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DEFORMITY

Pelvic Nonresponse Following Treatment of Adult Spinal Deformity: Influence of Realignment Strategies on Occurrence

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Purpose. Despite adequate correction, the pelvis may fail to readjust, deemed pelvic nonresponse (PNR). To assess alignment outcomes [PNR, proximal junctional kyphosis (PJK), postoperative cervical deformity (CD)] following adult spinal deformity (ASD) surgery utilizing different realignment strategies.

Materials and Methods. ASD patients with two-year data were included. PNR defined as undercorrected in age-adjusted pelvic tilt (PT) at six weeks and maintained at two years. Patients classified by alignment utilities. (a) improvement in Scoliosis Research Society-Schwab sagittal vertical axis, (b) matching in age-adjusted pelvic incidence–lumbar lordosis, (c) matching in Roussouly, (d) aligning Global Alignment and Proportionality (GAP) score. Multivariable regression analyses, controlling for age, baseline deformity, and surgical factors, assessed rates of PNR, PJK, and CD development following realignment.

Results. A total of 686 patients met the inclusion criteria. Rates of postoperative PJK and CD were not significant in the PNR group (both $P > 0.15$). PNR patients less often met substantial clinical benefit in Oswestry Disability Index by two years [odds ratio. 0.6 (0.4–0.98)]. Patients overcorrected in age-adjusted pelvic incidence–lumbar lordosis, matching Roussouly, or proportioned in GAP at six weeks had lower rates of PNR (all $P < 0.001$). Incremental addition of classifications led to 0% occurrence of PNR, PJK, and CD. Stratifying by baseline PT severity, Low and moderate deformity demonstrated the least incidence of PNR (7.7%) when proportioning in GAP at six weeks, while severe PT benefited most from matching in Roussouly (all $P < 0.05$).

Conclusions. Following ASD corrective surgery, 24.9% of patients showed residual pelvic malalignment. This occurrence was often accompanied by undercorrection of lumbopelvic mismatch and less improvement of pain. However, overcorrection in any strategy incurred higher rates of PJK. We recommend surgeons identify a middle ground using one, or more, of the available classifications to inform correction goals in this regard.

Key Words: adult spinal deformity, pelvic nonresponse, SRS-Schwab modifiers, realignment targets, Global Alignment and Proportion score, health-related quality of life, reoperation, proximal junctional kyphosis

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Adult spinal deformity (ASD) is frequently associated with pelvic malalignment, which can also lead to other compensatory measures within the lower extremities. These clinical conditions culminate in

inefficient energy use and poor patient quality of life.[1–5] Consequently, appropriate postoperative correction of pelvic compensation represents one of several goals in the effective surgical management of ASD.[6,7] Yet, patients commonly fail to compensate postoperatively, with these individuals conventionally termed pelvic nonresponders (PNR).[8] Pelvic nonresponders may continue to experience limitations in functional capacity and quality of life. At the same time, efforts to correct recalcitrant pelvic malalignment may lead to other mechanical complications such as construct failure, proximal junctional kyphosis (PJK) and cervical deformity (CD).

Several utilities are available to the surgeon that help inform operative strategies for the correction of ASD. These include the Scoliosis Research Society (SRS)-Schwab classification system, the Age-Adjusted Alignment ideals, the Roussouly spinal shape classification, and the Global Alignment and Proportion (GAP) Score.[9–12] The ability of each of these paradigms to inform the balance between appropriate pelvic correction and the risk of other postoperative mechanical complications has yet to be effectively studied.

In this context, we sought to assess PNR, postoperative CD, and PJK following ASD corrective surgery in a large cohort of patients treated for spinal deformity. We hypothesized that undercorrection as defined in any specific utility would result in an increased likelihood of PNR, while overcorrection would lead to a higher risk of mechanical complications.

MATERIALS AND METHODS

Data Source

This investigation was conducted retrospectively using a multicenter registry. Participating centers operated under Institutional Review Board approval with patient consent before enrollment and data collection. Patients included in the registry were collected from 2008 to 2016 with radiographic evidence of ASD defined as: coronal Cobb angle $\geq 20°$, sagittal vertical axis (SVA) ≥ 50 mm, pelvic tilt (PT) $\geq 25°$, pelvic incidence–lumbar lordosis (PI-LL) mismatch $> 10°$, and/or thoracic kyphosis $> 60°$.[13,14]

Study Inclusion Criteria and Data Collection

Surgical ASD candidates, age 18 or older, with available baseline, six-week, and two-year radiographic data were included in this investigation. Demographic data that was abstracted for eligible individuals consisted of: age, sex, body mass index, history of prior fusion, Passias and colleagues modified Adult Spinal Deformity Frailty Index, and baseline comorbidities categorized using the Charlson Comorbidity Index (CCI).[15,16] Clinical outcomes consisted of back disability [as assessed by the Oswestry Disability Index (ODI), modified for back pain], EuroQOL 5-Dimension Questionnaire (EQ-5D), pain Numerical Rating Scale for both leg (NRS Leg) and back (NRS Back), Short Form-36 (SF-36), and the Scoliosis Research Society-22 (SRS-22) questionnaire. Outcome assessments were completed via patient surveys at baseline and during subsequent follow-up encounters up to two years following surgery.

Radiographic Data Collection

Freestanding, full-length lateral and anteroposterior spine radiographs were collected at baseline and two years of follow-up and analyzed with SpineView® (ENSAM; Laboratory of Biomechanics, Paris, France).[17–19] Sagittal alignment parameters assessed in this investigation included: pelvic incidence (PI), PT, sacral slope (SS), lumbar lordosis (LL) between L1 and S1, PI–LL mismatch, thoracic kyphosis between T4 and T12, thoracolumbar kyphosis (T10–L2), C7–S1 SVA, and LL apex.

Patient Grouping

Patients were stratified into groups according to four corrective alignment utilities: SRS-Schwab modifiers, age-adjusted ideal alignment, Roussouly spinal shape, and GAP score.

First, the SRS-Schwab ASD classification system was assessed, involving the use of the three established modifiers of SVA with three tiers of the severity of deformity: 0 (nonpathologic), + (moderate deformity), ++ (marked deformity).[9] Next, age-adjusted alignment goals for sagittal correction were analyzed. In the present study, we used the previously published formulas for PI–LL:

$$\text{PI} - \text{LL} = \frac{(\text{Age} - 55)}{2} + 3.$$

We calculated the actual postoperative alignment to the age-adjusted values (ideal) generated from the above (as established by Lafage and colleagues) and correction groups were classified as matched, undercorrected, and overcorrected.[12] The actual postoperative alignment of Matched patients' was within a ± 10-year interval of age-adjusted values compared with unmatched cases (under and over) through the utilization of the equations.

We used the Roussouly Classification System as originally described ("theoretical classification"), relying on PI and LL to stratify patients into four groups: type 1 ($PI < 45°$ and LL apex below L4), type 2 ($PI < 45°$ and LL apex at or above the L4–L5 interspace), type 3 ($45° < PI < 60°$), and type 4 ($PI > 60°$). "Current" Roussouly type was assessed according to SS and defined as: type 1 ($SS < 35°$ and LL apex below L4), type 2 ($SS < 35°$ and LL apex above L4–L5 interspace), type 3 ($35° < SS < 45°$), and type 4 ($SS > 45°$).[11] The restoration of the "current" type to the "theoretical" at follow-up was employed as a measure of deformity correction.

Last, we assessed the spinal proportionality score (GAP score) in all included patients. Patients were then stratified into the following categories based on the GAP score: ≤ 2 Proportional, 3 to 6 Moderately Disproportional, and ≥ 7 Severely Disproportional.[10]

Incremental Benefit

Alignment improvement within each of the alignment utilities was assessed. Patients classified as low deformity or decreasing in the severity of an SRS-Schwab category from baseline to six weeks were classified as improved while matching in age-adjusted alignment and matching in theoretical Roussouly shape at six weeks were also deemed improved in the respective categories. Improving in GAP proportionality (*i.e.* Severely Disproportioned to Moderately Disproportioned, *etc.*) at six weeks compared with baseline were similarly classified as improved.

To assess the incremental benefit of adding layers of complexity to spinal correction, patients were separated into four groups (layers). The first layer would be an improvement in the SRS-Schwab modifier, while the second layer was meeting the first improvement layer and also matching Age-adjusted alignment. The third layer added was matching in Roussouly shape in addition to the two prior improvements in complex schemas. Last, the fourth included an improvement in GAP proportionality, as well as the three prior improvements.

Outcomes

Three major radiographic-based complications were assessed: PJK, PNR, and postoperative CD. PJK was assessed, or the proximal junctional sagittal Cobb angle between the lower end plate of the upper instrumented vertebra and the upper-end plate of the upper instrumented vertebra+2 of $\geq 10°$ and at least 10° greater than the preoperative measurement. PNR were defined as a patient's age-adjusted postoperative PT at six weeks being higher than that of an ideal patient 10 years older (*i.e.* undercorrected). This PT must have been maintained until two years to have been deemed undercorrected. A pelvic responder (PR), was someone who had matched their age-adjusted PT goals (± 10), defined by the equation below:

$$\text{PT} = \frac{(\text{Age} - 55)}{3} + 20.$$

Postoperative CD was defined as radiographic evidence of deformity in the cervical spine: C2–C7 SVA > 4 cm or C2–C7 lordosis < –10 degrees. PNR, PJK, and CD development by two years were compared within the alignment corrective groups incrementally. In addition, these parameters were reported for improvement/deterioration at these time points, along with being matched according to the age-adjusted criteria. Smith *et al*[20] defined "Best Clinical Outcome" criteria as meeting the following: a two-year ODI score <15 AND a two-year SRS-22 Total Score of > 4.5.

Statistical Analysis

Outcomes were compared via means comparison tests (χ^2 tests for categorical variables, independent-samples *t* tests, or one-way analysis of variance for continuous variables, as appropriate. Multivariable regression analysis, controlling for age, number of levels fused, baseline PT and PI–LL, assessed relationships between PNR and outcomes. All statistical tests were performed using SPSS software (v21.0; SPSS Inc., Armonk, NY).

Subanalysis

In a subanalysis of baseline PT, patients were stratified by severity of baseline PT into low (< 20°), moderate (20–30°), and severe (> 30°) groups. Multivariable regression analysis, controlling for age, number of levels fused, use of three-column osteotomy, baseline PT and PI, assessed relationships between improvement or matching in certain realignment strategies and the targeted outcomes. A second subanalysis was performed based on correction in age-adjusted PI–LL. Rates of PJK and proximal junctional failure (PJF) were assessed between PNR patients with undercorrected PI–LL *versus* those adequately corrected (matched or overcorrected). Multivariable regression analysis, controlling for age, number of levels fused, baseline PT and PI–LL, assessed relationships between PNR and outcomes. PJF was defined as a PJK angle of <–28° and a change in the PJK angle <–22° from baseline.

RESULTS

Cohort Overview

Six hundred eighty-six ASD patients met the inclusion criteria. The mean age was 56.3 years, with 76.5% of patients as female. When stratifying by PR, 24.9% of patients were classified as PNR and 75.1% as PR. PJK occurrence (55.6% in PNR patients, and 57.7% in PR patients) and postoperative CD development (19.3% in PNR and 24.5% in PR) were significantly less in the PNR group ($P < 0.05$).

Demographics and Six-week Outcomes in PNR and PR

When dividing the patients into PNR and PR, the groups differed in age (60.7 in PR *vs.* 55.7 in PNR, $P < 0.001$), but not in sex (77% female in PR *vs.* 83% female in PNR, $P = 0.10$). Patients in the PNR group had higher baseline PI (64.6° *vs.* 52.0°, $P < 0.001$) and PI–LL (25.1° *vs.* 12.9°, $P < 0.001$), but equivocal LL (39.6° *vs.* 39.1°, $P = 0.809$). The PR cohort had an average baseline PT of 21.45°, with 33.6% of this group matching their age-adjusted PT at baseline (PNR: 32.1°, 15.8% baseline match; both $P < 0.001$). This study also assessed these two cohorts based on six-week outcomes of realignment. When controlling for age, baseline PT and PI–LL, PNR patients were less often matched by Roussouly shape [odds ratio (OR): 0.12; 0.06–0.24; $P < 0.001$] or proportioned in GAP score (OR: 0.23; 0.13–0.4; $P < 0.001$). The two cohorts did not differ at six weeks in SVA or age-adjusted PI–LL (both $P > 0.5$). The two groups also did not vary in PJK or CD development at any point (both $P > 0.15$). However, the adjusted analysis demonstrated the groups did differ in age-adjusted PI–LL at six weeks, as PNR patients were much likely to be overcorrected (OR: 0.07; 0.03–0.15; $P < 0.001$). The results are shown in Table 1.

TABLE 1. Comparison of Baseline and Six-week Characteristics of Pelvic Responders and Nonresponders

	Pelvic Responder (%)	Pelvic Nonresponder (%)	Significance (*P*)
Age (yr)	60.7	55.7	<0.001*
Sex (female) (%)	77	83	0.1
Baseline PT (°)	21.4	32.1	<0.001*
Aligned in age-adjusted baseline PT	33.6	15.8	<0.001*
PJK at any point	55.6	57.7	0.629
CD at any point	24.5	19.3	0.15
6-wk alignment schema			
Aligned in SVA	30.9	31.6	0.863
Matched in age-adjusted PI–LL	21.6	24.6	0.414
Overcorrected in age-adjusted PI–LL	61.0	4.7	<0.001*
Proportioned in GAP	38.6	12.3	<0.001*
Matched in Roussouly	57.9	24.6	<0.001*

**Statistically significant.*

CD indicates cervical deformity; GAP, Global Alignment and Proportion; PI–LL, pelvic incidence–lumbar lordosis; PJK, proximal junctional kyphosis; PT, pelvic tilt; SVA, sagittal vertical axis.

PNR Effect on Patient-reported Outcomes

There were no differences at baseline between the PNR and PR groups in ODI, SRS-22 Total, EQ-5D, NRS Back or Leg, or any SF-36 Domain. However, the PR group had greater differences from BL to two years in ODI (–17.7 *vs.* –13.3; $P = 0.006$), SRS-22 Pain (1.1 *vs.* 0.9; $P = 0.007$), SRS-22 Appearance (1.4 *vs.* 1.0; $P < 0.001$) SRS-22 Mental (0.5 *vs.* 0.3; $P = 0.033$), SRS-22 Total (1.0 *vs.* 0.7; $P = 0.001$), and EQ-5D (0.08 *vs.* 0.04; $P = 0.016$). When controlling for age, levels fused, use of three-column osteotomy, baseline ODI, PT, and PI–LL, PNR patients less often met substantial clinical benefit in ODI by two years (OR: 0.61; 0.38–0.98; $P = 0.044$). By two years, PNR patients also had less improvement in their back pain (–3.1 *vs.* –3.8, $P = 0.028$) and leg pain (–1.7 *vs.* –2.2, $P = 0.031$), and more likely to report moderate to severe leg pain at two years (OR: 1.9; 1.2–3.2; $P = 0.008$).

Individual Alignment Impact on Outcomes

When assessing improvement in SRS-Schwab SVA, adjusted analysis demonstrated equivocal rates of PNR, PJK, and CD occurrence were not impacted postoperatively (all $P > 0.6$). Adjusted analysis revealed patients matched in age-adjusted alignment developed PNR less often than undercorrected patients (OR: 0.32; 0.18–0.59; $P < 0.001$), as well as less CD postoperatively (OR: 0.47; 0.23–0.97; $P = 0.042$). Matching Roussouly shape at six weeks produced lower rates of PNR (OR: 0.08; 0.03–0.21; $P < 0.001$). Patients who were proportioned in GAP at six weeks also developed less PNR compared with those disproportioned (OR: 0.13; 0.07–0.27; $P < 0.001$), with postoperative moderately disproportioned GAP suffering the highest rates of PJK ($P = 0.010$) (Table 2). The significance of each did not change in regard to PNR outcome when controlling for both PJK and CD.

Incremental Alignment Impact on Outcomes

Incremental addition of realignment was assessed for effect on malalignment outcomes. Of patients with low deformity in SRS-Schwab SVA (16.5% of patients), adjusted analysis revealed patients matched in age-adjusted alignment for PI –LL developed PNR less often than undercorrected patients (OR: 0.34; 0.17–0.68; $P = 0.003$). Addition of the Roussouly matching shape developed less PNR (OR: 0.12; 0.02–0.86; $P = 0.034$) and PJK (38.5% *vs.* 60.3%) than only Schwab and age-adjusted. Last, the addition of achieving GAP proportionality had 0% occurrence of PNR, PJK, and CD.

Subanalysis by Baseline PT

Stratifying by baseline severity in PT, the low group less often developed PNR when proportioned in GAP at six weeks (OR: 0.19; 0.05–0.76; $P = 0.019$). This remained the same for moderate PT (OR: 0.08; 0.02–0.31; $P < 0.001$). Adjusted analysis of patients with severe pelvic compensation at baseline showed PNR (OR: 0.24; 0.10–0.56; $P = 0.001$) and PJK (OR: 0.46; 0.21–0.99; $P = 0.048$) were the lowest with matching in Roussouly shape at six weeks.

Subanalysis by Correction in PI–LL

Stratifying by correction in PI–LL, there were 121 patients in the PNR group with undercorrection in age-adjusted PI–LL by six weeks and two years, while 50 demonstrated overcorrection or matched in their age-adjusted PI–LL. When assessing these two groups, the 50 patients with corrected PI–LL were significantly older (63.4 *vs.* 52.5 yr, $P < 0.001$), more often female (92% *vs.* 79%, $P = 0.020$), and higher frailty (0.37 *vs.* 0.30, $P = 0.022$). However, at baseline, these two groups did not differ significantly in regards to PI–LL or PT ($P > 0.2$). When assessing the outcomes in these two groups, adjusted analysis revealed that

TABLE 2. Impact of Individual Alignment at Six Weeks Postoperative on Rates of PNR, PJK, and CD Development in a Cohort of 686 Adult Spinal Deformity Patients

Alignment Schema at 6 wk Postoperative	PNR (%)	*P*	PJK (%)	*P*	CD Development (%)	*P*
SRS-Schwab SVA						
Improvement	36	0.161	57.8	0.796	22.4	0.593
Same	38.3		59.5		21.5	
Deteriorate	52.8		53.3		28.9	
Age-adjusted PI–LL						
Matched	32.6	<0.001	60.6	<0.001	22.0	0.885
Overcorrected	6.4		68.2		24.3	
Undercorrected	60.1		39.3		22.8	
Roussouly						
Matched	17.8	0.002	54.5	0.537	26.1	0.483
Unmatched	42.3		58.2		22.6	
GAP proportionality						
Proportional	19.7	<0.001	59.4	0.005	23.8	0.780
Moderately disproportionate	27.4		65.3		24.7	
Severely disproportionate	58.8		46.5		21.3	

CD indicates cervical deformity; GAP, Global Alignment and Proportion; PI–LL, pelvic incidence–lumbar lordosis; PJK, proximal junctional kyphosis; PNR, pelvic nonresponder; SRS, Scoliosis Research Society; SVA, sagittal vertical axis.

patients with high residual PT despite adequate PI–LL correction had higher rates of PJK (76.0% *vs.* 47.1%; OR: 4.0; 1.87–8.58; $P < 0.001$). In addition, the PI–LL corrected group was less likely to meet Smith and colleagues' Best Clinical Outcome criteria by two years (6.5% *vs.* 15.6%, $P = 0.026$).

DISCUSSION

Thoracolumbar corrective surgery is often utilized in cases of severe ASD to improve a patient's functioning and overall quality of life.[1–4] Despite considerable advances in surgical technique and knowledge over the years, surgeons continue to try to find the best methods and operative alignment targets to prevent alignment-based complications. In this study, four realignment target goals were tested individually and layered incrementally to determine the impact of nonideal postoperative pelvic alignment, termed pelvic nonresponsiveness. Secondarily, we investigated the effects of in regard to the development of kyphosis at the proximal junction and secondary CD. Our results showed PNR had less reduction of their back and leg pain by two years, and incurred higher rates of PJK when adequately aligned in PI–LL. In addition, we found that layering the correction blueprints for SRS-Schwab, age-adjusted SRS-Schwab, Roussouly match, and the GAP proportionality score demonstrated in an incremental decrease in the incidence of CD development, PNR, and PJK.

Restoration of appropriate pelvic alignment is a key feature of ASD surgery.[7] There is a paucity of literature to address the best approach to take when realigning the pelvis. When analyzing the primary objective of our study, we found that overcorrecting a patient in their age-adjusted PI–LL elicited the least incidence of PR (6.4%) across all four realignment strategies. Likewise, we found the best responses when matching Roussouly shape (17.8% PNRs), being proportioned in GAP score (19.7% PNRs), and improving the SRS-Schwab SVA (36% PNRs). This is clinically significant when managing patients at risk for becoming a PNR, such as those with a high baseline PT or PI, as these patients may benefit best from a more significant correction in a lumbopelvic mismatch or matching in Roussouly. In contrast, it may be less helpful to realign these patients in SVA, as they had the highest PNR percentage at six weeks, and their rates of PJK and CD were not different than the best outcomes of the other classifications.

An elevated PT represents compensation by the patient in response to a diminished LL.[6] Patients with higher compensation at baseline in our study more often developed PNR than those with lower PT, which may be occurring due to an inadequately corrected LL or a high PI. These results are similar to a study by Uribe and colleagues, who found that patients with a high preoperative PT ($> 30°$) continued to have a PI–LL mismatch in 76% of patients, compared with 34% of patients with a low PT ($< 20°$). The authors concluded that this may be due to patients compensating for a high PI.[21] Much like the findings in our study, patients with persistent postoperative back pain were found to have a PT greater than two times the normal value.[5,22] Patients in our cohort demonstrated higher residual back and leg pain following surgery, possibly due to the continued use of compensatory mechanisms in their lower extremities. Therefore, there is a tendency to attempt to overcorrect the lordosis to match the high PI and indirectly influence the compensating pelvic retroversion. Counterintuitively, despite meeting realignment criteria following surgery, the

literature shows some of these patients continue to demonstrate high postoperative PT.[23] Similarly, our study found fifty of the patients had high residual pelvic compensation despite adequate lordosis correction after surgery. While being older and more frail, this group suffered higher rates of PJK than those with inadequate mismatch correction.

Therefore, for these patients, a different approach must be taken to facilitate pelvic responsiveness. The present study found that patients with a severe baseline deformity in PT performed better when matching in Roussouly shape at six weeks compared with meeting the other strategical criteria, while low and moderate baseline deformity best benefited from proportioning in GAP. Previous studies did not find promising results when seeking to validate the GAP score and its ability to predict mechanical complications.[24,25] One of these studies reported a total PJK rate of only 11%, substantially lower than this study and previously reported incidences in this population.[25–27] The other study examined the GAP score and its ability to predict mechanical complications and revisions.[24] Although included in their definition of mechanical complications, the present study only assessed rates of PJK and the improvement in GAP score on these rates. Therefore, we conclude the GAP score has efficacy during the correction in the setting of low and moderate pelvic compensation at baseline. Future studies should evaluate whether there is further complication minimization potential when emphasizing proportioning in this cohort.

In various circumstances, including an elderly patient with arthritic hip joints, the pelvis may fail to appropriately retrovert to offset the reduced LL.[6] Schwab *et al*[28] initially described the optimal alignment goal for PT to be <20°, however, in a later study by Lafage *et al*,[29] this target was further refined to adjust with age so patients are not surgically undercorrected (leaving the pelvis to continue to compensate for residual structural spinal deformity) or overcorrected. Patients in our cohort overcorrected in age-adjusted PI–LL were five times less likely to be a PNR compared with those matched in PI–LL (6.4% *vs.* 32.4%, $P < 0.001$) and even less so compared with those undercorrected (60.1% were PNR). It would be helpful to only correct LL with regard to preventing pelvic nonresponsiveness. However, overcorrection in any realignment target, most notably age-adjusted PI–LL, led to a significantly higher rate of PJK development than those that were not matched or undercorrected. Overcorrection may at times be worth it in the right patient to maximize the potential for PR. Therefore, it is important to truly understand the patient's deformity at baseline to optimize intraoperative corrections and prevent the most likely complication in each patient. Hence, it would be best to screen patients beforehand for risk factors to minimize the threat of PJK.[30–35] Our study concludes utilizing baseline PT can guide the surgeon to realign the deformity with a specific strategy in mind (*i.e.* low baseline PT patients proportioned in GAP had the best outcomes in terms of complications, and for patients with severe baseline PT, matching Roussouly shape showed the best outcomes). Although no one strategy is able to completely eliminate any complication in the correction of spinal deformity, these findings can best help the surgeon contrive a game plan for each individual patient.

Unfortunately, too much of one thing is never a good thing. This could not be truer with consideration to realignment during ASD surgery. In our study, we were able to substantially decrease the risk of pelvic nonresponsiveness by using several different realignment strategies. However, like in previous studies, achieving realignment also meant increasing the risk for PJK overall.[25,27,31–33,36,37] Even in patients with minimal risk factors for postoperative structural complications, the optimal degree of overcorrection should be assessed for each group based on the baseline deformity. Therefore, future studies should target a "sweet spot" to aid the surgeon in maximizing pelvic responsiveness while minimizing the risk for PJK.

While significant outcomes were found in the prevention of PNR and the production of PJK, the difference in strategic realignment outcomes was negligible in regards to secondary CD. Our study demonstrated no statistical difference between the best and worst categories of each realignment strategy when assessing the incidence of CD in ASD surgery. Although not statistically significant, this finding across all four realignment strategies is clinically relevant. This may suggest that the rate of development of CD might in fact have a fixed range in patients undergoing ASD corrective surgery regardless of realignment tool.

Despite our findings, this study did carry several limitations. Future research is needed to properly cluster baseline radiographic parameters with realignment strategies and further individualize correction to achieve optimal outcomes. More often than not, multiple radiographic parameters are manipulated during surgery to achieve criteria-based realignment. This study only took into account baseline PT when determining categorical strategic matching and reduction of complication rates. However, this study did prove significant in this method, facilitating the use by future researchers in investigating other strategies based on different baseline radiographic parameters. Because hip deformities and disease can affect the PR, another important limitation of this study is the lack of data tracking the presence of concurrent hip conditions. Our study also analyzed the outcomes of surgeries done by multiple surgeons and does not account for surgeon-specific preoperative goals for ASD correction. Alongside this mention, we would like to address there were many separate indications for which patients underwent surgery. In addition, this study took an exploratory, retrospective approach examining these concepts in ASD, and the possible presence of expertise and selection bias should be acknowledged and heeded during surgical planning. Despite these limitations, we maintain that this study is an important step towards understanding this unique population, as

well as devising the best surgical plan to optimize realignment outcomes following surgery for ASD.

CONCLUSIONS

Following spinal deformity corrective surgery, 24.9% of patients showed residual pelvic malalignment, qualifying as PNR. PNR was more often due to undercorrection in LL, less improvement in leg and back pain, and higher rates of PJK when adequately corrected in the lumbar spine. However, despite lower rates of nonresponse, overcorrection in any system incurred higher rates of PJK. Therefore, surgeons should attempt to find the middle ground between risk of junctional failure and the risk of PNR during the surgical correction. Ultimately, the use of complex realignment schemas (SRS-Schwab, age-adjusted SRS-Schwab, Roussouly shape, GAP) can aid in the correction by decreasing rates of PJK, development of postoperative CD, and pelvic nonresponsiveness.

➢ Key Points:

- ❑ PNR following correction of ASD leads to poor clinical improvement and increased radiographic complications.
- ❑ PNR was often the result of undercorrection of lumbopelvic mismatch, even when using age-adjusted targets.
- ❑ Specific realignment strategies can be utilized across differing presentations of pelvic compensation to mitigate the occurrence of PNR following ASD surgery.

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