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Should pelvic incidence influence realignment strategy? A detailed analysis in adult spinal deformity

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OBJECTIVE The purpose of this study was to assess how various realignment strategies affect mechanical failure and clinical outcomes in pelvic incidence (PI)–stratified cohorts following adult spinal deformity (ASD) surgery.

METHODS Median and interquartile range statistics were calculated for demographics and surgical details. Further statistical analysis was used to define subsets within PI generating significantly different rates of mechanical failure. These subsets of PI were further analyzed as subcohorts for the outcomes and effects of realignment within each subcohort. Multivariate logistic regression analysis controlling for baseline frailty and lumbar lordosis (LL; L1–S1) analyzed the association of age-adjusted realignment and Global Alignment and Proportion (GAP) strategies with the incidence of mechanical failure and clinical improvement within PI-stratified groups.

RESULTS A parabolic relationship between PI and mechanical failure was noted, whereas patients with either < 51° (n = 174, 39.1% of cohort) or > 63° (n = 114, 25.6% of cohort) of PI generated higher rates of mechanical failure (18.0% and 20.0%, respectively) and lower rates of good outcome (80.3% and 77.6%, respectively) than those with moderate PI (51°–63°). Patients with lower PI more often met good outcome criteria when undercorrected in age-adjusted PI-LL mismatch and sagittal age-adjusted score, and those not meeting good outcome criteria were more likely to deteriorate in GAP relative LL from first to final follow-up (OR 13.4, 95% CI 1.3–139.2). In those with moderate PI, patients were more likely to meet good outcome when aligned on the GAP lordosis distribution index (LDI; OR 1.7, 95% CI 0.9–3.3). Patients with higher PI meeting good outcome were more likely to be overcorrected in sagittal vertical axis (OR 2.4, 95% CI 1.1–5.2) at first follow-up and less likely to be undercorrected in T1 pelvic angle (OR 0.4, 95% CI 0.2–0.9) by final follow-up. When assessing GAP alignment, patients were more likely to meet good outcome when aligned on GAP LDI (OR 3.5, 95% CI 1.4–8.9).

CONCLUSIONS There was a parabolic relationship between PI and both mechanical failure and clinical improvement following deformity correction in this study. Understanding the associations between this fixed parameter and poor outcomes can aid the surgeon in strategical planning when seeking to realign ASD.

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KEYWORDS spinal deformity; pelvic incidence; mechanical failure; realignment; age-adjusted

Adult spinal deformity (ASD) encompasses a spectrum of thoracolumbar spine pathology, with the potential to cause significant pain and debilitation in affected individuals.[1] The etiology of ASD is multifactorial and is commonly characterized by progressive, asymmetrical degenerative changes that may be focal, regional, and/or global in nature.[2,3] ASD is common, with some published reports of prevalence as high as 68% in

ABBREVIATIONS ASD = adult spinal deformity; CIT = conditional inference tree; GAP = Global Alignment and Proportion; IQR = interquartile range; LDI = lordosis distribution index; LL = lumbar lordosis; ODI = Oswestry Disability Index; PI = pelvic incidence; PJF = proximal junctional failure; PJK = proximal junctional kyphosis; PROM = patient-reported outcome measure; PT = pelvic tilt; SAAS = sagittal age-adjusted score; SRS-22r = Scoliosis Research Society-22r questionnaire; SVA = sagittal vertical axis; T1PA = T1 pelvic angle.

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adults older than 60 years of age.[4] Surgical intervention, when indicated, aims to correct the deformity and/or prevent deformity progression.

Pelvic incidence (PI) is an important sagittal alignment parameter that demonstrates the position of the sacral endplate in relation to the femoral heads. The lumbar spine is situated atop the sacral plateau, therefore pelvic morphology is inextricably linked to the position and alignment of the lumbar spine.[5] Mismatch between PI and lumbar lordosis (LL) is one of the most commonly noted malalignment parameters in patients with ASD.[6] Classification systems, including the Roussouly classification, the Global Alignment and Proportion (GAP) score, and the sagittal age-adjusted score (SAAS), have all incorporated PI into their assessment of alignment to either characterize the spine or inform surgical correction.[7–9] Yet, ASD populations are often heterogeneous, with a variety of different characteristics that are classified as "deformity" and, therefore, should warrant their own approach to realignment.

We sought to investigate the association between postoperative outcomes—notably clinical improvement and mechanical failure—and realignment strategies within cohorts stratified by PI. In this manner, we hoped to highlight the corrective tools that benefit certain subpopulations to increase the overall benefit of deformity correction. We hypothesized that patients with higher PI would have worse clinical improvement and higher rates of mechanical failure, as shown in previous literature, leading to a separate realignment strategy that provides success from that of patients with lower and moderate degrees of PI.

Methods

IRB approval was obtained from NYU Langone Hospital before enrolling patients in the prospective database. Informed consent was obtained from each patient prior to enrollment.

Data Source and Study Design

Patients with ASD were enrolled in a prospectively collected registry prior to undergoing surgery from 2012 to 2021. Patients older than 18 years and indicated to undergo correction of adult thoracolumbar deformity were enrolled in the database, which has been previously used in published studies that also examined deformity correction and its outcomes.[10] Thoracolumbar ASD was identified using a radiographic definition of either a coronal Cobb angle ≥ 20°, sagittal vertical axis (SVA) ≥ 50 mm, pelvic tilt (PT) ≥ 25°, and/or thoracic kyphosis > 60°. To be included within the cohort examined in this study, patients with operative deformity must have had complete demographic, surgical, radiographic, and clinical outcome data both preoperatively and at least 2 years following index surgery.

Data Collection and Radiographic Assessment

Data collection at enrollment visit included demographic information, preoperative radiographic assessment, as well as baseline clinical examination findings and patient-reported outcomes. Patient-reported outcome measures (PROMs) were collected by experienced providers at baseline clinic visit as well as at multiple follow-up time points (at least up to 2 years). These PROMs consisted of the Oswestry Disability Index (ODI), SF-36, and Scoliosis Research Society-22r questionnaire (SRS-22r).

For radiographic assessment, lumbar spine and full-body radiographs were used to assess preoperative parameters and used at all follow-up intervals. All images were analyzed using SpineView (ENSAM, Laboratory of Biomechanics).[11–13] Spinopelvic radiographic parameters assessed included PT (the angle between the vertical plane and the line through the sacral midpoint to the center of the two femoral heads), the mismatch between PI and LL (PI-LL), the SVA (C7 plumb line relative to the posterosuperior corner of S1), and the T1 pelvic angle (T1PA).

Measures of Radiographic Alignment Schema

Thoracolumbar deformity severity was assessed using an age-adjusted formula of all typical deformity parameters, known as the SAAS, which stratifies each parameter by severity based on age-related norms: undercorrected, matched, and overcorrected.[8] The GAP score was utilized to characterize and quantify malalignment. This scoring system includes 4 parameters relevant to a patient's PI, with a total score of 13, and determines proportionality based on previously defined distribution of the 4 parameters (relative pelvic version, relative LL, a spinopelvic parameter, and the lordosis distribution index [LDI]) and a factor accounting for age.[7]

Complication Assessment

Radiographic and mechanical forms of failure were assessed. Radiographic failure was characterized by either proximal junctional kyphosis (PJK) or proximal junctional failure (PJF). PJK was defined by both a proximal junctional angle < –10° and a pre- to postoperative difference < –10° from baseline at any time point up to 2 years. PJF was defined using the criteria of Lafage et al.:[14] both a proximal junctional angle < –28° and a pre- to postoperative difference < –22° from baseline at any follow-up time point up to 2 years. Any complication related to the implant, including prominence, malposition, fracture, dislocation, and/or causing nerve impingement, was deemed mechanical in nature. Mechanical failure was considered either a mechanical complication or junctional failure requiring invasive intervention for correction or causing prolonged morbidity or mortality.

Clinical Outcomes Assessment

Using a modified approach from that used by Smith et al., we defined clinical improvement as either: 1) a 2-year ODI score < 15 (scale 1–100) and an SRS-22r total score > 4.5, or 2) meeting substantial clinical benefit for the ODI, designated as an improvement > 18.8 from baseline disability at 2 years.[10,15] Overall, a good outcome was defined as meeting clinical improvement criteria and not experiencing mechanical failure by 2 years.

Cohort Division and Statistical Analysis

The primary outcome was meeting the requirements for a good outcome at 2 years. Secondary outcomes included mechanical failure, PJF, and clinical improvement.

TABLE 1. Baseline demographic and surgical details of the cohort

Variable	Value
Demographics	
Median age (IQR), yrs	63.8 (54.6–70.6)
% female	79.8
Median BMI (IQR), kg/m^2	26.3 (22.9–30.0)
Median CCI (IQR)	1 (0–2)
Median ASD-mFI (IQR)	6 (2.5–9.5)
% w/ osteoporosis	18.9
% w/ history of prior fusion	39.3
Surgical details	
Median op time (IQR), mins	383 (299–506)
Median EBL (IQR), ml	1200 (600–2100)
Median no. of levels fused (IQR)	10 (8–15)
% pelvic fixation	77.5
% combined approach	36.4
% 3-column osteotomies used	20.2
% interbodies placed, median no. (IQR)	59.3, 2 (1–3)

CCI = Charlson Comorbidity Index; EBL = estimated blood loss; mFI = modified Frailty Index.

The primary predictor was the effects of realignment within subsets of PI. Median and interquartile range (IQR) statistics were calculated for demographics and surgical details. Conditional inference tree (CIT) analysis was used to define subsets within PI generating significantly different rates of mechanical failure. These subsets of PI were further analyzed as subcohorts for the clinical outcomes, complications, and effects of realignment within each subcohort. Multivariable regression analysis controlling for baseline frailty and LL (L1–S1) analyzed the association of age-adjusted and GAP realignment with the incidence of mechanical failure and clinical improvement within PI-stratified groups. In all testing, significance was established a priori for ORs and 95% CIs exclusive of 1.0 and p values < 0.05. All statistical analyses were conducted using SPSS (version 29, IBM Corp.).

Results

Cohort Overview

There were 584 patients with ASD who were initially screened for enrollment into the database, 445 of whom met inclusion criteria and were included in analysis. The mean follow-up duration for the study was 3.8 ± 1.1 years. Tables 1 and 2 highlight the demographics, surgical details, and baseline radiographic characteristics of the cohort.

TABLE 2. Baseline and postoperative radiographic measurements

Parameter	Baseline	Postop
Median PI (IQR), °	54.1 (45.9–62.9)	53.9 (46.7–62.7)
Median PI-LL (IQR), °	16.5 (1.0–29.8)	0.6 (–7.8 to 11.6)
Median PT (IQR), °	24.2 (16.8–31.4)	19.2 (12.1–26.1)
Median SVA (IQR), mm	56.4 (13.9–110.1)	22.3 (–2.4 to 52.7)
Median T1PA (IQR), °	22.3 (13.6–31.8)	15.2 (8.7–21.6)
% matched in SAAS	17.6	28.1
% proportioned in GAP	25.8	35.8

TABLE 3. Association of PI with mechanical complications and clinical improvement

Mechanical Complication	OR	95% CI	p Value
Major hardware failure	1.01	0.99–1.03	**0.004**
PJF	1.00	0.98–1.03	0.813
Mechanical failure	0.99	0.97–1.02	0.587
Clinical improvement	1.01	0.99–1.02	0.342
Good outcome	0.99	0.96–1.02	0.502

Boldface type indicates statistical significance.

Linear Effects and Stratification of PI on Clinical Improvement and Mechanical Complications

The effects of PI as a continuous variable on relevant clinical improvement and mechanical complications are depicted in Table 3, demonstrating no significant associations between either mechanical complications or clinical improvement. CIT analysis was used to define subsets within PI generating significantly different rates of mechanical complications. This analysis demonstrated a parabolic relationship (Table 4, Fig. 1), in which patients with either < 51° (n = 174, 39.1% of cohort) or > 63° (n = 114, 25.6% of cohort) of PI generated higher rates of mechanical complications and lower rates of good outcome in clinical improvement than those with moderate PI (51°–63°; n = 157, 35.3% of cohort). These PI categories were further analyzed as subcohorts for the outcomes and effects of realignment within each.

Outcomes and Effects of Realignment Strategies

Lower PI

Patients with lower PI (< 51°) and meeting good outcome (Table 5) regarding age-adjusted alignment had higher rates of undercorrection in PI-LL (18.5% vs 0.0%, p < 0.001) and overall undercorrection in SAAS (12.3% vs 0.0%, p = 0.004) at first follow-up. When assessing GAP,

TABLE 4. Incidence of mechanical complications and clinical improvement in PI-stratified cohorts

Mechanical Complication	Lower PI (%)	Moderate PI (%)	Higher PI (%)	p Value
Major hardware failure	10.7	2.6	13.0	**0.004**
PJF	8.4	7.2	7.8	0.772
Mechanical failure	18.0	8.9	20.0	**0.045**
Clinical improvement	46.6	54.1	49.6	0.404
Good outcome	80.3	92.2	77.6	**0.040**

Boldface type indicates statistical significance.

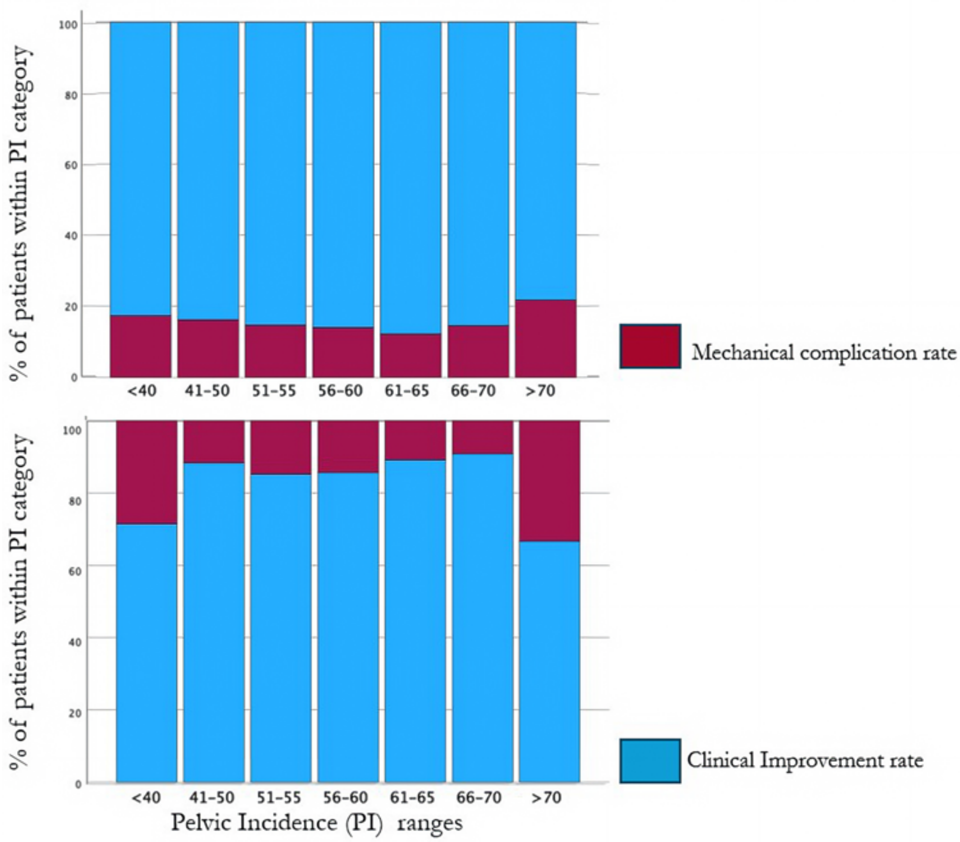

FIG. 1. Upper: Mechanical complication rates across the spectrum of PI. **Lower:** Rates of clinical improvement across the spectrum of PI.

TABLE 5. Associations of realignment with outcomes in patients with lower, moderate, and higher PI at first follow-up

Parameter	Lower PI, <51°	Moderate PI, 51°–63°	Higher PI, >63°
Age-adjusted alignment			
PI-LL undercorrection	—	0.6 (0.3–1.2)	1.1 (0.5–2.3)
PI-LL matched	0.8 (0.2–2.7)	1.5 (0.8–3.3)	0.9 (0.4–2.1)
PI-LL overcorrection	0.5 (0.2–1.8)	1.2 (0.6–2.2)	1.0 (0.5–2.4)
PT undercorrection	—	1.1 (0.5–2.2)	0.6 (0.3–1.2)
PT matched	0.7 (0.2–2.2)	0.7 (0.3–1.5)	1.8 (0.8–4.4)
PT overcorrection	1.1 (0.3–3.6)	1.2 (0.6–2.4)	1.2 (0.5–2.9)
T1PA undercorrection	1.8 (0.2–15.7)	0.7 (0.3–1.5)	0.8 (0.3–1.6)
T1PA matched	1.0 (0.3–3.5)	1.3 (0.7–2.6)	1.7 (0.8–3.7)
T1PA overcorrection	0.8 (0.3–2.7)	1.0 (0.5–2.0)	0.7 (0.3–1.9)
SAAS undercorrection	—	0.9 (0.4–1.8)	0.8 (0.4–1.6)
SAAS matched	0.6 (0.2–2.0)	1.2 (0.6–2.3)	1.2 (0.5–2.8)
SAAS overcorrection	0.9 (0.3–2.9)	1.0 (0.5–1.9)	1.2 (0.5–3.0)
GAP alignment (proportioned)			
LDI	0.7 (0.2–2.1)	1.0 (0.5–1.9)	2.0 (0.9–4.5)
Relative spinopelvic alignment	0.9 (0.3–2.7)	0.9 (0.5–1.7)	1.2 (0.6–2.6)
Relative LL	**0.7 (0.1–0.9)**	1.0 (0.5–2.0)	1.2 (0.5–2.6)
Relative pelvic version	1.1 (0.4–3.4)	1.4 (0.7–2.6)	0.6 (0.3–1.4)
GAP	1.0 (0.3–3.2)	1.2 (0.6–2.4)	1.1 (0.5–2.4)

All data given as OR (95% CI). Boldface type indicates statistical significance.

patients not attaining a good outcome were more likely to be aligned in GAP relative LL (OR 5.1, 95% CI 1.07–24.37; $p = 0.041$) at first follow-up and more likely to deteriorate in relative LL by final follow-up (OR 13.4, 95% CI 1.29–139.19; $p = 0.030$). Regarding mechanical complications, being proportioned in GAP overall at first follow-up did not lower the likelihood of mechanical complications (OR 1.2, 95% CI 0.52–2.66; $p = 0.707$). However, those deteriorating in GAP alignment between first and final follow-up demonstrated a higher likelihood of developing mechanical complications (OR 3.2, 95% CI 1.34–7.52; $p = 0.009$).

Moderate PI

In the moderate PI group (51°–63°; Table 5), when assessing GAP, patients meeting good outcome were not more likely to be aligned in GAP LDI (OR 1.0, 95% CI 0.53–1.93; $p = 0.983$) at first follow-up. At final follow-up, patients with moderate PI were more likely to meet good outcome when aligned in GAP LDI (OR 1.7, 95% CI 0.86–3.27; $p = 0.129$), indicating patients not meeting good outcome criteria were more likely to deteriorate on the LDI from first to final follow-up (OR 5.8, 95% CI 1.71–19.76; $p = 0.005$). While these patients had noticeably higher rates of mechanical failure (20.0% vs 8.9%, $p = 0.123$), patients losing alignment on the LDI had significantly lower rates of reaching substantial clinical benefit on the ODI or SRS-22r total > 4.5 (30.0% vs 66.7%, $p = 0.004$).

Higher PI

Patients with higher PI (> 63°) and meeting good outcome (Table 5) with regard to age-adjusted alignment were more likely to be overcorrected in SVA (OR 2.4, 95% CI 1.07–5.22; $p = 0.033$) at first follow-up. By final follow-up, patients meeting good outcome criteria were less likely to be undercorrected in T1PA (OR 0.4, 95% CI 0.17–0.86; $p = 0.020$). When assessing GAP, patients meeting good outcome were near significance for being more likely to be aligned in GAP LDI (OR 2.0, 95% CI 0.91–4.48; $p = 0.084$) at first follow-up. At final follow-up, patients with higher PI were also more likely to meet good outcome when aligned in GAP LDI (OR 3.5, 95% CI 1.40–8.85; $p = 0.007$).

Discussion

As PI has been labeled a fixed parameter due to its minimal change following spinopelvic realignment, it serves as a foundation for a number of realignment schema, including the GAP and Roussouly classifications.[7,9] However, there has been a lack of validation among these strategies in heterogeneous validation cohorts.[16,17] Therefore, this study set out to discern the positive effects of different realignment philosophies in subsets of varying degrees of PI. In doing so, we found a parabolic relationship between both clinical improvement and mechanical failure with increasing PI. Patients with lower PI benefited most from age-adjusted undercorrection, while those with higher PI achieved good outcomes more often when lordosis was properly distributed in the lumbar spine. Both cohorts also showed success with maintenance of alignment in these parameters to final follow-up.

Overall, studies have shown that patients with higher PI (designated as ≥ 65° in some studies) are at risk for maintaining high PT following spinal deformity correction, even in the instance of meeting certain realignment criteria.[18–20] In our study, patients with higher PI (≥ 63°) more often met good outcome criteria when overcorrected in SVA and less likely when undercorrected in T1PA. While correction to age-adjusted alignment may correlate with good outcomes overall in a spinal deformity cohort, this finding signifies that this specific population may benefit from additional sagittal correction than what is recommended in the "matched" range and may also be a reason for the lack of validation of age-adjusted criteria in several studies. However, increased correction often necessitates increased invasiveness in the form of posterior column osteotomies, which have notable potential for less than desirable postoperative outcomes.[21–23] Therefore, this understanding and these findings highlight that the majority of this correction should be focused within the distal lumbar spine (L4–S1), as these patients were three times more likely to achieve clinical gain and prevent mechanical failure when aligned in the distal lumbar spine.[24] Additionally, while the LDI may have significant effects overall in an ASD population, previous studies have shown its value may also be improved when accounting for the patient's PI.[25]

Higher PI has often been associated with poor outcomes following ASD surgery in the current literature, but few document the outcomes of realignment in those on the lower end of the spectrum. Our study showed this subcohort had similar mechanical failure rates and clinical improvement to that of patients with higher PI. Yet, we have fewer current recommendations for realignment in this population. Dr. Roussouly postulated that these patients may benefit from a reduction in kyphosis but will more often worsen clinically if their lordosis is overcorrected.[26] These observations correlate with our findings, as patients with lower PI fared better when undercorrected in age-adjusted alignment. These findings iterate that the age-adjusted match may actually be overcorrection in this subset of spine deformity and, therefore, would achieve better outcomes with a PI-adjusted strategy to deformity correction, such as achieving GAP relative LL alignment.

The importance of PI and its association with spinal alignment cannot be overstated. The pelvis has been described as the anchor for the vertebral column.[27] Yet, outcomes are not consistent when recommending the same corrective tools for each form of PI; thus, this study highlights the disparities among patients with ASD in rates of mechanical failure and clinical improvement according to a fixed radiographic factor. Accordingly, we can properly inform surgeons on more patient-specific realignment strategies that improve outcomes and mitigate troublesome complications following spinal deformity correction.

Limitations of the Study

The present study is not without limitations, particularly related to the relatively small sample size and retrospective cohort design. The single-surgeon database used may also limit the generalizability of our findings due to potential biases from patient selection limiting sample size and the operative techniques and strategy for realignment employed. Likewise, the demographic makeup of this cohort may not directly reflect that of the national and world populations, specifically regarding BMI, in which our cohort was less than obese on average. Secondarily, we focused on one factor in this single-surgeon pool of patients that may have less generalizability in other cohorts outside of academic centers. We did not stratify by surgical approach, history of revision, or other patient-specific factors that have been shown to influence both realignment strategies and outcomes and, therefore, should not be directly translated to clinical practice but inform surgeons when considering all factors at hand during surgical planning. Similar studies of a multicenter design, with a much larger population, will be most appropriate to further investigate the results of the present study.

Conclusions

There is a parabolic relationship between PI and both mechanical failure and clinical improvement following correction of ASD. Patients with lower PI may fare better with undercorrection in age-adjusted alignment, while those with higher PI may necessitate proper distribution of lordosis within the lumbar spine. In addition, loss of in-construct alignment led to higher rates of mechanical failure within lower PI and less clinical improvement among those with a higher grade. Understanding the associations between this fixed parameter and poor outcomes can aid the surgeon in strategical planning when seeking to realign ASD.

References

1. Smith JS, Shaffrey CI, Fu KM, et al. Clinical and radiographic evaluation of the adult spinal deformity patient. *Neurosurg Clin N Am*. 2013;24(2):143-156.
2. Diebo BG, Shah NV, Boachie-Adjei O, et al. Adult spinal deformity. *Lancet*. 2019;394(10193):160-172.
3. Ames CP, Scheer JK, Lafage V, et al. Adult spinal deformity: epidemiology, health impact, evaluation, and management. *Spine Deform*. 2016;4(4):310-322.
4. Schwab F, Dubey A, Gamez L, et al. Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. *Spine (Phila Pa 1976)*. 2005;30(9):1082-1085.
5. Le Huec JC, Aunoble S, Philippe L, Nicolas P. Pelvic parameters: origin and significance. *Eur Spine J*. 2011;20(Suppl 5):564-571.
6. Sparrey CJ, Bailey JF, Safaee M, et al. Etiology of lumbar lordosis and its pathophysiology: a review of the evolution of lumbar lordosis, and the mechanics and biology of lumbar degeneration. *Neurosurg Focus*. 2014;36(5):E1.
7. Yilgor C, Sogunmez N, Boissiere L, et al. Global alignment and proportion (GAP) score: development and validation of a new method of analyzing spinopelvic alignment to predict mechanical complications after adult spinal deformity surgery. *J Bone Joint Surg Am*. 2017;99(19):1661-1672.
8. 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.
9. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine (Phila Pa 1976)*. 2005;30(3):346-353.
10. Williamson TK, Krol O, Tretiakov P, et al. Crossing the bridge from degeneration to deformity: when does sagittal correction impact outcomes in adult spinal deformity surgery? *Spine (Phila Pa 1976)*. 2023;48(3):E25-E32.
11. Champain S, Benchikh K, Nogier A, Mazel C, Guise JD, Skalli W. Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. *Eur Spine J*. 2006;15(6):982-991.
12. Rillardon L, Levassor N, Guigui P, et al. Validation of a tool to measure pelvic and spinal parameters of sagittal balance. Article in French. *Rev Chir Orthop Reparatrice Appar Mot*. 2003;89(3):218-227.
13. O'Brien MF, Kuklo TR, Blanke KM, Lenke LG. Spinal Deformity Study Group Radiographic Measurement Manual. Medtronic Sofamor Danek USA; 2008. Accessed June 30, 2024. https://www.srs.org/Files/Research/Manuals-and-Publications/sdsg-radiographic-measuremnt-manual.pdf
14. 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.
15. Smith JS, Shaffrey CI, Lafage V, et al. Comparison of best versus worst clinical outcomes for adult spinal deformity surgery: a retrospective review of a prospectively collected, multicenter database with 2-year follow-up. *J Neurosurg Spine*. 2015;23(3):349-359.
16. Dial BL, Hills JM, Smith JS, et al. The impact of lumbar alignment targets on mechanical complications after adult lumbar scoliosis surgery. *Eur Spine J*. 2022;31(6):1573-1582.
17. Kwan KYH, Lenke LG, Shaffrey CI, et al. Are higher global alignment and proportion scores associated with increased risks of mechanical complications after adult spinal deformity surgery? An external validation. *Clin Orthop Relat Res*. 2021;479(2):312-320.
18. Passias PG, Bortz CA, Segreto FA, et al. Pelvic incidence affects age-adjusted alignment outcomes in a population of adult spinal deformity. *Clin Spine Surg*. 2021;34(1):E51-E56.
19. Lertudomphonwanit T, Gupta MC, Theologis AA, et al. Mechanical complications and patient-reported outcome measures associated with high pelvic incidence and persistent pelvic retroversion: the Roussouly "false type 2" profile. *J Neurosurg Spine*. 2023;39(2):151-156.
20. Passias PG, Pierce KE, Williamson TK, et al. Pelvic nonresponse following treatment of adult spinal deformity: influence of realignment strategies on occurrence. *Spine (Phila Pa 1976)*. 2023;48(9):645-652.
21. Tempel ZJ, Gandhoke GS, Bolinger BD, et al. The influence of pelvic incidence and lumbar lordosis mismatch on development of symptomatic adjacent level disease following single-level transforaminal lumbar interbody fusion. *Neurosurgery*. 2017;80(6):880-886.
22. Cheung JPY. The importance of sagittal balance in adult scoliosis surgery. *Ann Transl Med*. 2020;8(2):35.
23. Aoki Y, Nakajima A, Takahashi H, et al. Influence of pelvic incidence-lumbar lordosis mismatch on surgical outcomes of short-segment transforaminal lumbar interbody fusion. *BMC Musculoskelet Disord*. 2015;16:213.
24. Martini C, Pieracci EM, Lepori P. Influence of lumbar lordosis restoration on clinical outcome in degenerative lumbar patients from the "pre-balance" period: ex post analysis of spinal parameters restoration and clinical outcome in a medium follow-up. *Global Spine J*. 2016;6(1 Suppl):s-0036-1583091-s-0036-1583091.
25. Moon MH, Shin MH, Yoo SC, Choi DY, Kim JT. Lordosis distribution index for predicting mechanical complications after long-level fusion surgery: comparison of Global Alignment and Proportion score and Roussouly classification. *J Neurosurg Spine*. 2024;40(5):593-601.
26. Scemama C, Laouissat F, Abelin-Genevois K, Roussouly P. Surgical treatment of thoraco-lumbar kyphosis (TLK) associated with low pelvic incidence. *Eur Spine J*. 2017;26(8):2146-2152.

27. Rose PS, Bridwell KH, Lenke LG, et al. Role of pelvic incidence, thoracic kyphosis, and patient factors on sagittal plane correction following pedicle subtraction osteotomy. *Spine (Phila Pa 1976)*. 2009;34(8):785-791.

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Conception and design: Passias, Williamson, Lebovic, Lorentz. Acquisition of data: Passias, Williamson, Onafowokan, Owusu-Sarpong, Mir, Lorentz, R Lafage. Analysis and interpretation of data: Passias, Williamson, Onafowokan, Schoenfeld, Owusu-Sarpong, Lebovic, Lorentz, Galetta, Jankowski. Drafting the article: Williamson, Onafowokan, Schoenfeld, Lorentz, Galetta, Jankowski. Critically revising the article: Williamson, Onafowokan, Schoenfeld, Owusu-Sarpong, Lebovic, Das, Galetta, Jankowski, R Lafage. Reviewed submitted version of manuscript: Passias, Williamson, Onafowokan, Schoenfeld, Lebovic, Lorentz, Galetta, Jankowski. Approved the final version of the manuscript on behalf of all authors: Passias. Statistical analysis: Williamson, Schoenfeld, Lorentz. Administrative/technical/material support: Passias, Onafowokan, Schoenfeld, Mir, Das, R Lafage. Study supervision: Passias, Jankowski, V Lafage.

Supplemental Information

Previous Presentations

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