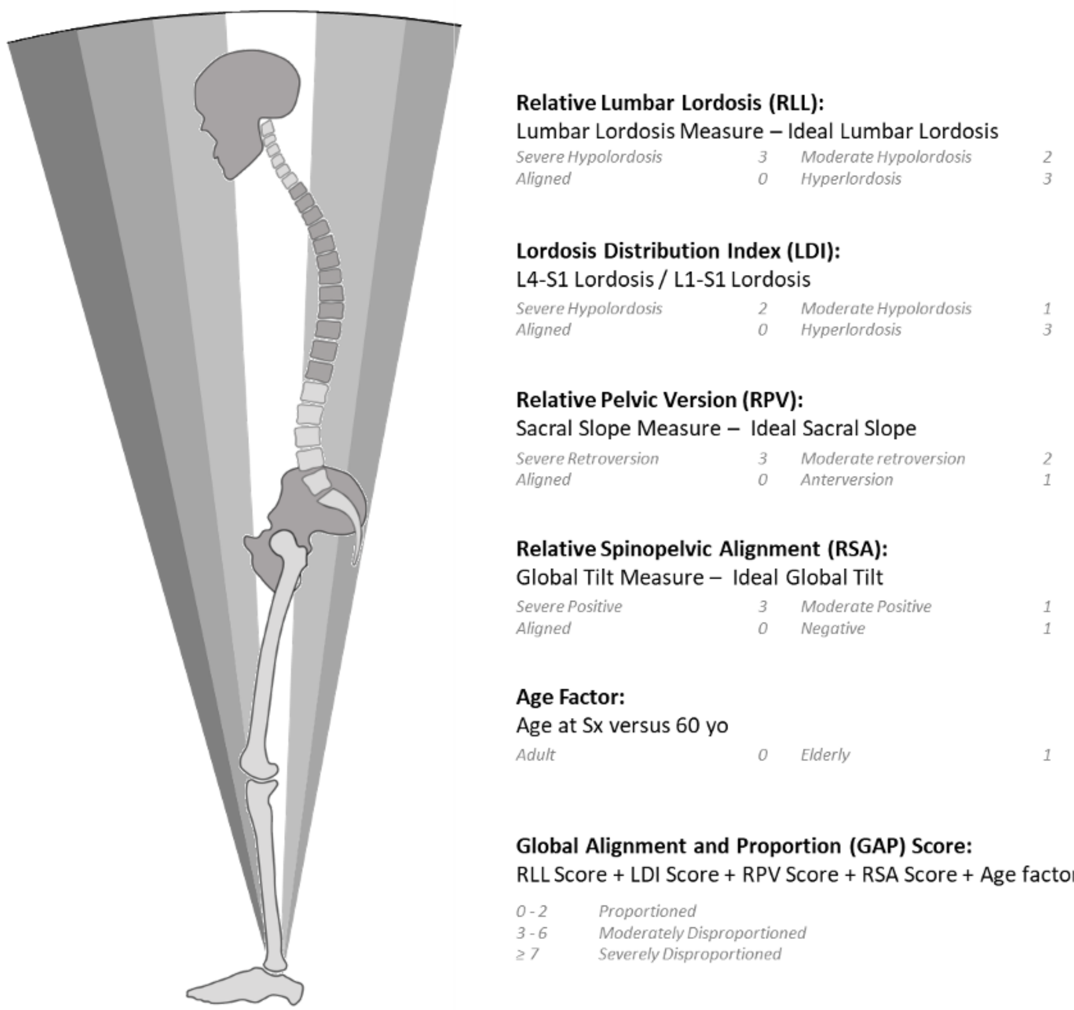

Figure 2. Global Alignment and Proportion score method.

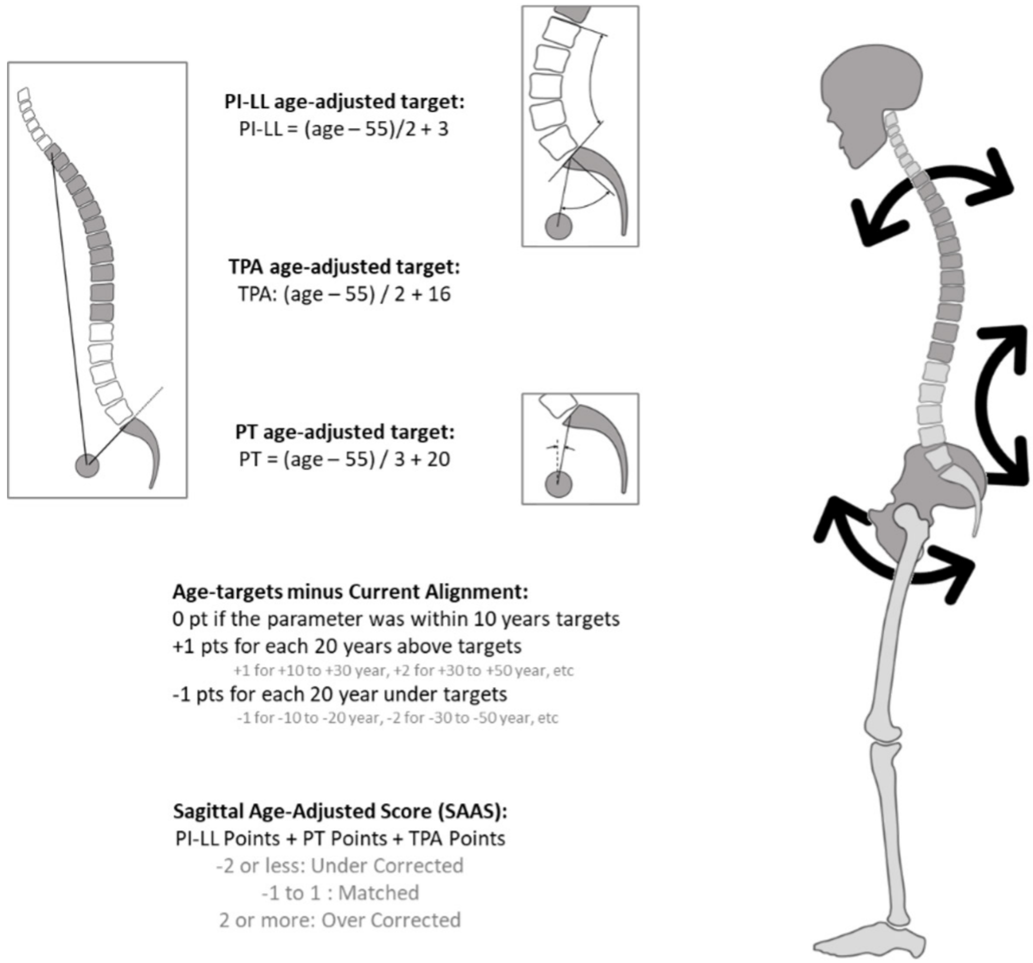

Figure 3. Sagittal age-adjusted score (SAAS) and age-alignment targets. PI-LL, pelvic incidence-lumbar lordosis; TPA, T1 pelvic angle; PT, pelvic tilt

al associated higher GAP scores with greater disproportion and a higher prevalence of mechanical complications.[29] Despite these findings, the GAP scoring system has given mixed results with external validation. There is ongoing work to refine the GAP score to include an assessment of fragility status, BMI, and BMD to maximize clinical outcomes in the ASD population.[30,31]

To address the limitations of previous classification work and build upon them, the Sagittal AA score (SAAS) was developed (Figure 3). The SAAS system assigns scores based on the difference between postoperative alignment and ideal AA alignment for PI-LL, PT, and T1PA. Based on all 3 of these parameters, the scoring system determines whether the alignment is age-matched and whether it is over- or undercorrected. When SAAS was retrospectively applied to a cohort of ASD patients, the SAAS score increased as PJK pathology progressed to PJF.[32] Furthermore, in patients with severe deformity, alignment with the SAAS system significantly reduced the odds of PJF.[22]

Overall Alignment Is Influenced by the Location of Correction

Although the degree of correction is a well-established alignment risk factor for PJK, more granular studies have begun to delve into the impact of the correction location on PJK risk. Lafage et al found that patients with PJK had regional overcorrection of lordosis, with more lordotic correction in the upper lumbar segments as opposed to lower lumbar segments (L4-S1), where most of the natural LL is thought to occur.[33–35] Pizones et al reported similar findings, demonstrating a positive correlation between the risk of PJK and distance from ideal lumbar apex location based on PI.[36] Increased rates of PJK following 3-column osteotomies, most located at L3, further substantiate the importance of postoperative lordotic distribution conservation.[37] To account for the relationship between PI and LL, PI-based proportional parameters for the magnitude and distribution of LL were developed, represented by relative

LL and lordosis distribution index (LDI), respectively. Surgical alignment with these parameters, detailed in a retrospective study by Yiglor et al, reduced the risk of mechanical complications by 20% when compared with surgical targeting of PI-LL <10°.[38] The authors attribute the reduction in complications to PI-LL being oversimplistic, whereas relative LL and LDI allow for a more precise and individualized interpretation of LL; however, these findings have yet to be validated in prospective studies.

Ang et al investigated whether the location of posterior spinal instrumentation influences the proportionality between LL and TK.[39] The group first established the baseline proportions between LL and TK using healthy volunteers, where TK is roughly equal to 40% of LL. The study demonstrated that following the fusion of the lumbar spine, there was a disproportion between curves unless the thoracic spine was flexible. When lumbar fusion occurred in patients with a flexible thoracic spine, compensatory reciprocal changes occurred in the thoracic spine to maintain proportionality between the 2 curves. This study underscores the importance of establishing adequate TK in patients with long spinal fusion. Inadequate restoration of TK proportional to LL led to higher rates of PJK in this subset of patients. This work finetunes earlier findings from Mendoza-Lattes et al where PJK rates increased in patients with a greater TK than final LL.[40]

Thoracic Spine and Alignment

Despite the evidence suggesting that inadequate restoration of TK is associated with PJK, studies regarding thoracic spine morphology have just begun to surface. Lafage et al recently detailed normative thoracic alignment in asymptomatic adults.[41] The study determined that utilizing T4-T12 kyphosis in surgical planning underestimated maximum TK, capturing only 78% of the maximum, whereas the use of T1-T12 kyphosis was representative of 90% of maximum TK. T7 was identified to be the apex of kyphosis and was preserved regardless of patient age or magnitude of overall kyphosis. The study also found that the distribution of kyphosis around the apex depends on the magnitude of maximum kyphosis. In patients with lower magnitudes of kyphosis, two-thirds of the total kyphosis is distributed superior to the apex. Patients with higher magnitudes of kyphosis had less kyphosis in the superior segment and a more symmetrical distribution of kyphosis around the apex.

Lovecchio et al illustrated how thoracic flexibility allows for position-dependent changes in TK that may be protective or increase the risk for PJK.[42] For certain patients, the transition from standing to supine positioning leads to increased TK (kyphotic change) or thoracic flattening (lordotic change) (Figure 4). Patients with thoracic flattening had a PJK rate of 35% compared with 0% in patients with increased TK. In patients with thoracic flattening while supine, PJK may result from an overestimation of the lordosis required for optimal alignment and fusion of patients in flatter-than-ideal positions. On the other hand, patients with an exaggeration of TK while supine have a reserve of thoracic compensation to protect against potential postoperative malalignment. These findings emphasize the utility of

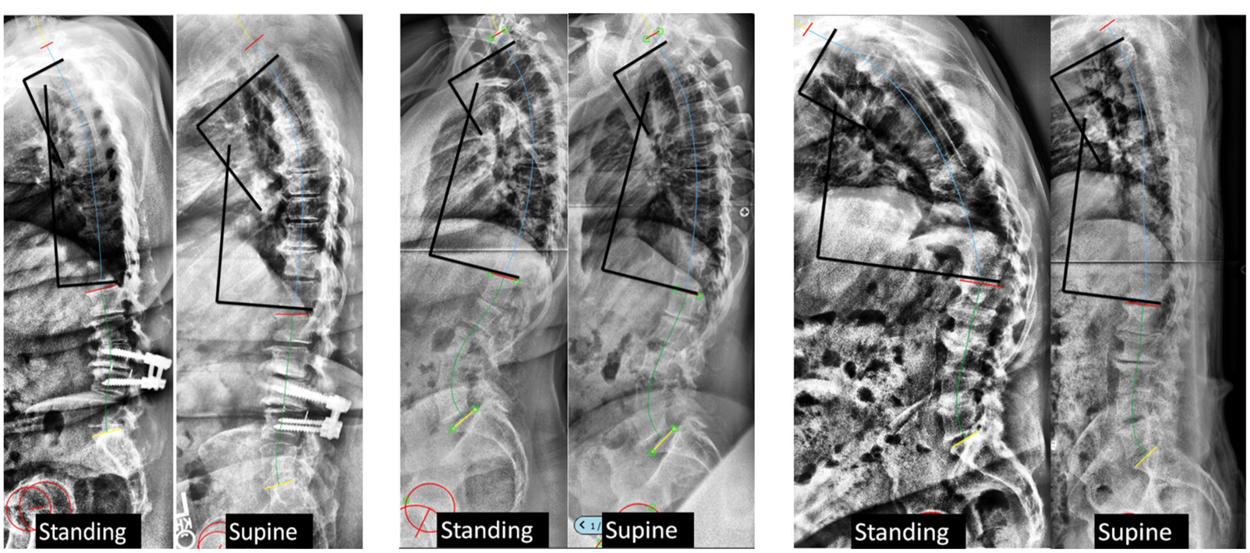

Figure 4. Change in thoracic kyphosis (TK) curvature between positions varied from an increase in TK from standing to supine (left) to a decrease in TK from standing to supine (right).

supine radiographs in preoperative surgical planning to predict postoperative thoracic changes.

Postoperative thoracic changes are also influenced by compensatory changes occurring in the thoracic spine preoperatively. Protopsaltis et al studied the phenomenon of reciprocal thoracic kyphosis (RK), defined by a postoperative increase of >15° from preoperative TK in the unfused segment.[43] Patients with RK had more preoperative lumbar mismatch (PI-LL) compared with controls, despite having similar preoperative SVA and TPA. The study attributed similarities in preoperative global deformity between the groups to compensatory changes in the RK group. The compensatory change, evidenced by a smaller preoperative magnitude of TK, was dubbed thoracic hypokyphosis. Preoperative compensation in the RK group was associated with greater deformity correction and an increased rate of PJK (66% vs 19%) compared with the control group. Underappreciation of preoperative compensation allows for surgical overcorrection relative to postoperative kyphosis restoration. This study highlights the importance of identifying TK reserve to anticipate postoperative changes that may impact the integrity of the construct.

An essential component of the mechanical integrity of the construct is dependent on the transition from the instrumented proximal spine at the UIV. Lafage et al examined the impact of the UIV location and orientation on the development of PJK.[44] In patients in whom the UIV is in the lower thoracic (T7-T12) region, rates of PJK were 63.5% compared with 49.2% for patients with UIV in the upper thoracic (T1-T6) region. The authors concluded that proximity between the corrected deformity and the end of the construct may contribute to the development of PJK, although it could be that PJK is also related to proximal forces, facet orientation, and ligamentous differences across levels. In patients who developed PJK, there was a decreased and more posterior-oriented UIV inclination but no difference in the UIV slope compared with controls without PJK. This finding exemplifies that posterior displacement of force predisposes the development of PJK. The authors suggested that a gradual transition from the rigid construct to the surrounding vertebrae may decrease posterior displacement of force and consequently decrease the risk for PJK.

LIMITATIONS OF CURRENT LITERATURE AND THE FUTURE OF ALIGNMENT RESEARCH

While significant progress has occurred in the understanding of spinal alignment, the current knowledge base fails to recapitulate the complexity of ASD. Many studies to date have used only parameters based on bony landmarks to evaluate the spine. Simplifying the spine in this way leads to an examination of the spine in isolation. Furthermore, this approach to alignment often fails to consider the surrounding soft tissues or the dynamic changes that occur in the spine. Investigation into the soft tissue surrounding the spine and its influence on mechanical outcomes is surprisingly limited. Hyun et al examined the size and quality of the thoracolumbar musculature in 44 cases of ASD surgery.[45] The study revealed that patients with PJK had decreased muscularity and increased fatty degeneration of the thoracolumbar musculature (Figure 5). Pennington et al corroborated these earlier findings by showing that decreased paraspinal muscle size at the UIV correlates positively with the development of PJK.[46]

Current analysis of spinal alignment has largely been limited to a single static position, most often from standing radiographs, even though the spine must change position to allow for sitting, standing, and walking

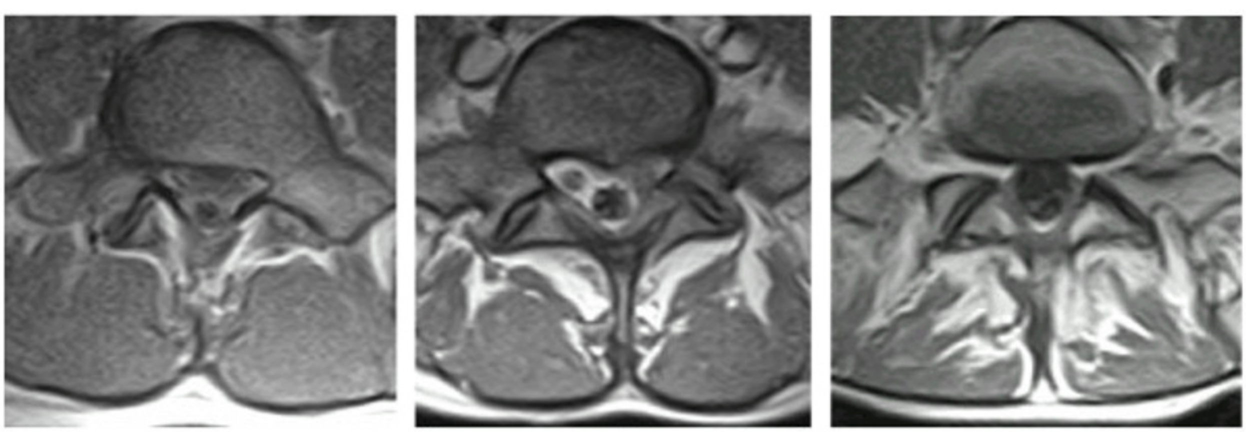

Figure 5. Increase in fat infiltration in posterior muscle from left to right.

necessary for everyday life. Suzuki et al and Moon et al both demonstrated sitting was associated with lower LL and increased PT compared with standing.[47,48] Moon et al additionally found that sitting reduced sacral slope.[48] Otayek et al examined asymptomatic volunteers using 3D gait analysis (3DGA) and found that increased SVA was associated with increased knee flexion during gait, an increase in forward inclination of the trunk while standing, and limited pelvic mobility.[49] An increased PT was associated with a retroverted pelvis and reduced mobility of the pelvis while walking. Finally, a larger TK correlated with decreased hip mobility in the sagittal plane. These changes in the spinopelvic parameters with dynamic positioning are integral to the next steps in alignment-based research. Since spinal body balance is an active process, preoperative planning with 3DGA could be an invaluable tool to assess the dynamic, rotational, and horizontal aspects of deformity that would otherwise be unobtainable.[50]

CONCLUSION

ASD is associated with significant morbidity; surgeons have sought to restore global alignment to reduce morbidity and improve PROMs. However, utilizing one-size fits all spinopelvic parameters to achieve global alignment carries a significant risk for mechanical complications like PJK. Instead, surgical intervention should aim to restore patients to their AA ideal alignment and should consider the interplay between the spinopelvic parameters. Work is ongoing to utilize this comprehensive appreciation of individual anatomy to fine-tune current classification systems.

In addition to establishing the appropriate degree of correction, we must consider how the location of the intended correction will impact postsurgical TK and LL and the overall proportionality between these curves. Compensatory changes occurring in the spine, surrounding soft tissues, and pelvis in response to deformity must also be appreciated to anticipate their impact on postsurgical alignment. A complete understanding of spinal deformity and its induced compensatory changes necessitates evaluations, such as 3DGA, that can recapitulate some of the complexity of this disease process. Given the complexity of ASD, considering alignment alone cannot eliminate the risk of PJK. Line et al examined the risk of PJK following the use of AA alignment goals and surgical implant prophylaxis.[51] The combined use of AA alignment goals and implant prophylaxis led to a significant reduction in the incidence of PJK from 24.2% to 9.9%. These results support approaching PJK prevention through combined optimization of patient risk factors, surgical approach, and alignment goals. An approach with so many variables may seem daunting, but advances in artificial intelligence are making it easier than ever to apply machine-based learning to predict ASD outcomes tailored to each patient.[52] These up-and-coming advances will hopefully allow for more personalized preoperative counseling.

REFERENCES

1. Bridwell KH, Glassman S, Horton W, et al. Does treatment (nonoperative and operative) improve the two-year quality of life in patients with adult symptomatic lumbar scoliosis: a prospective multicenter evidence-based medicine study. *Spine (Phila Pa 1976)*. 2009;34(20):2171–2178. doi:10.1097/BRS.0b013e3181a8fdc8
2. Glassman SD, Carreon LY, Shaffrey CI, et al. Cost-effectiveness of adult lumbar scoliosis surgery: an as-treated analysis from the adult symptomatic scoliosis surgery trial with 5-year follow-up. *Spine Deform*. 2020;8(6):1333–1339. doi:10.1007/s43390-020-00154-w
3. Smith JS, Kelly MP, Yanik EL, et al. Operative versus nonoperative treatment for adult symptomatic lumbar scoliosis at 5-year follow-up: durability of outcomes and impact of treatment-related serious adverse events. *J Neurosurg Spine*. 2021:1–13. doi:10.3171/2020.9.SPINE201472
4. Smith JS, Shaffrey CI, Kim HJ, et al. Prospective multicenter assessment of all-cause mortality following surgery for adult cervical deformity. *Neurosurgery*. 2018;83(6):1277–1285. doi:10.1093/neuros/nyx605
5. Alshabab BS, Lafage R, Smith JS, et al. Evolution of proximal junctional kyphosis and proximal junctional failure rates over 10 years of enrollment in a prospective multicenter adult spinal deformity database. *Spine*. 2022;47(13):922–930. doi:10.1097/BRS.0000000000004364
6. Scheer JK, Tang JA, Smith JS, et al. Reoperation rates and impact on outcome in a large, prospective, multicenter, adult spinal deformity database: clinical article. *J Neurosurg Spine*. 2013;19(4):464–470. doi:10.3171/2013.7.SPINE12901
7. Kim JS, Phan K, Cheung ZB, et al. Surgical, radiographic, and patient-related risk factors for proximal junctional kyphosis: a meta-analysis. *Global Spine J*. 2019;9(1):32–40. doi:10.1177/2192568218761362
8. Liu FY, Wang T, Yang SD, Wang H, Yang DL, Ding WY. Incidence and risk factors for proximal junctional kyphosis: a meta-analysis. *Eur Spine J*. 2016;25(8):2376–2383. doi:10.1007/s00586-016-4534-0
9. Glattes RC, Bridwell KH, Lenke LG, Kim YJ, Rinella A, Edwards C. Proximal junctional kyphosis in adult spinal deformity following long instrumented posterior spinal fusion: incidence, outcomes, and risk factor analysis. *Spine (Phila Pa 1976)*. 2005;30(14):1643–1649. doi:10.1097/01.brs.0000169451.76359.49
10. Lau D, Clark AJ, Scheer JK, et al. Proximal junctional kyphosis and failure after spinal deformity surgery. *Spine*. 2014;39(25):2093–2102. doi:10.1097/BRS.0000000000000627
11. Kim YJ, Bridwell KH, Lenke LG, Glattes CR, Rhim S, Cheh G. Proximal junctional kyphosis in adult spinal deformity after segmental posterior spinal instrumentation and fusion: minimum five-year follow-up. *Spine (Phila Pa 1976)*. 2008;33(20):2179–2184. doi:10.1097/BRS.0b013e31817c0428

12. Lau D, Clark AJ, Scheer JK, et al. Proximal junctional kyphosis and failure after spinal deformity surgery: a systematic review of the literature as a background to classification development. *Spine (Phila Pa 1976)*. 2014;39(25):2093–2102. doi:10.1097/BRS.0000000000000627

13. Kim HJ, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis results in inferior SRS pain subscores in adult deformity patients. *Spine (Phila Pa 1976)*. 2013;38(11):896–901. doi:10.1097/BRS.0b013e3182815b42

14. Yagi M, Rahm M, Gaines R, et al. Characterization and surgical outcomes of proximal junctional failure in surgically treated patients with adult spinal deformity. *Spine (Phila Pa 1976)*. 2014;39(10):E607–E614. doi:10.1097/BRS.0000000000000266

15. Lau D, Funao H, Clark AJ, et al. The clinical correlation of the Hart-ISSG proximal junctional kyphosis severity scale with health-related quality-of-life outcomes and need for revision surgery. *Spine (Phila Pa 1976)*. 2016;41(3):213–223. doi:10.1097/BRS.0000000000001326

16. Lafage R, Schwab FJ, et al. Redefining radiographic thresholds for junctional kyphosis pathologies. *The Spine Journal*. 2015;15(10):S216. doi:10.1016/j.spinee.2015.07.307

17. Theologis AA, Miller L, Callahan M, et al. The economic impact of revision surgery for proximal junctional failure after adult spinal deformity surgery. *Spine*. 2016;41(16):E964–E972. doi:10.1097/BRS.0000000000001523

18. Kim HJ, Bridwell KH, Lenke LG, et al. Patients with proximal junctional kyphosis requiring revision surgery have higher postoperative lumbar lordosis and larger sagittal balance corrections. *Spine (Phila Pa 1976)*. 2014;39(9):E576–E580. doi:10.1097/BRS.0000000000000246

19. Yagi M, Akilah KB, Boachie-Adjei O. Incidence, risk factors and classification of proximal junctional kyphosis: surgical outcomes review of adult idiopathic Scoliosis. *Spine (Phila Pa 1976)*. 2011;36(1):E60–E68. doi:10.1097/BRS.0b013e3181eeaee2

20. Yang J, Khalifé M, Lafage R, et al. What factors predict the risk of proximal junctional failure in the long term, demographic, surgical, or radiographic?: results from a time-dependent ROC curve. *Spine (Phila Pa 1976)*. 2019;44(11):777–784. doi:10.1097/BRS.0000000000002955

21. Lafage R, Schwab F, Glassman S, et al. Age-adjusted alignment goals have the potential to reduce PJK. *Spine (Phila Pa 1976)*. 2017;42(17):1275–1282. doi:10.1097/BRS.0000000000002146

22. Joujon-Roche R, Krol O, Imbo B, et al. 182. impact of realignment Schemas on rates of proximal junctional changes in adult spinal deformity surgery. *The Spine Journal*. 2022;22(9):S97. doi:10.1016/j.spinee.2022.06.201

23. Lafage R, Schwab F, Challier V, et al. Defining spino-pelvic alignment thresholds: should operative goals in adult spinal deformity surgery account for age? *Spine (Phila Pa 1976)*. 2016;41(1):62–68. doi:10.1097/BRS.0000000000001171

24. Im S-K, Lee J-H, Kang K-C, et al. Proximal junctional kyphosis in degenerative sagittal deformity after under- and overcorrection of lumbar lordosis. *Spine (Phila Pa 1976)*. 2020;45(15):E933–E942. doi:10.1097/BRS.0000000000003468

25. Rothenfluh DA, Mueller DA, Rothenfluh E, Min K. Pelvic incidence-lumbar lordosis mismatch predisposes to adjacent segment disease after lumbar spinal fusion. *Eur Spine J*. 2015;24(6):1251–1258. doi:10.1007/s00586-014-3454-0

26. Byun CW, Cho JH, Lee CS, Lee D-H, Hwang CJ. Effect of overcorrection on proximal junctional kyphosis in adult spinal deformity: analysis by age-adjusted ideal sagittal alignment. *Spine J*. 2022;22(4):635–645. doi:10.1016/j.spinee.2021.10.019

27. Sebaaly A, Sylvestre C, El Quehtani Y, et al. Incidence and risk factors for proximal junctional kyphosis: results of a multicentric study of adult scoliosis. *Clin Spine Surg*. 2018;31(3):E178–E183. doi:10.1097/BSD.0000000000000630

28. Lafage R, Passias P, Sheikh Alshabab B, et al. Patterns of lumbar spine malalignment leading to revision surgery for proximal junctional kyphosis: a cluster analysis of over- versus under-correction. *Global Spine J*. 2022:21925682211047460. doi:10.1177/21925682211047461

29. Yilgor C, Sogunmez N, Boissiere L, et al. Global alignment and proportion (GAP) score. *The Journal of Bone and Joint Surgery*. 2017;99(19):1661–1672. doi:10.2106/JBJS.16.01594

30. Passias PG, Williamson TK, Krol O, et al. Should global realignment be tailored to frailty status for patients undergoing surgical intervention for adult spinal deformity? *Spine (Phila Pa 1976)*. 2022. doi:10.1097/BRS.0000000000004501

31. Noh SH, Ha Y, Park JY, et al. Modified global alignment and proportion scoring with body mass index and bone mineral density analysis in global alignment and proportion score of each 3 categories for predicting mechanical complications after adult spinal deformity surgery. *Neurospine*. 2021;18(3):484–491. doi:10.14245/ns.2142470.235

32. Lafage R, Smith JS, Elysee J, et al. Sagittal age-adjusted score (SAAS) for adult spinal deformity (ASD) more effectively predicts surgical outcomes and proximal junctional kyphosis than previous classifications. *Spine Deform*. 2022;10(1):121–131. doi:10.1007/s43390-021-00397-1

33. Lafage R, Obeid I, Liabaud B, et al. Location of correction within the lumbar spine impacts acute adjacent-segment kyphosis. *J Neurosurg Spine*. 2018;30(1):69–77. doi:10.3171/2018.6.SPINE161468

34. Harrison DE, Harrison DD, Cailliet R, Janik TJ, Holland B. Radiographic analysis of lumbar lordosis: centroid, cobb, TRALL, and Harrison posterior tangent methods. *Spine (Phila Pa 1976)*. 2001;26(11):E235–E242. doi:10.1097/00007632-200106010-00003

35. Gelb DE, Lenke LG, Bridwell KH, Blanke K, McEnery KW. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *Spine*. 1995;20(12):1351–1358. doi:10.1097/00007632-199520120-00005

36. Pizones J, Perez-Grueso FJS, Moreno-Manzanaro L, et al. Ideal sagittal profile restoration and ideal lumbar apex positioning play an important role in postoperative mechanical complications after a lumbar PSO. *Spine Deform*. 2020;8(3):491–498. doi:10.1007/s43390-019-00005-3

37. Diebo BG, Lafage V, Varghese JJ, et al. After 9 years of 3-column osteotomies, are we doing better? Performance curve analysis of 573 surgeries with 2-year follow-up. *Neurosurgery*. 2018;83(1):69–75. doi:10.1093/neuros/nyx338

38. Yilgor C, Sogunmez N, Yavuz Y, et al. Relative lumbar lordosis and lordosis distribution index: individualized pelvic incidence-based proportional parameters that quantify lumbar lordosis more precisely than the concept of pelvic incidence minus lumbar lordosis. *Neurosurg Focus*. 2017;43(6):E5. doi:10.3171/2017.8.FOCUS17498

39. Ang B, Lafage R, Elysée JC, et al. In the relationship between change in kyphosis and change in kordosis: which drives which *Global Spine Journal*. 2021;11(4):541–548. doi:10.1177/2192568220914882

40. Mendoza-Lattes S, Ries Z, Gao Y, Weinstein SL. Proximal junctional kyphosis in adult reconstructive spine surgery results from incomplete restoration of the lumbar lordosis relative to the magnitude of the thoracic kyphosis. *Iowa Orthop J*. 2011;31:199–206.

41. Lafage R, Steinberger J, Pesenti S, et al. Understanding thoracic spine morphology, shape, and proportionality. *Spine (Phila Pa 1976)*. 2020;45(3):149–157. doi:10.1097/BRS.0000000000003227

42. Lovecchio F, Lafage R, Elysee JC, et al. The utility of supine radiographs in the assessment of thoracic flexibility and risk of proximal junctional kyphosis. *J Neurosurg Spine*. 2021:1–7. doi:10.3171/2020.11.SPINE201565

43. Protopsaltis TS, Diebo BG, Lafage R, et al. Identifying thoracic compensation and predicting reciprocal thoracic kyphosis and proximal junctional kyphosis. *North American Spine Society*. 2015.

44. Lafage R, Line BG, Gupta S, et al. Orientation of the upper-most Instrumented segment influences proximal junctional disease following adult spinal deformity surgery. *Spine*. 2017;42(20):1570–1577. doi:10.1097/BRS.0000000000002191

45. Hyun S-J, Kim YJ, Rhim S-C. Patients with proximal junctional kyphosis after stopping at thoracolumbar junction have lower muscularity, fatty degeneration at the thoracolumbar area. *Spine J*. 2016;16(9):1095–1101. doi:10.1016/j.spinee.2016.05.008

46. Pennington Z, Cottrill E, Ahmed AK, et al. Paraspinal muscle size as an independent risk factor for proximal junctional kyphosis in patients undergoing thoracolumbar fusion. *J Neurosurg Spine*. 2019;31(3):380–388. doi:10.3171/2019.3.SPINE19108

47. Suzuki H, Endo K, Sawaji Y, et al. Radiographic assessment of spinopelvic sagittal alignment from sitting to standing position. *Spine Surg Relat Res*. 2018;2(4):290–293. doi:10.22603/ssrr.2017-0074

48. Moon MS, Lee H, Kim ST, Kim SJ, Kim MS, Kim DS. Spinopelvic orientation on radiographs in various body postures: upright standing, chair sitting, Japanese style kneel sitting, and Korean style cross-legged sitting. *Clin Orthop Surg*. 2018;10(3):322. doi:10.4055/cios.2018.10.3.322

49. Otayek J, Bizdikian AJ, Yared F, et al. Influence of spinopelvic and postural alignment parameters on gait kinematics. Gait Posture. 2020;76:318-326. 10.1016/j.gaitpost.2019.12.029

50. Diebo BG, NV Shah, Pivec R, et al. From static spinal alignment to dynamic body balance: utilizing motion analysis in spinal deformity surgery. JBJS Rev. 2018;6(7e310.2106/JBJS.RVW.17.00189

51. Line BG, Bess S, Lafage R, et al. Effective prevention of proximal junctional failure in adult spinal deformity surgery requires a combination of surgical implant prophylaxis and avoidance of sagittal alignment overcorrection. *Spine*. 2020;45(4):258–267. doi:10.1097/BRS.0000000000003249

52. Joshi RS, Lau D, Ames CP. Artificial intelligence for adult spinal deformity: current state and future directions. *Spine J*. 2021;21(10):S1529-9430(21)00216-3):1626–1634:. doi:10.1016/j.spinee.2021.04.019

Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests: Bassel G. Diebo discloses the following: consulting fees from SpineVision. Alan H. Daniels discloses the following: consulting fees from Stryker, Orthofix, Spineart, and EOS; research support from Southern Spine; fellowship support from Orthofix. Frank Schwab discloses the following: consulting fees from Mainstay Medical, Medtronic, Zimmer; IP royalties from K2M, Medtronic Sofamor Danek; research support from DePuy, Nuvasive, and Stryker; board member for International Spine Study Group. Virgine Lafage discloses the following: consulting fees from Alphatec Spine, Globus Medical; IP royalties from Nuvasive; board member for International Spine Study Group, Scoliosis Research Society. The remaining authors have nothing to report.

Corresponding Author: Virginie Lafage, Department of Orthopedics, Lenox Hill Hospital, Northwell Health, 130 E 77th St, 12th Floor, New York, NY 10075, USA; virginie.lafage@gmail.com