Original Article

The importance of Hounsfield units in adult spinal deformity surgery: finding an optimal threshold to minimize the risk of mechanical complications

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Background: Low bone mineral density (BMD) is a well-established risk factor for mechanical complications following adult spinal deformity (ASD) surgery. Hounsfield units (HU) measured on computed tomography (CT) scans are a proxy of BMD. In ASD surgery, we sought to: (I) evaluate the association of HU with mechanical complications and reoperation, and (II) identify optimal HU threshold to predict the occurrence of mechanical complications.

Methods: A single-institution retrospective cohort study was undertaken for patients undergoing ASD surgery from 2013–2017. Inclusion criteria were: ≥5-level fusion, sagittal/coronal deformity, and 2-year follow-up. HU were measured on 3 axial slices of one vertebra, either at the upper instrumented vertebra (UIV) itself or UIV ±4 from CT scans. Multivariable regression controlled for age, body mass index (BMI), postoperative sagittal vertical axis (SVA), and postoperative pelvic-incidence lumbar-lordosis mismatch.

Results: Of 145 patients undergoing ASD surgery, 121 (83.4%) had a preoperative CT from which HU were measured. Mean age was 64.4±10.7 years, mean total instrumented levels was 9.8±2.6, and mean HU was 153.5±52.8. Mean preoperative SVA and T1PA were 95.5±71.1 mm and 28.8°±12.8°, respectively. Postoperative SVA and T1PA significantly improved to 61.2±61.6 mm (P<0.001) and 23.0°±11.0° (P<0.001). Mechanical complications occurred in 74 (61.2%) patients, including 42 (34.7%) proximal junctional kyphosis (PJK), 3 (2.5%) distal junctional kyphosis (DJK), 9 (7.4%) implant failure, 48 (39.7%) rod fracture/pseudarthrosis, and 61 (52.2%) reoperations within 2 years. Univariate logistic regression showed a significant association between low HU and PJK [odds ratio (OR) =0.99; 95% confidence interval (CI): 0.98–0.99; P=0.023], but not on multivariable analysis. No association was found regarding other mechanical complications, overall reoperations, and reoperations due to PJK. HU below 163 were associated with increased PJK on receiver operating characteristic (ROC) curve analysis [area under the curve (AUC) =0.63; 95% CI: 0.53–0.73; P<0.001].

Conclusions: Though several factors contribute to PJK, it appears that 163 HU may serve as a preliminary threshold when planning ASD surgery to mitigate the risk of PJK.

Keywords: Adult spinal deformity (ASD); Hounsfield unit; mechanical complications; proximal junctional kyphosis (PJK); reoperations

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Introduction

Adult spinal deformity (ASD) affects an estimated 32–68% of the population older than 65 years (1,2). Expectantly, there is a growing body of literature devoted to improving outcomes following ASD surgery in the elderly (3-5). An emphasis is frequently placed on proximal junctional kyphosis (PJK), which is observed in 5–40% of patients following ASD surgery (6-10) and can lead to substantial morbidity, including revision surgery and neurological compromise (11-13). Bone quality is considered an important determinant of successful ASD surgery, as low bone quality has been shown to influence rates of PJK. Traditionally, this is quantified using dual-energy X-ray absorptiometry (DEXA). Several studies have demonstrated that low preoperative T-scores increase the rate of PJK (14,15).

On the other hand, DEXA scans show variable sensitivity depending on which area is sampled, with prior instrumentation, spondylosis, and pathologic sclerosis artificially raising bone mineral density (BMD) scores (14,16). Additionally, DEXA scan T-score values are often taken from the distal radius or hip, which may not accurately reflect the bone quality of the spinal column. However, Hounsfield units (HU), a measure of radiodensity on computed tomography (CT) images, can be a surrogate for BMD and provide the advantage that they are calculated directly from the spinal column (17). Duan *et al.* (18) demonstrated that lower HUs of the upper instrumented vertebra (UIV) in ASD patients were associated with higher rates of postoperative PJK, with a HU threshold of 104.

The influence of HU on mechanical complications is a burgeoning area of research within the ASD literature. Further studies in this domain may improve our ability to avoid mechanical complications and improve patient outcomes. In this study, we sought to: (I) evaluate the association of HU with mechanical complications and reoperation in patients who underwent ASD surgery, and (II) identify an optimal HU threshold to predict the occurrence of mechanical complications. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-22-102/rc).

Highlight box

Key findings

- Hounsfield units (HU) of 163 may serve as a threshold when planning adult spinal deformity (ASD) surgery to mitigate the risk of proximal junctional kyphosis (PJK). No association was found between HU and other mechanical complications or reoperations.

What is known and what is new?

- HU is a surrogate of bone mineral density (BMD) on CT scan that showed potential association with PJK.
- We investigated the impact of a low HU on PJK, DJK, implant failure rod fracture, pseudarthrosis, and reoperations following ASD surgery.

What is the implication, and what should change now?

- The measurement of BMD in ASD surgery is still suboptimal and is not an established predictor of outcomes.

Methods

Study design

A single-institution, retrospective, cohort study was designed using prospectively collected data from our institution's spine outcomes registry from 2013–2017. The registry team includes three full-time employees, whose role includes contacting patients before and after surgery to collect patient-reported outcome measures (PROMs) data. A total of 12 fellowship-trained neurosurgery and orthopedic spine surgeons have contributed patients in the decade of the registry's existence. Institutional review board (IRB) approval from Vanderbilt University Medical Center was obtained for this study (IRB No. 211290). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Patient consent was obtained to comply with the prospectively collected data included in our registry.

Patient population

Registry data were selected for patients who underwent elective ≥5 level fusion ASD surgery between 2013–2017. In keeping with prior ASD literature (19,20), the inclusion

Figure 1 Demonstration of the HU measurement (A-D). HU, Hounsfield units.

criteria were: Cobb angle ≥30°, sagittal vertical axis (SVA) ≥5 cm, coronal vertical axis (CVA) ≥3 cm, pelvic tilt (PT) of ≥25°, thoracic kyphosis (TK) ≥60°, or pelvic incidence (PI)-lumbar lordosis (LL) mismatch of >10°. All patients had a minimum of 2-year follow-up to assess of the occurrence of a mechanical complication. Therefore, all patients were included in the same analysis regardless of their specific follow-up period, aiming to increase study power. Patients who were lost to follow-up were noted as well.

Exposure variables

The primary exposure variable was HU taken on three axial slices of one vertebra, either at the UIV itself or at a vertebra within UIV ±4 from CT scans preoperatively (21). This method is similar to previous reports in the literature (22). However, other reports have used different measures including the average of UIV/UIV +1 (23) and UIV/UIV +2 (18). This method was chosen to maximize the sample of vertebral bodies (*Figure 1A-1D*).

Other exposure variables consisted of demographic data, including age, sex, body mass index (BMI), and comorbidities such as osteopenia and osteoporosis. Osteopenia was determined by the World Health Organization (WHO) criteria when the lowest T-score (radius, lumbar spine, femur) was between −1 to −2.5, while osteoporosis was determined when a T score was lower than −2.5 (24). Operative variables included: UIV region, UIV implant, and total instrumented levels (TIL). UIV selection was based on each surgeon's practice. Radiographic variables included PI, PT, TK, SVA, LL L1-S and L4-S1, PI:LL mismatch, and lordosis distribution index (LDI). Radiographic measurements were recorded preoperatively and at 6-week postoperatively by an orthopedic/neurosurgery resident. Any complex radiographs were confirmed by a fellowship trained spine surgeon. Preoperative PROMs included Oswestry Disability Index (ODI), numeric rating scale (NRS)-Back, NRS-Leg, EuroQol-5 Dimension (EQ-5D).

Outcome variables

The primary outcomes were: (I) the occurrence of a mechanical complication, including proximal/distal junctional kyphosis (PJK/DJK), rod fracture, pseudarthrosis and implant failure, and (II) reoperations. Similar to previous literature (25), mechanical complications were defined as follows: PJK occurred if there was ≥10° increase in kyphosis between the UIV and UIV+2 on postoperative imaging (26). DJK occurred if there was ≥10° increase in kyphosis between lowest instrumented vertebra (LIV) and LIV-1 on postoperative radiographs. A rod fracture was defined as a single or double rod breakage. Any screw pullout, breakage, loosening, or dislodgement was considered an implant failure.

Due to the common co-occurrence of rod fracture with pseudarthrosis, these two complications were grouped together. Though both rod fracture and pseudarthrosis can occur independently of one another, we a-priori decided to group these complications together due to their similarity. Combining rod fracture and pseudarthrosis as a single group was in accordance with previous literature (27-30). There were 42 patients with pseudarthrosis, 27 with rod fractures, and 21 had both.

Statistical analysis

Descriptive statistics were computed for all demographic, preoperative, and postoperative characteristics. Mean and standard deviation (SD) for continuous variables and frequency for categorical variables were calculated. HU was treated as a continuous variable. Mechanical complications were treated as binary outcomes. HU was compared using Student's *t*-test between patients with and without mechanical complications. Univariate and multivariable logistic regression was then performed, controlling for age, BMI, postop SVA, and postop PI/LL, to describe the relationship between HU and mechanical complications. A receiver operating characteristic (ROC) curve analysis was also performed and area under the curve (AUC) was calculated. For AUC >0.60, a Youden's index was calculated, which provided the optimal value of HU that best predict the occurrence of a mechanical complication. A P value of <0.05 was regarded as statistically significant. The analysis was performed using SPSS version 22 (IBM Inc., Chicago, IL, USA).

Results

Patient sample

This study included 145 patients who underwent ASD surgery during the study period. A total of 121 (83.4%) had CT scan from which a HU was measured. The mean age of the cohort was 64.4±10.7 years with a mean BMI of 29.3±5.9. There were 100 (82.6%) females in the cohort. The mean HU was 153.5±52.8. A total of 41 (33.9%) patients had osteopenia, 8 (6.6%) had osteoporosis, and 30/121 (24.8%) were on anabolic medication, specifically teriparatide, for a mean duration of 469.5±259.5 days. The UIV was in the upper thoracic spine (above T8) in 21 (17.4%) patients and lower thoracic area (T8 or below) in 100 (82.6%). Mean preoperative PT was 26.7°±9.8° and preoperative TK was 34.9°±17.9°. Regarding preoperative PROs, mean ODI was 50.8±12.6 and mean EQ-5D was 0.49±0.21. Mean preoperative SVA and T1PA were 95.5±71.1 mm, and 28.8°±12.8°, respectively. Postoperative SVA and T1PA significantly improved to 61.2±61.6 mm (P<0.001) and 23.0°±11.0° (P<0.001). The cohort's full demographics and perioperative characteristics are reported in *Table 1*.

Mechanical complications and reoperations

A total of 74 (61.2%) patients experienced mechanical complications. 42 (34.7%) patients experienced PJK, 3 (2.5%) had DJK, 9 (7.4%) had implant failure, 48 (39.7%) had rod fracture/pseudarthrosis, and 61 (50.4%) required reoperation. Of note, the rate of PJK in patients with thoracic UIV (above T7) *vs.* thoracolumbar UIV (T7 and below) was not significantly different between the two groups (23.8% *vs.* 37.0%, P=0.248). Mechanical complication and reoperation rates were summarized in *Table 2*.

Impact of HU

On bivariate analysis, HU was significantly lower in the PJK group (138.2±43.7 *vs.* 161.7±55.6, P=0.012), with no significant difference in DJK (P=0.475), pseudarthrosis/rod fracture (P=0.408), implant failure (P=0.488), or overall

Table 1 Demographics, operative variables, radiographic measurements, and PROs of sample

Variables	Total sample (N=121)
Age (years), mean ± SD	64.4±10.7
Female, n (%)	100 (82.6)
BMI (kg/m^2), mean ± SD	29.3±5.9
CCI weighted score, mean ± SD	2.0±2.7
Comorbidities, n (%)	
Diabetes	21 (17.4)
COPD	37 (30.6)
CHF	15 (12.4)
HTN	88 (72.7)
Dependent	13 (10.7)
Hounsfield units	
Mean ± SD	153.5±52.8
Median (IQR)	139.3 (120.3–180.4)
Range	56–324
Prior fusion, n (%)	41 (33.9)
UIV region upper thoracic, n (%)	
Upper thoracic	21 (17.4)
Thoracolumbar	100 (82.6)
UIV Implant, n (%)	
Pedicle screws	114 (94.2)
Hooks	7 (5.8)
Fused to sacrum, n (%)	111 (91.7)
Total instrumented levels, mean ± SD (Min–Max)	9.8±2.6 (5–16)
Preoperative radiographic, mean ± SD	
PI (°)	52.6±10.9
PT (°)	26.7±9.8
TK (°)	34.9±17.9
PI:LL	22.5±18.9
LL L1-S1 (°)	30.1±18.9
LL L4-S1 (°)	27.8±12.2
LDI	59.6±317.6
Preoperative PROs, mean ± SD	
ODI	50.8±12.6
NRS-Back	7.2±1.6
NRS-Leg	6.1±2.6
EQ-5D	0.49±0.21

PROs, patient-reported outcomes; SD, standard deviation; BMI, body mass index; CCI, Charlson Comorbidity Index; COPD, chronic obstructive pulmonary disease; CHF, congestive heart failure; HTN, hypertension; IQR, interquartile range; UIV, upper instrumented vertebra; PI, pelvic incidence; PT, pelvic tilt; TK, thoracic kyphosis; LL, lumbar lordosis; LDI, lordosis distribution index; ODI, Oswestry Disability Index; NRS, numeric rating scale; EQ-5D, EuroQol-5 Dimension.

Table 2 Mechanical complications, types of mechanical complications, and reoperations

Outcome variables	Total sample (N=121)
Mechanical complication, n (%)	74 (61.2)
PJK, n (%)	42 (34.7)
DJK, n (%)	3 (2.5)
Implant failure, n (%)	9 (7.4)
RF/pseudarthrosis, n (%)	48 (39.7)
Reoperation, n (%)	61 (50.4)
Reoperation PJK, n (%)	30 (24.8)

PJK, proximal junctional kyphosis; DJK, distal junctional kyphosis; RF, rod fracture.

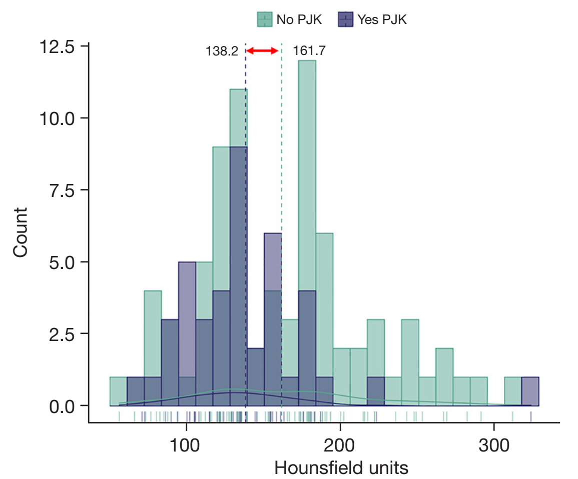

Figure 2 Distribution of HU and PJK. Mean HU in patients with PJK: 138.2. Mean HU of patients without PJK: 161.7. PJK, proximal junctional kyphosis; HU, Hounsfield units.

mechanical complications (P=0.131). *Figure 2* shows the distribution of HU overlapping with the occurrence of PJK. Univariate logistic regression found that higher HU significantly reduced the odds of developing postoperative PJK [odds ratio (OR) =0.99; 95% confidence interval (CI): 0.98–0.99; P=0.023]. However, in multivariable regression controlling for age, BMI, postoperative SVA and postoperative PI-LL, this association was not statistically significant (*Table 3*). Furthermore, HU was not associated with other types of mechanical complication when analyzed as a composite outcome or analyzed as individual mechanical complications, overall reoperations, and reoperations due to PJK (*Table 3*). ROC analysis demonstrated that HU may be

Table 3 Univariate and multivariable logistic regression of Hounsfield units and mechanical complications

Independent variable	Outcome variable	Univariate		Multivariable	
		OR (95% CI)	P value	OR (95% CI)	P value
Hounsfield units	Mechanical complications	0.99 (0.98–1.00)	0.104	0.99 (0.98–1.00)	0.499
	PJK	0.99 (0.98–0.99)	0.023*	0.99 (0.98–1.00)	0.125
	DJK	0.99 (0.96–1.01)	0.472	0.99 (0.99–1.00)	0.672
	Implant failure	0.99 (0.98–1.00)	0.486	1.00 (0.98–1.01)	0.784
	RF/pseudarthrosis	0.99 (0.99–1.00	0.445	0.99 (0.98–1.00)	0.486
	Reoperation	0.99 (0.98–1.00)	0.178	0.96 (0.91–1.01)	0.149
	Reoperation due to PJK	0.99 (0.98–1.02)	0.115	0.99 (0.98–1.03)	0.166

*, statistical significance. PJK, proximal junctional kyphosis; DJK, distal junctional kyphosis; RF, rod fracture; OR, odds ratio; CI, confidence interval.

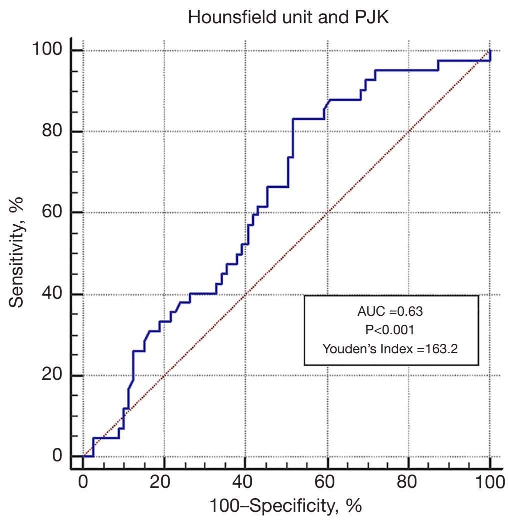

Figure 3 Receiver operating characteristic curve and Youden's index of HU and PJK. AUC, area under the curve; PJK, proximal junctional kyphosis; HU, Hounsfield units.

a moderate predictor of PJK (AUC =0.63; 95% CI: 0.53–0.73; P<0.001), with a calculated Youden's index of 163.2, which signifies that a HU threshold of 163 is associated with an increased risk of PJK (*Figure 3*). Due to low AUC values for other mechanical complications and reoperation, no Youden's index was calculated.

Discussion

As surgery for ASD becomes more common, it is increasingly important to identify risk factors associated with poor surgical outcomes to allow for improved risk stratification, preoperative counseling, and mitigation of postoperative complications (31). While low T-scores have been associated with higher rates of PJK, T-scores taken from other parts of the body may not represent BMD in the spinal column (32). A more practical method applicable to a greater proportion of patients undergoing ASD surgery involves measuring HU on preoperative CT scans that are commonly obtained for surgical planning purposes. We investigated the association between preoperative HU values and the development of mechanical complications and reoperations. In univariate, low HU demonstrated a significant association PJK, however this was not statistically significant in multivariable analysis. HU were not associated with other studied mechanical complications. In ROC analysis, patients with preoperative HU values less than 163 had increased odds of PJK. Although HU were not universally associated with increased complications, the authors believe our results still emphasize the importance of bone density optimization prior to ASD surgery.

The association of lower HU values with the development of PJK in this study aligns with previous literature (33). In a retrospective cohort study of 63 patients undergoing ASD surgery, Yao *et al.* (33) found that a HU value less than 120 at the UIV/UIV +4 was significantly associated with PJK. Similarly, Mallory *et al.* (34) enrolled 108 patients with ASD surgery and reported that HU values below 126.8 at the UIV were associated with a nearly 3-fold risk of developing postoperative PJK. A recent study by Mikula *et al.* (23) of 81 patients with ASD found that lower HU at UIV/UIV +1 was an independent predictor of PJK (OR =0.96, P=0.005), with 159 (AUC =0.77) being the optimal cutoff, similar to the current findings of 163 (23).

Moreover, in 127 patients undergoing ASD surgery, Duan *et al.* (18) found that HU was associated with PJK at the following thresholds: 104 HU at the UIV, 113 HU at the UIV+1, and 110 HU at the UIV+2. In another analysis of 144 patients undergoing primary posterior thoracolumbar or lumbar fusion, not just deformity cases, St Jeor *et al.* (35) found that lower lumbar HU was an independent predictor of mechanical complications, as the rate of mechanical complications increased by 70% for each 25 point decrease in HU. Furthermore, the authors found that HU was superior to DEXA scan in predicting mechanical complications on multivariable regression, which may hint at the potential application of HU as a convenient alternative to DEXA scan.

While our study showed a potential association between lower HU and PJK, no association was found with other types of mechanical complications. Previous studies have investigated the association between HU and implant failure, but mixed results have been reported. Xu *et al.* (36) conducted a retrospective study of 143 patients with L3-5 instrumentation and found that HU alone were insufficient to accurately assess the risk of pedicle screw loosening. In contrast, Zou *et al.* (37) examined 503 patients undergoing lumbar pedicle screw fixation and found that lower HU at L1-4 were independent predictors of screw loosening. While our study only focused on HU around the UIV, and we also only included long-construct ASD fusions, the statistical significance found in the previously mentioned studies might originate from the vertebral level selection when measuring HU.

Similarly, our statistical analysis showed a lack of statistical significance between HU and reoperation on univariate and multivariable analysis. This is in contrast with a retrospective study of ASD patients conducted by Uei *et al.* (38), who found that patients with reoperations for PJK had lower preoperative HU score at T8 and T9 compared to patients who did not undergo a revision surgery. In a retrospective study of 52 females undergoing ASD surgery, Hiyama *et al.* (39) demonstrated a significantly lower preoperative HU in patients with proximal junctional failure (PJF), and the mean HU values at the UIV and UIV+1 showed a significantly negative correlation with the global alignment and proportion (GAP) score. In comparing their data to the current authors, an important difference is that we chose to include all different types of reoperations, not just reoperation for PJK. However, in our subanalysis strictly for PJK requiring reoperation, we still did not find any significant association with HU. This may be due to a difference in study populations, as the previously mentioned study had a mean age of 73, which is 9 years older than patients included in this study. In addition, to capture the association between HU and operative outcomes, our study investigated overall mechanical complications, DJK, implant failure, rod fracture, pseudarthrosis, and overall reoperation.

The current study examined patients undergoing ASD surgery and found a potential association of lower HU and PJK on univariate analysis. Regardless of the current findings, PJK remains a multifactorial phenomenon. Other predictors of PJK include long fusions to the sacrum, over correction or under correction of sagittal plane deformities, disruption of the posterior ligamentous tissues, poor upper rod contour, or extreme rod stiffness (6,7). As different types of PJK exist (i.e., ligamentous, bone implant interface, or fracture) (6), future studies may focus on defining which type is associated with HU to strengthen its value as a prognostic variable and a more practical alternative to DEXA.

The results of our study have several limitations. First, the retrospective nature of this study limits the predictive value of our results in the clinical setting. Second, statistical significance was not achieved in multivariable, which prevents us from concluding HU is independently associated with PJK. Third, we had a moderately low AUC, which further limits the interpretation of the correlation found. Fourth, HU was measured within 4 levels of UIV, rather than at UIV/UIV+1, as several previous studies have done (40). The method to measure HU was adopted to maximize the sample of vertebral bodies around the UIV. Fifth, due to the small sample size, we could not account for other important covariates in the multivariable analysis, such as anabolic intake or UIV selection. Sixth, the choice of the UIV is often debated among spine surgeons, and no consensus exists regarding optimal UIV location (40). Our data belongs to a retrospective, multi-surgeon registry. Therefore, the choice of the UIV could not be tracked through a retrospective chart review and was most likely based on each surgeon's practice and clinical intuition. Seventh, this data belongs to a multi-surgeon registry and goes back to 2013–2017, which might not reflect the current practice at our institution. However, through the encountered clinical and operative outcomes, we found value in reporting the institution's experience even though it's partially outdated. As a retrospective study based on chart review, it was difficult to ascertain the reasons of the high reoperation rate. Future studies are warranted with a larger sample size and a prospective data to establish the association of lower HU and PJK, as well as to compare DEXA scan and HU in their ability to predict mechanical complications.

Conclusions

In a retrospective cohort of patients undergoing ASD surgery at a single institution, we investigated the prognostic value of HU on postoperative outcomes. We found that lower HU were associated with PJK in univariate with a HU threshold of 163. While no significant association was found between HU and overall mechanical complications, rod fracture, pseudarthrosis, implant failure, or reoperations, these preliminary results showed that HU may be a practical surrogate for BMD, and may help stratify the risk of PJK in ASD surgery.

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Footnote

Reporting Checklist: Available at https://jss.amegroups.com/article/view/10.21037/jss-22-102/rc

Data Sharing Statement: Available at https://jss.amegroups.com/article/view/10.21037/jss-22-102/dss

Peer Review File: Available at https://jss.amegroups.com/article/view/10.21037/jss-22-102/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-22-102/coif). SLZ serves as an unpaid editorial board member of *Journal of Spine Surgery*. SLZ reports being an unaffiliated neurotrauma consultant for the National Football League. BFS is a consultant for Nuvasive and Carbofix and receives institutional research support from Nuvasive and Stryker Spine. AMA received an institutional research support from Stryker Spine. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional review board of Vanderbilt University Medical Center (No. 211290), and informed consent was obtained from all individual participants.

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