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Transverse Pedicle Angle Is Associated With Pelvic Incidence and Increased in Lumbar Isthmic Spondylolisthesis

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Abstract

Study Design: Retrospective radiographic review.

Objectives: Investigate and quantify transverse pedicle angle (TPA), the medial-to-lateral pedicle angulation, and its potential association with pelvic incidence (PI) in patients with isthmic lumbar spondylolisthesis (ISLS) and compare to those with degenerative lumbar spondylolisthesis (DSLS) and controls.

Methods: A total of 200 patients (64 ISLS, 70 DSLS, 66 control) were included. TPA was calculated at the L3-5 vertebral levels using axial computed tomography slices. PI was measured on lateral radiographs. Two independent observers completed the measurements. As a sensitivity analysis, TPA was also measured at the most cranial and caudal aspects of the L3-5 vertebral levels of a subset of participants (29 ISLS, 31 DSLS, 35 control) and the cranial to caudal change (ΔTPA) was calculated.

Results: TPA values (mean ± SD) at L4 and L5 for ISLS (L4: 17.3° ± 3.7°, L5: 26.0° ± 5.2°) were significantly higher than those for the DSLS (L4: 14.3° ± 3.8°, L5: 22.2° ± 5.0°) and control (L4: 14.5° ± 3.9°, L5: 20.7° ± 3.8°) groups. TPA in the DSLS group was significantly higher than controls at L5, but not L4. High PI predicted wider TPA at L5 in both DSLS and ISLS. ΔTPA (mean ± SD) increased sequentially proceeding through the L3-5 spinal levels for the ISLS (L3: 6.8° ± 4.4°, L4: 8.7° ± 5.2°, L5: 15.6° ± 9.0°), DSLS (L3: 8.2° ± 6.0°, L4: 8.3° ± 5.9°, L5: 18.3° ± 7.2°), and control (L3: 6.8° ± 4.4°, L4: 8.2° ± 4.7°, L5: 17.7° ± 7.0°) groups.

Conclusions: TPA was significantly increased in ISLS compared with DSLS and controls. High PI significantly predicted high TPA at the L5 vertebral level in ISLS and DSLS. ΔTPA increased sequentially proceeding through the lumbar spine across groups.

Keywords

spondylolysis, isthmic spondylolisthesis, degenerative spondylolisthesis, transverse pedicle angle, pelvic incidence

Introduction

Isthmic lumbar spondylolisthesis (ISLS) has a prevalence of up to 6% in adulthood[1] and occurs most frequently at the lumbosacral junction. Surgical intervention for ISLS has become progressively more common, with a greater than 4-fold increase across spinal fusion techniques documented between 1998 and 2011 in the United States.[2] Several anatomic changes have been described in association with ISLS, including facet joint tropism,[3-7] small transverse processes, bifid posterior arch, trapezoidal L5, sacral doming, and thinning of the posterior arches and spinous processes.[8-11] In addition, it has been observed clinically that there is significant alteration in pedicle

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morphology in ISLS. However, these alterations have not yet been well characterized.

Pedicle anatomy and orientation in normal patients—without deformity or spondylolisthesis—was first evaluated by Saillant and has been described using anatomic specimens, plane radiography, and computed tomography (CT).[12-18] Many of these studies were first performed in the 1970s and 1980s with the introduction of pedicle screw instrumentation, and described the orientation of pedicles by vertebral level in the sagittal and axial planes. The transverse pedicle angle (TPA) is a radiographic measurement used to characterize the lateral-to-medial orientation of the vertebral pedicles in the axial plane.[18] In ISLS, the TPA in particular has been observed to be increased, making pedicle screw insertion during open midline spine surgeries more difficult due to the wide angulation necessary. Therefore, more extensive exposure may be required to allow for greater medial screw angle trajectory in the setting of high TPA and knowledge of the degree of increase in TPA in patients with ISLS may result in changes in surgical approach. However, the TPA in ISLS has not yet been described and quantified.

Sagittal spinopelvic alignment has been described as an additional anatomic consideration in the progression and possible etiology of ISLS.[19] Pelvic incidence (PI) has been associated with ISLS in a number of studies,[20-23] and has been shown to increase in direct linear proportion to grade of slippage and severity of deformity.[19,24] PI has also been correlated to increase in conjunction with other measures of spinopelvic balance, including lumbar lordosis (LL), pelvic tilt, and sacral slope.[25] High PI, resulting in greater LL, causes greater shear stress on the L5-S1 disk, inducing increased loading on the pars interarticularis and posterior elements.[24] Among those with ISLS, it remains unknown if the PI also has an association with pedicle morphology and orientation.

This study was structured as a preliminary analysis aiming to investigate and quantify the TPA in patients with ISLS and compare them with controls, including those with degenerative lumbar spondylolisthesis (DSLS) and patients without spondylolisthesis. In addition, we sought to investigate the reliability and sensitivity of TPA as a radiologic parameter. In accordance with clinical observations, we hypothesized that individuals with ISLS would have higher TPA compared with DSLS and controls. We also hypothesized that TPA measurements could be made with reasonable intra- and interrater reliability. Further, this study aimed to characterize the relationship between TPA and PI in those with ISLS, and again compare them to both DSLS and controls. We hypothesized that higher PI would be related to larger TPA.[26]

Methods

This study was a retrospective radiographic review and analysis of patients who underwent treatment at a single institution between 2007 and 2017. This study was approved by the hospital's institutional review board. Patients with either DSLS or ISLS who had received a dedicated lumbar CT scan during their evaluation and treatment were identified utilizing Current Procedural Terminology codes. Eligibility for study participation and patient classification was subsequently determined through review of the patient's chart and confirmation of diagnosis on imaging. Classification was made by confirmation of the charted diagnosis with the patient's imaging studies. Inclusion criteria were (1) age >18 years; (2) successful classification as ISLS or DSLS; and (3) complete patient data (demographic information, lateral radiographs, dedicated lumbar spinal CT). Patients were excluded if they presented with 1) comorbid spinal deformity such as scoliosis; (2) excessive degenerative changes or osteopenia limiting radiographic visualization; (3) active infection, (4) neoplasm, or (5) previous spinal surgery in the involved area.

Controls in the current study were selected from patients that had received a dedicated lumbar CT scan during their evaluation and treatment. Most often, these were patients that had contraindications to magnetic resonance imaging (MRI). Patients were identified using current procedural terminology codes for dedicated lumbar CT scans. The same inclusion and exclusion criteria were applied to the identified control group, with the additional exclusion of patients found to have lumbar spinal deformity (spondylolysis, spondylolisthesis, degenerative scoliosis >10° by Cobb measurement) or significant degenerative arthritic changes (settling, lateral olisthesis, rotatory subluxation, severe facet joint arthropathy). Confirmation that patients met inclusion and exclusion criteria for classification as controls was made through review of the patients' charts and imaging studies.

Radiographic Measurements:

TPA was measured as the angle between a line perpendicular to the transverse isthmus and a line parallel to the vertebral midline in the transverse plane[18] (Figure 1). TPA measurements were made from the sagittal midline of the pedicle and were reported as the average between the right and left sides. Axial views of the L3-L5 vertebra from CT scans of the lumbar spine were used for TPA measurements, with measurements made at the widest portion of the pedicle visualized (ie, in the middle of the cranial-caudal aspect of the pedicle). MRI scans were used in a minority of patients when the CT scan available did not allow optimal visualization of the mid-sagittal aspect of the vertebral pedicle.

PI was measured as the angle from a line perpendicular to the midpoint of the sacral endplate and a line drawn from the center of the superimposed femoral heads to the sacral endplate,[25] and were made on lateral plane radiographs. The lateral scout view from the CT scan was used if the femoral heads were not adequately visualized on the patient's radiograph.

Two independent observers, an orthopedic spine surgeon and a neuroradiologist, each board certified with more than 10 years of experience in their respective fields, completed the measurements. Validated software (Synapse Software version 4.4.2, FUJIFILM Medical Systems) was used. Measurements from these raters were utilized for all study analyses.

Reliability and Sensitivity

Interrater reliability was statistics were calculated for TPA and PI using the complete set of study data, for example, measurements completed by both raters on all 200 participants. Intrarater reliability statistics were calculated for each of the raters using repeated measurements made on a subgroup of 45 participants, which consisted of 15 subjects from each study group. The repeat measurements were made after a minimum of 2 weeks had passed since the original measurement.

To further characterize the sensitivity of the TPA parameter to which axial slice in the cranial-caudal direction was used, a second set of measurements was completed by the orthopedic surgeon rater. TPA was measured at both the most cranial and caudal aspects of the L3-L5 pedicles. The difference in TPA between the most cranial and most caudal aspects of the lumbar pedicles for each vertebral level was then calculated (ΔTPA) (Figure 2). These measurements were made on subset of the study population that included patients with CT scans that provided optimal cephalad and caudal visualization of the lumbar vertebral pedicles.

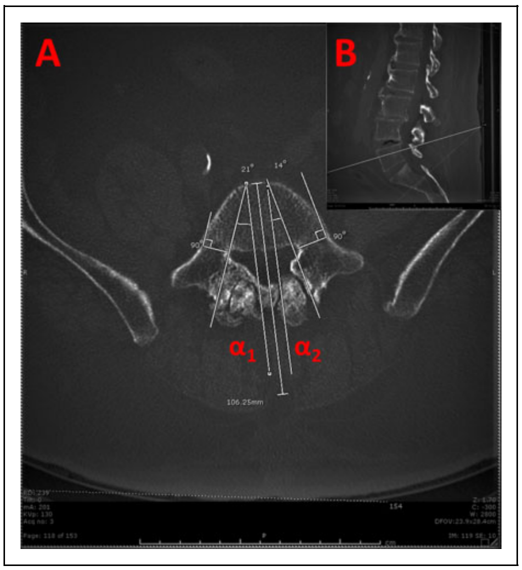

Figure 1. Axial (A) and sagittal (B) views from computed tomgography scan demonstrating transverse pedicle angle (TPA) measurement. TPA was calculated as $(\alpha_1 + \alpha_2)/2$ for vertebral levels L3-L5. Axial slices through the widest portion of the pedicle in the cranial-caudal direction were used for measurements.

Data Analytic Strategy

To assess interrater reliability across both raters in the study for PI and TPA measurements at the L3, L4, and L5 levels, interclass correlation coefficients (ICCs) were calculated in SAS 9.4 (SAS Institute Inc, 2013). The ICC assesses the consistency of measurements made by multiple observers measuring the same quantity.[27] ICCs were also calculated using the repeated measurements for each rater for PI and TPA measurements at the L3, L4, and L5 levels in order to examine intrarater reliability. ICCs can describe the extent to which test measurements remain consistent within raters over repeated trials.[28] ICC values of less than 0.40 indicate poor reliability, values between 0.40 and 0.59 indicate fair reliability, values between 0.60 and 0.74 represent good reliability, and values between 0.75 and 1.00 signify excellent reliability.[29]

Multivariate analyses of variance (MANOVA) was used to assess the effect of category of illness (eg, ISLS, DSLS, and Control) across PI and TPA at the L3, L4, and L5 levels (ML; SAS Institute Inc, 2013). Additionally, age, gender, body mass index (BMI), and scan type (CT vs MRI) were initially entered as covariates across all analyses. Nonsignificant covariates were dropped from the model for parsimony.[30] If the MANOVA was significant, a posteriori tests were conducted.

Regarding the characterization of the relationship between TPA and PI, we estimated nine linear regression models in

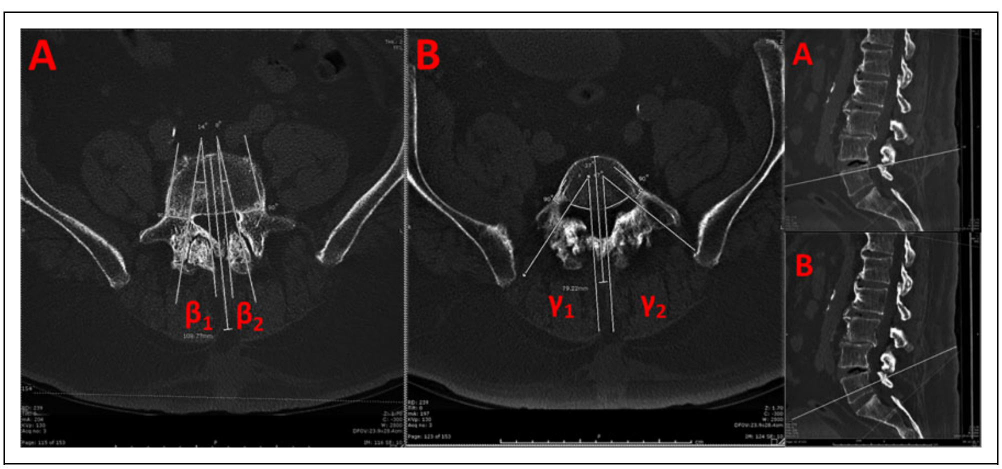

Figure 2. Axial and sagittal computed tomography (CT) scan images demonstrating measurement of the change in transverse pedicle angle (ΔTPA) based on the axial slice position in the cranial-caudal direction. Measurements at the (A) cephalad and (B) caudal axial sections of L5 pedicle. Cephalad TPA was calculated as $(\beta_1 + \beta_2)/2$. Caudal TPA was calculated as $(\gamma_1 + \gamma_2)/2$. ΔTPA was calculated as the difference between cephalad and caudal TPA values.

Table 1. Patient Demographics.

Variable	ISLS (n = 64)	DSLS (n = 70)	Control (n = 66)
Age, y, mean ± SD	45.8 ± 16.3	62.4 ± 9.6	53.9 ± 14.8
BMI, kg/m^2, mean ± SD	30.5 ± 5.5	33.6 ± 5.7	31.3 ± 6.1
Sex, n (%)			
Male	46 (72)	19 (27)	44 (67)
Female	18 (28)	51 (73)	22 (33)
Level of olisthesis, n (%)	L3: 3 (4.7)	L3: 3 (4.3)	—
	L4: 6 (9.4)	L4: 48 (68.6)	
	L5: 53 (82.8)	L5: 12 (17.1)	
	L3, L5: 2 (3.1)	L3, L4: 2 (2.9)	
		L4, L5: 5 (7.1)	

Abbreviations: ISLS, isthmic spondylolisthesis; DSLS, degenerative spondylolisthesis; BMI, body mass index

Mplus 8.2.[31] PI was entered as the independent variable across all models, and TPA at one vertebral level was entered as the dependent variable. This process was repeated across all 3 vertebral levels and across all 3 study groups. Age, gender, BMI, and scan type (CT vs MRI) were entered as covariates across all regression models. Additionally, when each particular vertebral level (eg, L5) was analyzed as the dependent variable, the other 2 vertebral levels (eg, L3, L4) were also entered as covariates. We report standardized beta (β) and standard errors. β compares the strength of the effect of the independent variable (PI) to the dependent variable (TPA). β generally ranges from −1 to 1. The higher the absolute value of β, the stronger the effect. SE denotes the variability of the β coefficient, describing the precision of this value.[32]

Results

Descriptive Statistics

There were 865 patients identified for study participation, of which 200 met inclusion criteria. All study variables were normally distributed (Table 1). The sample was evenly split on gender and the average age was 54.37 years (SD = 15.44). BMI was similar for all 3 groups and the average BMI across groups was 31.5 kg/m^2. Olisthesis occurred most frequently at L4 for the DSLS group and at L5 for the ISLS group. MRI scans were used to complete TPA measurements for 32 participants.

Reliability

Our hypothesis that PI and TPA at the L3, L4, and L5 levels could be reliability measured with reasonable intrarater was supported. ICCs were excellent across both the orthopedic surgeon and neuroradiologist raters for L3 (0.92 and 0.93, respectively), L4 (0.94 and 0.87, respectively), L5 (0.85 and 0.91, respectively), and PI (0.94 and 0.99, respectively).

Our hypothesis that PI and TPA at the L3, L4, and L5 levels could be reliability measured across raters was partially supported. Regarding PI, interrater reliability was excellent (ICC = 0.81, 95%CI [0.75, 0.85]). Interrater reliabilities for TPA were fair at the L3 and L4 levels (ICCs = 0.49, 95% CI [0.38, 0.59]; 0.50, 95% CI [0.39, 0.60], respectively). However, analysis at the L5 level indicated that interrater reliability was poor (ICC = 0.33, 95%CI [0.20, 0.45]).

Relationships Between PI, TPA, and Spondylolisthesis Type

Results from the initial MANOVA model evaluating the effect of condition (eg, ISLS, DSLS, and control) on TPA and PI measurements revealed that gender, BMI, and scan type were all nonsignificant ($P > .10$), and thus these covariates were removed from the model. There was a statistically significant difference across the dependent variables (TPA and PI measurements) based on spondylolisthesis type ($P < .0001$). Additionally, there was a statistically significant difference based on age ($P < .01$). Contrasts from the final MANOVA model indicated that there was a statistically significant difference across the dependent variables between the ISLS and DSLS and control groups ($P < .0001$). Additionally, the contrast for differences across the dependent variables between the DSLS and control groups was significant ($P < .001$).

A posteriori tests revealed that condition did not have a significant effect at the L3 level. Condition effect was statistically significant at the L4 ($P < .01$) and L5 ($P < .0001$) levels, controlling for age. Additionally, PI significantly varied based on condition ($P < .0001$), controlling for age. Pairwise comparisons between groups (Table 2) revealed ISLS was significantly different from controls across the L4 ($P = .001$) and L5 ($P < .001$) levels, and for PI ($P < .001$). ISLS was also significantly different from DSLS for L4 ($P = .008$) and L5 ($P < .001$). Finally, DSLS was significantly different from controls at the L5 level ($P = .05$) and for PI ($P < .001$).

Relationship Between PI and TPA

Among the ISLS and DSLS groups, high values of PI were significantly related to high values of L5 TPA, above and beyond L3, L4, gender, age, BMI, and scan type (Table 3). Regarding the control group, the association between PI and L5 TPA approached significance ($P = .06$). Associations between PI and TPA were nonsignificant at the L3 and L4 levels across all 3 groups.

ΔTPA

ΔTPA measurements were completed on 95 patients (29 ISLS, 31 DSLS, 35 control). Transverse pedicle angle increased proceeding cranially to caudally through the lumbar pedicles for all vertebral levels measured and across groups (Table 4). ΔTPA increased sequentially proceeding through the L3-5 spinal levels across groups. ΔTPA nearly doubled at the L5 vertebral level, as compared with the L3 and L4 vertebral levels, for each group.

Table 2. TPA and PI Parameters With Pairwise Comparisons by Study Group.

Parameter	ISLS			DSLS		Control
	Mean ± SD	*P* value vs control	*P* value vs DSLS	Mean ± SD	*P* value vs control	Mean ± SD
L3 TPA	14.0 ± 3.6	.31	.09	12.0 ± 3.1	.66	12.84 ± 3.7
L4 TPA	17.3 ± 3.7	.001	.008	14.3 ± 3.8	.85	14.5 ± 3.9
L5 TPA	26.3 ± 5.2	<.001	<.001	22.2 ± 5.0	.05	20.7 ± 3.8
PI	63.4 ± 12.0	<.001	.07	57.8 ± 9.7	<.001	50.6 ± 9.4

Abbreviations: TPA, transverse pedicle angle; PI, pelvic incidence; DSLS, degenerative spondylolisthesis; ISLS, isthmic spondylolisthesis.

Table 3. Association of TPA With PI.

		L3 TPA			L4 TPA			L5 TPA		
		β	SE	*P*	β	SE	*P*	β	SE	*P*
PI	ISLS	−0.16	0.11	.16	0.05	0.11	.67	0.31	0.10	<.01
	DSLS	0.17	0.11	.12	−0.10	0.10	.31	0.32	0.10	<.01
	Control	0.09	0.10	.35	−0.01	0.09	.91	0.20	0.10	.06

Abbreviations: TPA, transverse pedicle angle; PI, pelvic incidence; ISLS, isthmic spondylolisthesis; DSLS, degenerative spondylolisthesis; β, standardized beta; SE, standard error.

Table 4. ΔTPA Values for Each Study Group.

Parameter	ISLS (n = 29), mean ± SD	DSLS (n = 31), mean ± SD	Control (n = 35), mean ± SD
L3 ΔTPA	6.8 ± 4.4	8.2 ± 6.0	6.8 ± 4.4
L4 ΔTPA	8.7 ± 5.2	8.3 ± 5.9	8.2 ± 4.7
L5 ΔTPA	15.6 ± 9.0	18.3 ± 7.2	17.7 ± 7.0

Abbreviations: ΔTPA, change in transverse pedicle angle; DSLS, degenerative spondylolisthesis; ISLS, isthmic spondylolisthesis.

Discussion

ISLS is a common cause of spine disability. With pedicle screw instrumentation, it has been observed clinically that pedicle morphology is significantly altered in ISLS. However, these changes have never before been studied or quantified. This study is the first to demonstrate that TPA is significantly higher in ISLS compared to both controls and those with DSLS. Further, we found that a higher PI was associated with high levels of L5 TPA in patients with ISLS and DSLS. Therefore, this study is the first to demonstrate a relationship between spinopelvic anatomy and pedicle morphology in these conditions.

This study supported our clinical impression as well as our hypothesis that TPA is significantly increased in patients with ISLS compared to others. This has been a well-known challenge in treating those with ISLS with an open instrumented midline posterior spinal fusion approach, as it is often difficult to obtain the necessary lateral-medial angulation for optimal screw insertion without extensive soft tissue detachment. It is possible that wide TPA may alter the spinal column contact force (CF), which is composed of the combined forces of gravity and abdominal pressure summed with the force of the posterior spine muscles.[11] In ISLS, the CF parallel to the vertebral plate increases, resulting in olisthesis.[11] Wide TPA may further disrupt these force vectors, increasing the likelihood of spondylolisthesis.

Unexpectedly, L5 TPA was also significantly increased in the DSLS group as compared to controls. Results from the regression analyses examining the association between PI, TPA, and spondylolisthesis type provide a possible explanation insofar as these analyses demonstrated that high PI was directly related to L5 TPA in the ISLS and DSLS groups, both conditions well-characterized to be associated with high PI.[19,24,26] Meanwhile in the control group, which was found to have significantly lower PI, this association was not significant. This finding must be interpreted in the context of the fact that L5 articulates directly with the sacrum and has demonstrated a high degree of variability in gross morphology and pedicle angle.[33] It is perhaps not all that surprising, then, that the pelvic anatomy has such a close relationship with and impact on its nearest vertebrae.

This study is the first to provide descriptive statistics of TPA in the setting of ISLS and DSLS. Lumbar pedicle morphology has previously been described exclusively in control populations for the purpose of establishing normal measurement distributions for pedicle screw instrumentation. There has been appreciable variation in TPA measurement technique across previous studies and considerable differences in mean TPA have been reported for the L3-5 vertebral levels.[16] The TPA has been shown to be 12° to 19° at L3, 16° to 20° at L4, and 23° to 32° at L5.[14,16,18,34] Data for the controls from the current study show good agreement with previous data demonstrating values of 13°, 15°, and 21° for the L3-5 lumbar levels, respectively. Mean TPA for our results also showed good agreement across studies and measurement techniques with respect to trend of increasing transverse pedicle angulation between L3 and L5.[12,14,16,18,34] This study expands upon previous findings as it is the first to document the difference in TPA between the caudal and cephalad portions of the lumbar vertebra. ΔTPA increased proceeding down the lumbar spine across groups. Values nearly doubled, or more than doubled, for each group at the L5 vertebral level, corresponding to the high degree of variation and large standard deviations for this level across previous studies.[16] The characterization and quantification of this relationship is important from a clinical perspective due to the fact that while the lower TPA found at the cranial aspect of the pedicle may be more amendable to open screw insertion, care must also be taken to avoid violation of the supra-adjacent facet joint. These challenges are increased in those with higher PI, as we have shown that the TPA increases even further with increased PI.

The demonstrated high values of ΔTPA, particularly at the L5 level, illustrate one of the limitations of this project, related to the interrater reliability of TPA measurement. The most likely explanation for the observed deficit in reliability, for example, poor interrater reliability for TPA at the L5 level, relates to the demonstrated ΔTPA values. Both of the study raters attempted to measure TPA at the midsagittal aspect of the pedicle. The determination of this location on the pedicle was made subjectively. Clearly, if the 2 raters made different determinations of the midsagittal aspect of the pedicle, the differences in their measurements would be compounded by increasing ΔTPA. Accordingly, interrater reliability was fair at the L3 and L4 vertebral levels, which demonstrated relatively moderate values of ΔTPA as compared with L5, with higher ΔTPA and poor interrater reliability.

In some patients, the determination of the midsagittal aspect of the pedicle was further compounded by the quality of the imaging studies available. Considerable effort was made to consistently measure TPA on CT scans; however, MRI scans were utilized in a minority of patients when the midsagittal aspect of the pedicle could not be best visualized on CT. It should be noted that scan type was controlled for in each of the analyses performed in the study and was not significantly related to any of the outcomes. However, the variation in scan type remains a limitation of the study. Further, taking into consideration the magnitude of the demonstrated ΔTPA values in the lumbar spine, there may be 3-dimensional differences in pedicle morphology which 2-dimensional morphologic parameters, such as TPA, may not be best-suited to capture.

Future work should aim to determine if high TPA results in changes in local biomechanical characteristics leading to abnormal force distributions. As previously mentioned, it is possible that wide TPA may alter CF. Future considerations can include producing Finite Element Models of the lumbar spine in patients with increased TPA. These models could then be compared to those constructed for patients with normal TPA. Such an approach may be able to delineate if high TPA results in greater degree of slip or vice-versa due to changes in force distribution. Additionally, utilizing these methods other radiologic parameters, including sagittal vertical axis, sacral slope, and facet joint angulation could also be evaluated in an efficient manner to determine their association with the observed changes in pedicle morphology.

This study offers novel insight into 2 well-known spinal conditions and further characterizes anatomic features of the lumbar spine in patients with these spinal deformities. This study is the first to demonstrate an association between TPA and PI, and the first to characterize transverse vertebral anatomy in ISLS. Our findings suggest that pedicle anatomy is an important consideration in spondylolisthesis and that an anatomic relationship may exist between spinal sagittal balance and pedicle morphology. Further work is warranted to expand upon the results demonstrated by this preliminary investigation.

Declaration of Conflicting Interests

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