The value of sitting radiographs: analysis of spine flexibility and its utility in preoperative planning for adult spinal deformity surgery

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OBJECTIVE Preoperative planning of thoracolumbar deformity (TLD) surgery has been shown to improve radiographic and clinical outcomes. One of the confounders in attaining optimal postoperative alignment is the reciprocal hyperkyphosis of unfused thoracic segments. Traditional planning utilizes standing radiographs, but the value of sitting radiographs to predict thoracic flexibility has not been investigated. Authors of the present study propose that alignment changes from a sitting to a standing position will predict changes in unfused thoracic segments after TLD correction.

METHODS Patients with degenerative spine pathology underwent preoperative sitting and standing full-spine stereotactic radiography. A subset of TLD patients who had undergone corrections with minimum T10–pelvis fusions was analyzed in terms of pre- to postoperative alignment. Radiographic parameters were analyzed, including the T1 pelvic angle (TPA), T1–L1 pelvic angle (TLPA), lumbar pelvic angle (LPA), pelvic tilt (PT), mismatch between pelvic incidence and lumbar lordosis (PI–LL mismatch), and T2–12 kyphosis (TK). Thoracic compensation was calculated as the expected TK minus actual TK (i.e., $[2/3 \times \text{PI}] - \text{actual TK}$). Statistical analysis consisted of paired and unpaired t-tests and linear regression analysis.

RESULTS The authors retrospectively identified 137 patients with full-body standing and sitting radiographs. The mean age of the patients was 60.9 years old, 60.0% were female, and the mean BMI was 27.8 kg/m². The patients demonstrated significantly different radiographic alignments in baseline spinopelvic and global parameters from the preoperative sitting versus the standing positions: LL (-34.20° vs -47.87° , $p < 0.001$), PT (28.31° vs 17.50° , $p < 0.001$), TPA (27.85° vs 16.89° , $p < 0.001$), TLPA (10.63° vs 5.17° , $p < 0.001$), and LPA (15.86° vs 9.67° , $p < 0.001$). Twenty patients (65.0% female) with a mean age of 65.3 years and mean BMI of 30.2 kg/m² had TLD and underwent surgical correction (pre- to postoperative standing change in TPA: 33.90° to 24.50° , $p = 0.001$). Preoperative sitting radiographs demonstrated significant differences in alignment compared to postoperative standing radiographs: larger TPA (39.10° vs 24.50° , $p < 0.001$), PT (35.40° vs 28.10° , $p < 0.001$), LL (-11.20° vs -44.80° , $p < 0.001$), LPA (22.80° vs 14.20° , $p < 0.001$), and unfused Cobb (T2 to upper instrumented vertebra [UIV] Cobb angle: 19.95° vs 27.50° , $p = 0.039$). Also in the TLD group, mean thoracic compensation was 6.75° . In the linear regression analysis, the change from sitting to standing predicted pre- to postoperative changes for TK and the unfused thoracic component of TPA (5° change in preoperative sitting to preoperative standing corresponded to a pre- to postoperative change in standing TK of 6.35° and in standing TPA of 7.23° , $R^2 = 0.30$ and 0.38 , respectively).

CONCLUSIONS Sitting radiographs were useful in demonstrating spine flexibility. Among the TLD surgery group, relaxation of the unfused thoracic spine in the sitting position predicted the postoperative increase in kyphosis of the unfused thoracic segments. Sitting radiographs are a useful tool to anticipate reciprocal changes in thoracic alignment that diminish global corrections.

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KEYWORDS sitting radiographs; preoperative planning; spinal deformity; thoracolumbar correction surgery

ABBREVIATIONS ASD = adult spinal deformity; LPA = lumbar pelvic angle; PI–LL mismatch = pelvic incidence–lumbar lordosis mismatch; PJK = proximal junctional kyphosis; PT = pelvic tilt; SVA = sagittal vertical axis; TC = thoracic compensation; TK = T2–12 kyphosis; TLD = thoracolumbar deformity; TLPA = T1–L1 pelvic angle; TPA = T1 pelvic angle; UIV = upper instrumented vertebra.

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ADULT spinal deformity (ASD) is associated with severe back pain, neurological symptoms, and limited functional mobility. With the advent of better healthcare, hexagenarians are becoming the fastest growing proportion of the US population.¹¹ As the percentage of middle-aged to elderly people in the US grows, more patients are expected to present with painful spinal pathologies. The prevalence of spinal deformity in the US population has been estimated to be as high as 60%, and this rate increases substantially with age.²⁶ As the functional expectations of this population increase, so will the need for corrective spinal surgeries to optimize their quality of life. The field of ASD research has advanced significantly from early reports on utilizing coronal Cobb angles for scoliotic deformity to increasingly sophisticated descriptions of sagittal spinal deformity, such as the sagittal vertical axis (SVA) and various spinopelvic alignment measurements. It is well established that sagittal spinal deformity is correlated with functional disability, as quantified by validated health-related quality of life (HRQOL) measures.^{3,8,9,15,28} According to a prospective multicenter evaluation study by Schwab et al. and the International Spine Study Group, HRQOL measures were correlated most strongly with three radiographic parameters, the SVA, pelvic tilt (PT), and the mismatch between pelvic incidence and lumbar lordosis (PI-LL mismatch).²⁷

Recently, Protopsaltis et al. introduced a novel angular measure of global sagittal spinal deformity, the T1 pelvic angle (TPA),²⁵ an angle that combines information from both the SVA and PT simultaneously to more directly measure the geometry of global spinal deformity.²⁵ The TPA has an advantage over other spinopelvic measures in that it can be measured in various body positions: standing, sitting, and prone on the operating table.²⁵

Preoperative planning is prudent for attaining optimal alignment in spinal deformity surgery. Complete assessment of a patient with ASD requires a thorough physical examination including a detailed neurological examination, laboratory testing, 3D spinal imaging, and full-spine radiographs to create a complete understanding of all the potential challenges involved in a case, such as disruptions in neurological status and standing posture, the presence of hip flexion contractures, leg length inequality and pelvic obliquity, and challenges related to body habitus and nutritional status.²⁹ Standing radiographs are technique dependent and require visualization of the entire spine in the coronal and sagittal planes, as well as the femoral heads, for accurate measurement of sagittal alignment through the SVA, PT, and PI-LL mismatch. Traditional preoperative planning is performed using standing radiographs. However, advanced supine imaging such as MRI or CT can be an adjunct. A recent study has demonstrated the utility of advanced supine imaging to assess the flexibility of the lumbar spine as a part of surgical planning.¹ However, postoperative alignment changes in unfused adjacent segments are often overlooked. The concept of reciprocal changes in unfused segments proximal to the instrumentation and deformity correction has been well described in the literature.¹⁶ The greater incidence of kyphosis progression reported among patients undergoing shorter segment fusions following lower tho-

racic or lumbar osteotomies versus among patients with longer segment fusions could be attributable to this progression.¹³ These reciprocal changes could diminish the global correction obtained in thoracolumbar deformity (TLD) surgery and should be considered as part of preoperative alignment planning to avoid the pathological phenomenon of proximal junctional kyphosis (PJK) or proximal junctional failure (PJF).¹⁶ The main objective of this study was to evaluate a novel planning tool—the use of sitting radiographs—in assessing the flexibility of unfused thoracic segments and predicting postoperative reciprocal thoracic hyperkyphosis in patients undergoing TLD correction.

Methods

This is a retrospective review of consecutive patients who presented for evaluation at a multidisciplinary academic musculoskeletal center. All patients underwent full-body standing stereoradiography in addition to full-spine sitting stereoradiography. Institutional review board approval was obtained for the single center involved in this study.

Image Acquisition

Patients included in the study had undergone low-dose-radiation, full-body, biplanar standing and sitting stereoradiography (EOS Imaging). The EOS system is a slot-scanning radiographic device consisting of two x-ray source-detector pairs, allowing simultaneous orthogonal image acquisition. The imaging protocol involved patients standing unsupported in a position of comfort with their arms flexed and their fingers touching their clavicles to avoid superimposition of their arms over the spine. Sitting image acquisition involved patients sitting in a position of comfort with arms flexed and fingers touching their clavicles (Fig. 1). Included patients had the standing and sitting imaging done on the same day at the same site.

Data Collection and Analysis

Common radiographic parameters were measured for each image, including TPA, PT, PI, LL, PI-LL mismatch, and T2–12 kyphosis (TK). Component angles of the TPA were analyzed to assess regional contributions to alignment: the lumbar pelvic angle (LPA) is the angle formed by a line from the center of the L1 vertebral body to the femoral head axis and a line from the femoral head axis to the center of the S1 endplate, and the T1–L1 pelvic angle (TLPA) is formed by a line extending from the center of T1 to the femoral head axis and a line from the femoral heads to the midpoint of the superior endplate of L1 (Fig. 2). The LPA describes lumbopelvic alignment, whereas the TLPA assesses sagittal alignment of the thoracic spine. Radiographic measurements for both sitting and standing images were performed using validated surgical planning software (Surgimap version 2.2.3, Nemaris Inc.). A single observer performed all measurements; however, all measurements were rechecked by a second observer to avoid interobserver variability.

Preoperative thoracic compensation (TC) was calculated with the following formula: expected TK – actual

FIG. 1. Stereotactic radiograph acquisition in a sitting position. This process is standardized for all patients. Figure is available in color online only.

TK, where expected TK = $2/3 \times \text{PI}$. Patients were grouped by their degree of TC ($> 10^\circ$ vs $\leq 10^\circ$), and TK and TLPA were compared between preoperative sitting and standing radiographs for the two groups.

A subset of TLD patients underwent surgical corrections with minimum T10-pelvis fusions. Their preoperative sitting and standing alignments were compared, as were their preoperative and postoperative alignments. For this subset of patients, two parameters were used to assess alignment of the unfused thoracic segments before and after surgical correction: 1) a TPA component angle, the unfused TPA (the angle of a line drawn from the center of T1 to the center of the femoral heads and a line from the femoral heads to the center of the upper instrumented vertebra [UIV]); and 2) a sagittal Cobb angle containing only the unfused thoracic segments (angle of a line drawn tangent to the superior endplate of T2 and another line drawn tangent to the superior endplate of the UIV; Figs. 3 and 4).

Statistical Analysis

Comparisons between standing and sitting radiographic parameters, as well as an analysis of preoperative and postoperative time points, were performed using paired samples t-tests and independent samples t-tests, with significance set at $p < 0.05$. Linear correlations between radiographic parameters were evaluated and reported with

FIG. 2. The T1 pelvic angle (TPA), and its component angles, the TLPA and LPA. Figure is available in color online only.

Pearson correlation coefficients. All statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS Version 23.0, IBM Corp.).

Results

We identified 137 patients with full-body standing and sitting radiographs. The mean age of the whole cohort was 60.9 years, the mean BMI was 27.8 kg/m², and the population was 60.0% female (Table 1). Twenty-seven patients (20%) had prior spinal fusions with a mean of 9.04 levels fused. Twenty patients underwent TLD corrections. The mean age of the TLD cohort was 65.3 years, the mean BMI was 30.3 kg/m², and 65% of the population was female. Six patients (30%) had a mean of 1.83 levels fused at baseline. Following deformity correction, the mean number of levels instrumented postoperatively was 9.89. Forty percent of patients underwent Schwab grade 3 or higher osteotomy (pedicle subtraction osteotomy or vertebral column resection). Thirty percent of the patients had upper thoracic (T3 or T4) and 70% of the patients had lower thoracic (T10 or T11) instrumentation and fusion.

FIG. 3. Preoperative standing (A), preoperative sitting (B), and postoperative standing (C) radiographs of a patient with TLD. The sitting radiograph shows relaxation of thoracic compensatory hyperkyphosis (note the increase in T2-UIV Cobb). The change from standing to sitting in the unfused component (T2-UIV Cobb) of the TK predicted the increase in the change in unfused thoracic alignment that occurs postoperatively.

Radiographic Analysis: Whole Cohort

In comparing preoperative sitting and standing alignment, we noted differences in regional, global, and spinopelvic parameters: LL (sit vs stand: -34.2° vs -47.9° , $p < 0.001$), PT (28.3° vs 17.5° , $p < 0.001$), TPA (27.9° vs 16.9° , $p < 0.001$), TLPA (10.6° vs 5.17° , $p < 0.001$). Note that LPA, the lumbar component of TPA, was larger while sitting than while standing (15.9° vs 9.67° , $p < 0.001$; Table 2).

Radiographic Analysis: TLD Cohort

In the TLD cohort, there were significant differences in preoperative sitting and standing alignment in the following measurements: PT (35.40° vs 28.45° , $p = 0.003$), TLPA (22.75° vs 14.10° , $p = 0.009$), and TPA (39.10° vs 33.90° , $p = 0.031$; Table 2).

When comparing preoperative standing and postoperative standing radiographs, we noted significant improvements in LL (-11.45° vs -44.80° , $p < 0.001$), TPA (33.90° vs 24.50° , $p < 0.001$), and LPA (20.30° vs 14.20° ,

$p < 0.001$). In contrast, TLPA increased (14.10° vs 22.05° , $p = 0.017$), as did the unfused component of TK (unfused Cobb: 18.90° vs 27.50° , $p < 0.001$).

There were significant differences in preoperative sitting compared with postoperative standing alignment in the following parameters: LL (-11.20° vs -44.80° , $p < 0.001$), PT (35.40° vs 28.10° , $p = 0.011$), TPA (39.10° vs 24.50° , $p < 0.001$), LPA (22.80° vs 14.20° , $p < 0.001$), and the unfused component of TK (unfused Cobb: 19.95° vs 27.50° , $p = 0.039$; Table 3). Additionally, the unfused TPA was not statistically significantly different between preoperative sitting and postoperative standing (13.50° vs 8.50° , $p > 0.05$; Table 3 and Figs. 3 and 4).

Thoracic Compensation Analysis: Whole Cohort

Mean TC for the whole cohort was determined to be 5.38° . During subgroup analysis, 55 patients exhibited $TC > 10^\circ$, whereas 72 patients demonstrated $TC \leq 10^\circ$. Among the 55 patients with $TC > 10^\circ$, TLPA was different when comparing sitting and standing (10.05° vs 6.42° , $p < 0.001$). In contrast, among the 72 patients who did not

FIG. 4. Preoperative standing (A), preoperative sitting (B), and postoperative standing (C) radiographs of a patient with TLD. The sitting radiograph shows relaxation of thoracic compensatory hyperkyphosis (note the increase in T1-U1V PA). The change in the unfused thoracic component (T1-U1V PA) of the TPA from the standing to the sitting position predicted the increase in the change in unfused thoracic alignment that occurs postoperatively.

exhibit TC, there were statistically significant differences in sitting versus standing TK (41.47° vs 45.51° , $p < 0.001$) and TLPA (11.68° vs 6.38° , $p < 0.001$; Table 4).

Thoracic Compensation Analysis: TLD Cohort

The mean TC was 6.75° in the TLD patients. Linear regression analysis demonstrated that the changes in alignment from preoperative sitting to preoperative standing were significant predictors for changes in alignment from preoperative standing to postoperative standing in terms of TK ($R^2 = 0.304$) and TPA ($R^2 = 0.387$). Taking into account the slope for each of the equations, a 5° change in preoperative sitting to preoperative standing corresponded to a pre- to postoperative change in TK of 6.35° and in TPA of 7.23° (Figs. 3 and 4).

Discussion

With the demographic trends toward increasingly aging populations in many developed countries, the prevalence of ASD is expected to rise substantially. Despite the extensive nonoperative measures utilized in most patients

with such deformities, a substantial number will seek surgical correction. Given this fact, certain preoperative spinopelvic parameters have routinely been considered in the planning of such surgeries. Assessment of these parameters is essential for suitable correction to obtain optimal clinical results. A recent relative risk analysis revealed that patients with a PI-LL mismatch $> 11^\circ$ had 4.2-fold greater risk of pelvic retroversion, 10.9-fold greater risk of developing positive sagittal malalignment (SVA), and 3.9-fold greater risk of severe disability.²⁷ Thus, targets for alignment correction in ASD have been proposed, including SVA < 50 mm, PT $< 22^\circ$, and PI-LL mismatch $< 11^\circ$. The coxofemoral joints and pelvis are involved in the modulation of standing spinal alignment in ASD.¹⁷ This modulation results in a cascade of compensatory mechanisms once the deformed spine loses its normal alignment. Pelvic retroversion is the first event of compensation.^{5,17} When pelvic compensation is exhausted, activation of lower extremity compensatory mechanisms occurs.⁵ Nevertheless, some patients exhibit a decrease in their TK to compensate for the loss of LL, a mechanism called thoracic compensation (TC).^{2,5} This mechanism of

TABLE 1. Demographic details of the whole cohort and TLD cohort

Variable	Full Cohort	TLD Cohort
No. of patients	137	20
Age in yrs	60.92 ± 14.63	65.35 ± 10.42
Female sex	0.60 ± 0.49	0.65 ± 0.49
BMI in kg/m ²	27.83 ± 6.77	30.26 ± 7.01
Patients w/ prior spinal fusions	20%	30%
Baseline no. of levels fused	9.04 ± 4.18	1.83 ± 1.60

Values expressed as the mean ± standard deviation unless indicated otherwise.

hypokyphosis requires thoracic flexibility and good motor strength. There are limited investigations focused on TC.² The present study explores this compensatory mechanism in detail in the preoperative sitting versus standing position, and the results indicated that 55 patients with TC > 10° had a significant decrease in TLPA ($p < 0.001$ from a sitting to a standing position) (Table 4). This mechanism of TC should be accounted for in preoperative planning and can have potential implications for progressive postoperative kyphosis through an increased reciprocal change in alignment in the standing position.⁵

In ASD surgery, in which a large percentage of patients have fusions to the pelvis, a major unknown is the fate of the unfused thoracic segments. We anticipate that there is an inherent flexibility of the spinal segments above the instrumentation through a mechanism of preoperative TC, which starts to lose correction over time. Ikenaga et al. have reported that increased TK occurs postoperatively, a phenomenon that has been termed “reciprocal change.”¹³ Although not a focus of this study, the progressive pathological form of this reciprocal change, in which the vertebral body or spinal segment rostral to the spinal construct will exhibit $\geq 10^\circ$ of change, results in PJK.^{10,21} Proximal junctional kyphosis alone does not warrant an absolute indication for revision surgery, but rates of revision surgery for PJK have been reported to be between 13% and 47.4%.^{10,21} Nicholls et al. reported on factors associated with PJK, including age, longer follow-up, female sex, higher preoperative PT, and higher TK.²²

In an attempt to further evaluate overall spinal alignment, Protopsaltis et al. introduced a new angular measure to assess global sagittal alignment in patients with ASD.²⁵ The TPA is the angle that is a summation of both the SVA and PT simultaneously. This angle can be further divided into component parts: TLPA, LPA, and unfused TPA (T1 to UIV PA). The LPA, which accounts for lumbopelvic alignment, has been shown to be a valid alternative to the PI-LL mismatch.²⁴ Thus, spinopelvic angles such as TPA and its component angles are useful as a means of assessing the contribution of specific spinal regions to global spinal deformity.²⁴ Oren et al. showed that component angles of TPA can be measured intraoperatively and that these measurements correlated highly with postoperative standing alignment.²³ In the present study, TLPA and LPA were significantly different between preoperative sitting and standing radiographs in the whole cohort. These data cor-

TABLE 2. Comparison of sagittal parameters between preoperative sitting and preoperative standing position

Measurement & Cohort	Preop Sitting		Preop Standing		p Value
	Mean	Standard Deviation	Mean	Standard Deviation	
Whole cohort					
LL	-34.20	19.56	-47.87	21.73	0
PT	28.31	12.89	17.5	10.72	0
TK	18.48	37.23	19.32	39.46	0.28
TLPA	10.63	9.58	5.17	6.82	0
TPA	27.85	13.27	16.89	14.17	0
LPA	15.86	11.65	9.67	11.52	0
TLD cohort					
LL	-11.2	23.64	-11.45	30.52	0.963
PT	35.40	11.65	28.45	7.59	0.003
TK	29	15.78	30.65	19.97	0.592
TLPA	22.75	14.45	14.1	8.28	0.009
TPA	39.1	13.54	33.9	13.96	0.031
LPA	22.8	11.88	20.3	13.69	0.054
Unfused Cobb	19.95	14.1	18.9	16.16	0.724
Unfused TPA	13.5	12.39	9.35	7.23	0.16

Unfused Cobb = sagittal Cobb angle of unfused segment of TK (T2 to UIV Cobb angle); unfused TPA = T1 to UIV PA.

All but the p values are expressed in degrees. Boldface type indicates statistical significance.

roborate prior studies that have demonstrated the spinal alignment changes that occur between sitting and standing.^{4,6,7,12,14,20} In the TLD cohort, LPA was not significantly different between sitting and standing, which reflects the fact that 30% of these patients had prior spine surgery with a mean baseline of 1.83 levels fused. While there were no significant differences in LL and TK in the TLD patients between preoperative sitting and preoperative standing, the PT, TPA, and TLPA were significantly different, reflecting the alignment changes that occur as patients relax their spine posture in the sitting position. These findings demonstrate the utility of TPA and its component angles in assessing spinal alignment in different patient positions.

While little has been published regarding the utility of sitting radiographs, some authors have argued that supine or prone radiographs are valuable in preoperative planning.²³ However, supine radiographs do not predict reciprocal changes in the unfused segments of the thoracic spine. Sitting radiographs have been utilized in preoperative planning of total hip arthroplasties (THAs).¹⁹ Prior work has demonstrated that the sitting position causes increased retroversion of the pelvis, a decrease in LL, and a relaxation of global spinal alignment.¹⁸ Results of the current study corroborate these findings; mean differences between preoperative sitting and standing in the whole cohort for PT, LL, and TPA are 10.81, 13.67, and 10.96, respectively. Therefore, the changes in spinopelvic alignment from standing to sitting result in a dramatic change in pelvic retroversion beyond that which a standing patient can accomplish through compensatory mechanisms. As a result

TABLE 3. Comparison of sagittal parameters between preoperative sitting and postoperative standing position in TLD cohort

Measurement	Preop Sitting		Postop Standing		p Value
	Mean	Standard Deviation	Mean	Standard Deviation	
LL	-11.20	23.64	-44.80	10.65	0.000
PT	35.40	11.65	28.10	11.64	0.011
TK	29.00	15.78	31.55	16.95	0.459
TLPA	22.75	14.45	22.05	14.71	0.833
TPA	39.10	13.54	24.50	9.61	0.000
LPA	22.80	11.88	14.20	9.55	0.000
Unfused Cobb	19.95	14.10	27.50	20.56	0.039
Unfused TPA	13.50	12.39	8.50	5.28	0.068

All but the p values are expressed in degrees. Boldface type indicates statistical significance.

of this increased pelvic retroversion, there is relaxation of supra-adjacent spinal alignment. Thus, sitting radiographs offer an additional assessment of spine flexibility.

The phenomenon of reciprocal change following deformity correction and spinopelvic fusion should be anticipated and accounted for in surgical planning.^{13,16} The hypothesis of this study was that sitting spinal alignment could predict the postoperative hyperkyphosis of unfused thoracic segments following corrective surgery. To this point, in the TLD cohort, the preoperative sitting unfused component of TPA was not dissimilar to the postoperative standing unfused component of TPA ($p > 0.05$). Figure 4 shows figures from a representative patient who underwent spinal realignment with fusion from T10 to the pelvis. His preoperative standing alignment demonstrates TC ($> 10^\circ$), whereas his preoperative sitting unfused component of TPA was similar to the postoperative standing unfused component of TPA. Moreover, the results of linear regression analysis in this study demonstrated that a 5° change in preoperative sitting to preoperative standing alignment corresponded to a preoperative to postoperative change in TK of 6.35° and change in TPA of 7.23° .

Preoperative thoracic hypokyphosis, or TC, was defined as $(2/3 \times \text{PI}) - \text{actual TK}$. Thoracic flexibility (the change in TK and TLPA from sitting to standing) was analyzed in the compensated ($\text{TC} > 10^\circ$) and uncompensated cohorts ($\text{TC} \leq 10^\circ$). While TK was not statistically different in the compensating cohort, TLPA was larger in the sitting position (10.05° vs 6.42° , $p < 0.001$). This demonstrates the utility of TLPA as a component measure of TPA, which can be utilized to assess the inherent flexibility of the thoracic spine in sitting versus standing radiographs preoperatively.

There are some limitations to the present study, the most prominent of which is the retrospective study design. Secondly, the relatively small cohort of TLD patients may have limited the statistical power of that subset analysis. Furthermore, 30% of patients in the TLD cohort had upper thoracic segment fusions, which could limit the significance of the unfused TPA from the preoperative sitting to the postoperative standing position. Future prospective

TABLE 4. Paired t-test analysis of whole cohort in preoperative sitting and standing TK and TLPA

Measurement	Preop Sitting		Preop Standing		p Value
	Mean	Standard Deviation	Mean	Standard Deviation	
TC >10°					
TK	34.15	16.43	34.71	17.28	0.642
TLPA	10.05	7.64	6.42	4.97	0.000
TC ≤10°					
TK	41.47	13.49	45.51	12.03	0.000
TLPA	11.68	10.19	6.38	6.26	0.000

TC = thoracic compensation (expected TK [i.e., $2/3$ of PI] – actual TK); TK = thoracic kyphosis, T2–12 sagittal Cobb angle; TLPA = T1 to L1 pelvic angle. All but the p values are expressed in degrees. Boldface type indicates statistical significance.

investigations with more patients undergoing deformity corrections are warranted. Despite these limitations, we had conducted consecutive prospective data collection in which all radiographic measurements were performed at a single center. This is the first study to assess the utility of specific flexibility imaging in predicting the changes in alignment of the unfused thoracic spine in TLD surgery.

Conclusions

Preoperative planning is prudent for deformity surgery. The TPA is emerging as an increasingly useful angular measure of spinopelvic alignment relevant to sagittal deformity. Since the TPA measure is independent of many postural compensatory mechanisms, it has considerable utility as a preoperative planning tool.²⁵ Moreover, component measures of TPA (TLPA, LPA) can be utilized to study the regional flexibility of the spine and the contributions of different spinal regions to global spinal deformity.^{16,24,25} Traditional preoperative planning is performed utilizing standing radiographs. Additional flexibility imaging techniques such as supine or prone radiographs have been proposed, but none to date has demonstrated utility in predicting postoperative reciprocal thoracic hyperkyphosis. The present study indicates that sitting radiographs are useful in demonstrating thoracic spine flexibility to predict postoperative thoracic hyperkyphosis. Sitting radiographs should be considered in the preoperative planning of ASD surgery to predict reciprocal changes in thoracic alignment that diminish global sagittal spinal correction.

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Author Contributions

Conception and design: Protopsaltis. Acquisition of data: Janjua, Tishelman. Analysis and interpretation of data: Janjua, Tishelman, Buckland, Protopsaltis. Drafting the article: Janjua. Critically revising the article: Janjua, Protopsaltis. Reviewed submitted version of manuscript: Janjua, Vaynrub, Errico, Buckland, Protopsaltis. Approved the final version of the manuscript on behalf of all authors: Janjua. Statistical analysis: Tishelman, Vasquez-Montes.

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