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DEFORMITY

The Lumbar Pelvic Angle, the Lumbar Component of the T1 Pelvic Angle, Correlates With HRQOL, PI-LL Mismatch, and it Predicts Global Alignment

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Study Design. Prospective multicenter analysis of adult spinal deformity (ASD) patients.

Objective. The aim of this study was to introduce the lumbar pelvic angle (LPA), a novel parameter of spinopelvic alignment.

Summary of Background Data. The T1 pelvic angle (TPA), a measure of global spinopelvic alignment, correlates with health-related quality of life (HRQOL), but it may not be measureable on all intraoperative x-rays. In patients with previous interbody fusion at L5-S1, the plane of the S1 endplate can be blurred, creating error in pelvic incidence and lumbar lordosis (PI-LL) measure. The LPA is more readily measured on intraoperative imaging than the TPA.

Methods. ASD patients were included with either coronal Cobb angle >20°, sagittal vertical axis (SVA) >5 cm, thoracic kyphosis >60°, or pelvic tilt (PT) >25°. Measures of disability included Oswestry Disability Index (ODI), Scoliosis Research Society (SRS), and Short Form (SF)-36. Baseline and 2-year follow-up radiographic and HRQOL outcomes were evaluated. Linear regressions compared LPA with radiographic parameters and HRQOL.

Results. A total of 852 ASD patients (407 operative) were enrolled (mean age 53.7). Baseline LPA correlated with PI-LL ($r=0.79$), PT ($r=0.78$), TPA ($r=0.82$), and SVA ($r=0.61$) (all $P<0.001$). PI-LL, LPA, and TPA correlated with ODI ($r=0.42$/0.29/0.45), SF-36 physical component score (−0.43/−0.28/−0.45) SRS (−0.354/−0.23/−0.37) with all $P<0.001$. At 2 years' follow-up, LPA correlated with PI-LL ($r=0.77$), PT ($r=0.78$), TPA ($r=0.83$), and SVA ($r=0.57$) (all $P<0.001$). Categorizing patients by increasing LPA (<7°; 7°–15°; >15°) revealed progressive increases in all HRQOL, PI-LL (−3.2°/12.7°/32.4°), and TPA (9.7°/20.1°/34.6°) with all $P<0.001$. Moderate disability (ODI = 40) corresponded to LPA 10.1°, PI-LL 12.6°, and TPA 20.6°. Mild disability (ODI = 20) corresponded to LPA 7.2°, PI-LL 4.2°, and TPA 14.7°.

Conclusion. LPA correlates with TPA, PI-LL, and HRQOL in ASD patients. LPA can be used as an intraoperative tool to gauge correction with a target LPA of <7.2°. LPA predicts global alignment, as it correlates with baseline and 2-year TPA and SVA. Along with the cervical-thoracic pelvic angle and TPA, LPA completes the fan of spinopelvic alignment.

Key words: adult spinal deformity surgery, global spinopelvic alignment, health-related quality of life, interbody fusion, intraoperative planning, lumbar pelvic angle, patient-reported outcomes, radiographic parameters, sagittal malalignment, T1-pelvic angle, thoracolumbar surgery.

Level of Evidence: 3

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Sagittal spinal deformity is a major driver of disability and has been shown to have a tremendous health impact equivalent to diseases such as cancer, diabetes, and heart disease.[1–6] As the Western population continues to age, adult spinal deformity (ASD) has become

increasingly prevalent, with estimated rates up to 60% in the elderly US population.[7]

Recognition of the relationship between pelvic morphology, as represented by pelvic incidence, and lumbar lordosis has enhanced the understanding of sagittal spinal malalignment.[3] A pathologic mismatch between pelvic incidence and lumbar lordosis (PI-LL) results in lumbar flatback deformity, which can drive global sagittal deformity.[3,8] Smith *et al*[8] demonstrated that even among lumbar flatback patients with adequate compensation, disability measures are worse; these patients still respond well to correction of the pathologic loss of lumbar lordosis. The PI-LL parameter has been shown to be an invaluable perioperative tool for correction of lumbar flatback deformity because it is one of the few measures that can be assessed intraoperatively to gauge the adequacy of correction. However, there are some limitations to the PI-LL parameter. First, it depends on clear visualization of both the L1 and S1 endplates. In patients with previous interbody fusion, the exact orientation of the endplate may be obscured, leading to errors in measurement. Moreover, spinal alignment parameters that require Cobb angles measured by two or more endplates are more likely to have erroneous meausurements.[2,9]

The T1 pelvic angle (TPA) was introduced as an alternative to linear and endplate-based measures of sagittal spinal deformity.[2] Unlike sagittal vertical axis (SVA) or pelvic tilt (PT), which are defined on radiographs of upright, freely-standing individuals, TPA can be assessed on a prone intraoperative 36-inch radiograph.[2] However, in addition to visualization of the S1 endplate, this also requires visualization of the T1 vertebral body, which can be challenging to obtain and often difficult to delineate intraoperatively when the shoulders often obscure the T1 vertebral body.

Therefore, the purpose of this study is to introduce a novel measure of spinopelvic alignment, the lumbar pelvic angle (LPA). The 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 (Figure 1). LPA represents the lumbar component of TPA, and is more easily measured on intraoperative radiographs or fluoroscopic images. This study sought to assess LPA's correlation with disability measures, as well as its ability to predict global sagittal alignment.

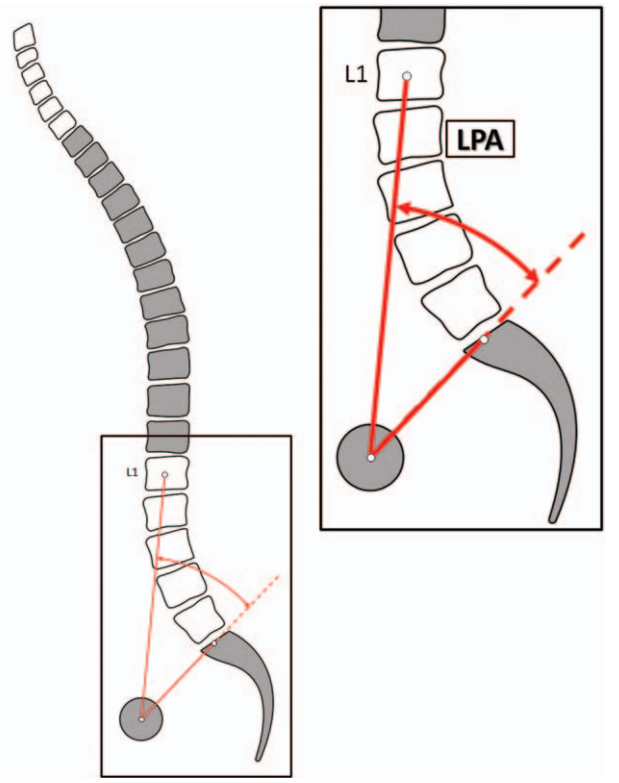

Figure 1. The L1 pelvic angle (LPA) is the angle formed by a line from the center of the L1 vertebral body to the femoral head axis and a line from the femoral head axis to the center of the S1 endplate.

MATERIALS AND METHODS

Study Design

This study is a multicenter, prospective data analysis of patients with ASD conducted through the International Spine Study Group, a collaboration of spine surgeons from 11 sites across the United States. Institutional review board approval was obtained at each site before patient enrollment and data collection. Inclusion criteria were age >18 years and a radiographic diagnosis of ASD, defined as at least one of the following: coronal Cobb angle ≥20°, SVA ≥5 cm, PT ≥25°, or thoracic kyphosis ≥60°. For the present study, all subjects had 36-inch standing radiographs and health-related quality of life (HRQOL) outcomes available at baseline.

Radiographic Analysis and Data Collection

Data collection at baseline and 2-year follow up included standardized HRQOL questionnaires, as well as clinical, demographic, and radiographic information. Demographic and clinical data included patient age, sex, body mass index (BMI), and Charlson Comorbidity Index (CCI).[10]

All subjects had 36-inch standing scoliosis radiographs, for which patients were free of any external support such as walkers or hanging bars. All radiographic measurements were performed at a central location using standard techniques and a dedicated, validated software (Spineview, ENSAM ParisTech, Paris).[11,12] Radiographic parameters included LPA, TPA, SVA, T9 pelvic angle (T9PA), T1 and T9 spino-pelvic inclination (T1SPi and T9SPi), PT, and pelvic incidence minus lumbar lordosis (PI-LL).

HRQOL outcomes included the Oswestry Disability Index (ODI), Scoliosis Research Society (SRS)-22, and Short Form (SF)-36 questionnaires.[13] Two standard summary scores were calculated based on the SF-36, the Physical Component Score (PCS), and the Mental Component Score (MCS). The SRS-22 provides a summary score in addition to scores for specific subdomains of activity, pain, appearance, mental health, and satisfaction.

Reliability Analysis

To assess the reliability of LPA, five observers measured the LPA, T9PA, TPA, SVA, PT, and PI in 20 sample cases on two separate occasions. The observers were comprised of three spine research fellows and two orthopedic surgeons, all with experience in performing spine measurements. Interobserver and intraobserver reliability was assessed with an absolute agreement intraclass correlation coefficient (ICC) analysis using a two-way random effects model. Agreement was classified as excellent for an ICC of >0.75.

Statistical Analysis

Radiographic parameters for the cohort were expressed using means, standard deviations (SD), ranges, and coefficient of variation (CV), calculated as the standard deviation divided by the mean. Correlations between LPA, radiographic parameters, and HRQOL were performed both at baseline and 2-year follow-up. Then, subjects were stratified into three groups based on increasing magnitude of LPA (<7°; 7°–15°; >15°). HRQOL and alignment parameters were compared between these three groups. Multiple linear regression was performed between the ODI score and different radiographic parameters such as PI-LL, TPA, and LPA to calculate the high disability threshold (corresponding to ODI <40) and moderate disability threshold (corresponding to ODI <20). Where appropriate, significance was set at $P < 0.05$.

RESULTS

Demographic

A total of 852 subjects met inclusion criteria at baseline, 407 of which underwent surgical correction. The mean age was 53.7 years (SD = 16 years, range = 18–86 years), and the mean BMI was 26 kg/m^2. The mean CCI score was 1.26 (SD = 1.5). Among the patients, 83% were female and 33% had previous spine surgery. Baseline radiographic parameters for the cohort are shown in Table 1.

Mean HRQOL measures for the cohort at baseline were 34.1 for ODI, 36.9 for SF-36 PCS, 47.5 for SF-36 MCS, and 3.1 for SRS-22.

Correlations

At baseline, LPA was highly correlated with PT ($r = 0.781$), PI-LL ($r = 0.790$), SVA ($r = 0.610$), TPA ($r = 0.819$), and well correlated with T9SPi ($r = 0.447$) and T1SPi ($r = 0.440$). In terms of HRQOL (Table 2), LPA was significantly correlated with ODI, SF-36 PCS, and SF-36 MCS. A similar trend was seen at 2 years (Table 2).

Stratification by LPA

Stratification by LPA produced the following group sizes: LPA <7°, n = 396; LPA 7° to 15°, n = 249; LPA >15°, n = 207. As LPA increased, there was a progressive worsening in PT, PI-LL, SVA and TPA, as well as in HRQOL (for all, analysis of variance $P < 0.01$) (Figure 2).

Reliability Analysis

The interobserver and intraobserver reliability of the L1 pelvic angle measure had excellent agreement (ICC = 0.961 and 0.906, respectively). It compared favorably with the interobserver and intraobserver reliability for the pelvic incidence (0.943 and 0.821), TPA (0.965 and 0.936), SVA (0.996 and 0.996), and PT (0.974 and 0.951).

Linear Regressions

Using the relationship between radiographic parameters and ODI, linear regressions linking ODI with different sagittal parameters were performed, generating the following equations:

$$PT = 15.046 + 0.190 * ODI;\ r = 0.349$$

$$PI - LL = -4.214 + 0.421 * ODI;\ r = 0.423$$

$$SVA = -12.902 + 1.598 * ODI;\ r = 0.468$$

TABLE 1. Means, SDs, Minimum, Maximum, and CVs of Sagittal Alignment Parameters for the Cohort at Baseline

Sagittal Alignment Parameters					
Parameter	**Mean**	**SD**	**Min**	**Max**	**CV**
PT	21.5	11.2	−13	68	1.9
PI	54.6	13.2	8	111	4.1
PI-LL	10.1	20.4	−47	86	0.5
T9SPi	−10.8	5.7	−37	19	−1.9
T1SPi	−2.7	5.5	−15	28	−0.5
SVA	41.1	70.2	−120	326	0.6
TPA	18.8	13.6	−9	69	1.4
T9PA	10.7	12.0	−18	54	1.1
LPA	9.3	10.3	−18	47	0.9

CV, coefficients of variation; LPA, lumbar pelvic angle; Max, maximum; Min, minimum; PI, pelvic incidence; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; T1SPI, T1 spinopelvic inclination; T9PA, T9 pelvic angle; T9SPI, T9 spinopelvic inclination; TPA, T1 pelvic angle. All measurements are in degrees except SVA (millimeters).

TABLE 2. Baseline and 2-year Correlations Between LPA, T9PA, PI-LL, and Other Sagittal Alignment Parameters

Correlations Between Sagittal Alignment Parameters					
Baseline	**PT**	**T9SPi**	**T1Spi**	**SVA**	**TPA**
LPA	0.781	0.447	0.440	0.61	0.819
PI-LL	0.827	0.345	0.551	0.720	0.890
T9PA	0.889	0.379	0.542	0.746	0.950
2-y FU	PT	T9SPi	T1Spi	SVA	TPA
LPA	0.779	0.253	0.297	0.566	0.833
PI-LL	0.787	0.193	0.341	0.641	0.860
T9PA	0.870	0.198	0.360	0.677	0.943

FU indicates follow up; LPA, lumbar pelvic angle; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; T9PA, T9 pelvic angle; T9SPi, T9 spinopelvic inclination; T1SPi, T1 spinopelvic inclination; TPA, T1 pelvic angle. All reported correlations have $P < 0.001$.

$$TPA = 8.773 + 0.296 * ODI;\ r = 0.447$$

$$T9PA = 2.794 + 0.232 * ODI;\ r = 0.398$$

$$LPA = 4.297 + 0.146 * ODI;\ r = 0.290$$

Based on this equation, the values of the radiographic parameters corresponding to severe disability (ODI = 40) and mild disability (ODI = 20) were calculated (Table 4).

DISCUSSION

Within the spectrum of spinal disorders, sagittal spinal deformity patients are among the most disabled.[1–6] Along with the recognition that sagittal spinal malalignment is more highly correlated with disability measures than coronal deformity, there has been a proliferation of various sagittal alignment parameters to describe the varied presentations of ASD.[1–5] These efforts have culminated in the description of the SRS Schwab classification of ASD, within which the sagittal modifiers command the lead role in

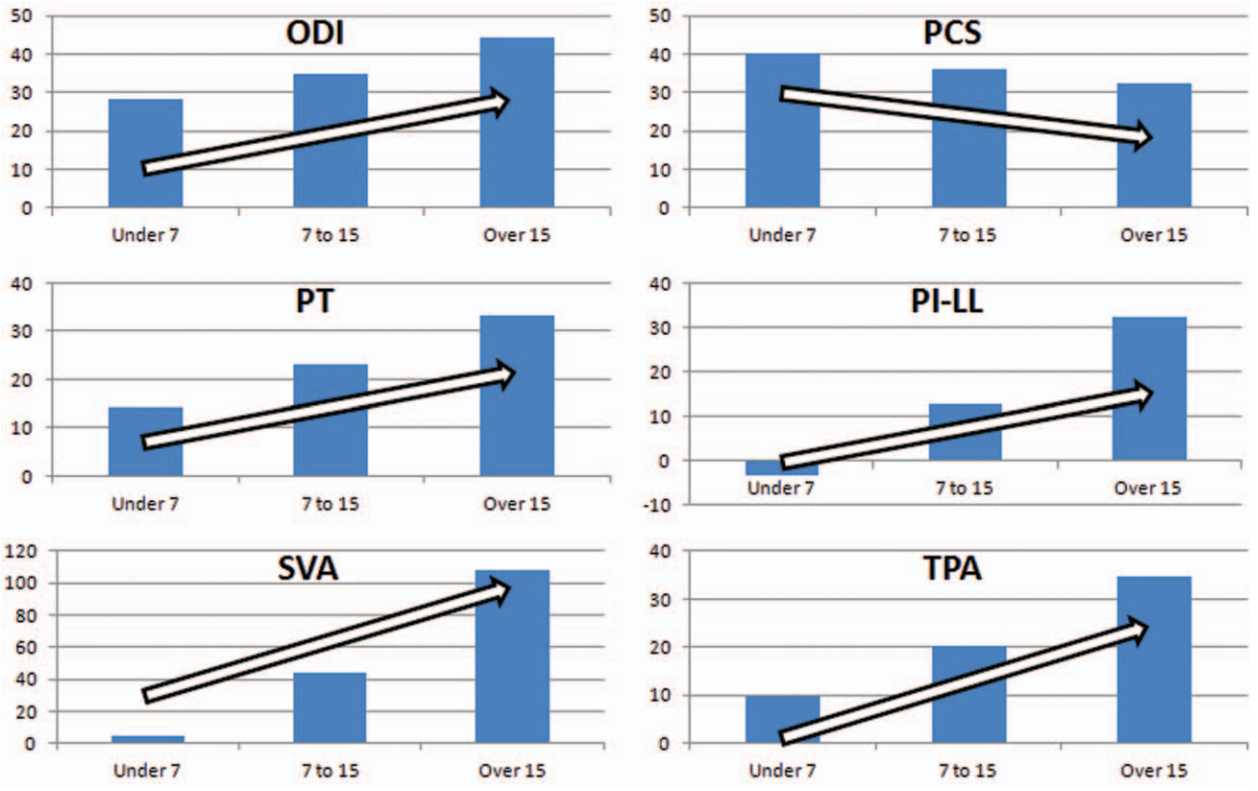

Figure 2. The mean ODI, Short Form-36 PCS), PT, PI-LL, SVA, and TPA by increasing severity of the LPA. LPA indicates lumbar pelvic angle; ODI, Oswestry Disability Index; PCS, physical component Score; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; TPA, T1 pelvic angle.

delineating spinal deformity, as they are most highly correlated with HRQOL measures.[5]

The PI-LL measure has been shown to correlate with HRQOL measures while also proving to be a valuable tool for perioperative planning.[2,5] It remains the only measure of the SRS Schwab classification that can be assessed intraoperatively to gauge the adequacy of lumbar flatback correction. However, the PI-LL parameter is composed of Cobb angle measures of 2 endplates, L1 and S1, and a measurement of the pelvic incidence which is also reliant on accurate identification of the angle and width of the S1 endplate. Studies have shown that parameters that are dependent on the accurate measurement of two or more vertebral endplate angles have higher error rates and less reliability.[2,9] To assess the reliability of the new L1 pelvic angle, the novel measure and the pelvic incidence, TPA, SVA, and PT and were assessed with ICC analysis. The interobserver and intraobserver reliability of the L1 pelvic angle measure was excellent (0.961 and 0.906, respectively) and compared favorably with the interobserver and intraobserver reliability for the pelvic incidence (0.909 and 0.866), TPA (0.980 and 0.902), SVA (0.995 and 0.917), and PT (0.959 and 0.853). Moreover, in cases in which a previous or subsequent intebody fusion is present, the exact orientation angle of the S1 endplate can be obscured adding more error to the measurement of endplate-based measures like the PI-LL.

The TPA is a global thoracolumbar deformity measure that has been shown to correlate with HRQOL in ASD patients.[2] It allows for the measurement of the geometry of the spinopelvic deformity separate from pelvic and lower extremity compensation. Unlike the SVA and the PT, the TPA can be measured in various patient positions, including prone on an operating room table.[2] However, accurate intraoperative measurement of the TPA requires visualization of the T1 vertebral body and the S1 endplate at a minimum, which can be difficult on a 36-inch cassette radiograph, especially in a tall individual.

Thus, this study introduces the L1 pelvic angle, the lumbar component of the TPA. As the LPA is measured from the center of the L1 vertebral body, it is dependent on one less endplate Cobb angle measurement. Figure 3 shows a representative illustrative case of a patient with lumbar flatback deformity undergoing sagittal correction with an L4 PSO; the LPA correction corresponds to the global alignment correction.

In the present study, LPA correlated with HRQOL measures and global spinal alignment measures such as the SVA and the TPA. The LPA correlated well with the TPA preoperatively and postoperatively (0.82 and 0.83 respectively, $P < 0.001$), the SVA preoperatively and postoperatively (0.61 and 0.57 respectively, $P < 0.001$), and PI-LL (0.79 and 0.77, respectively, $P < 0.001$). Thus, LPA can be utilized as an additional perioperative and intraoperative measurement tool to gauge the adequacy of correction and to predict global postoperative alignment. Figure 4A–C offers a representative case demonstrating correction of lumbar

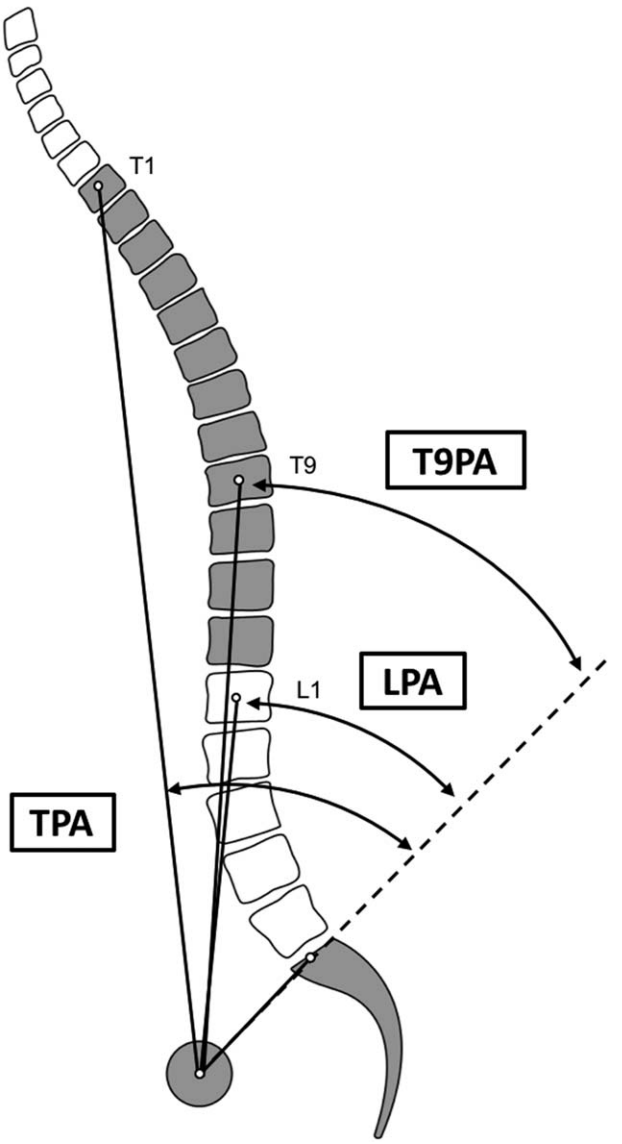

Figure 3. Relationships between the TPA, LPA, and T9PA. LPA indicates lumbar pelvic angle; T9PA, T9 pelvic angle; TPA, T1 pelvic angle.

flatback deformity including preoperative, intraoperative, and postoperative LPA measurements.

Although significant correlations were identified between LPA and all the baseline and 2-year postoperative HRQOL outcomes included in this study, the correlations between the HRQOL were not as strong as those for TPA and SVA (Table 3). The likeliest reason for this is that TPA and SVA account for global thoracolumbar alignment, whereas LPA measures lumbopelvic malalignment. Patients with deformities in both the thoracic and lumbar spine are likely to be more disabled than those with deformity only in the lumbar region alone.

Although prospectively collected radiographic and HRQOL data were utilized, the primary limitation of the study is its retrospective design. Moreover, intraoperative imaging was not available for the entire cohort to analyze and further validate the new parameter relative to existing

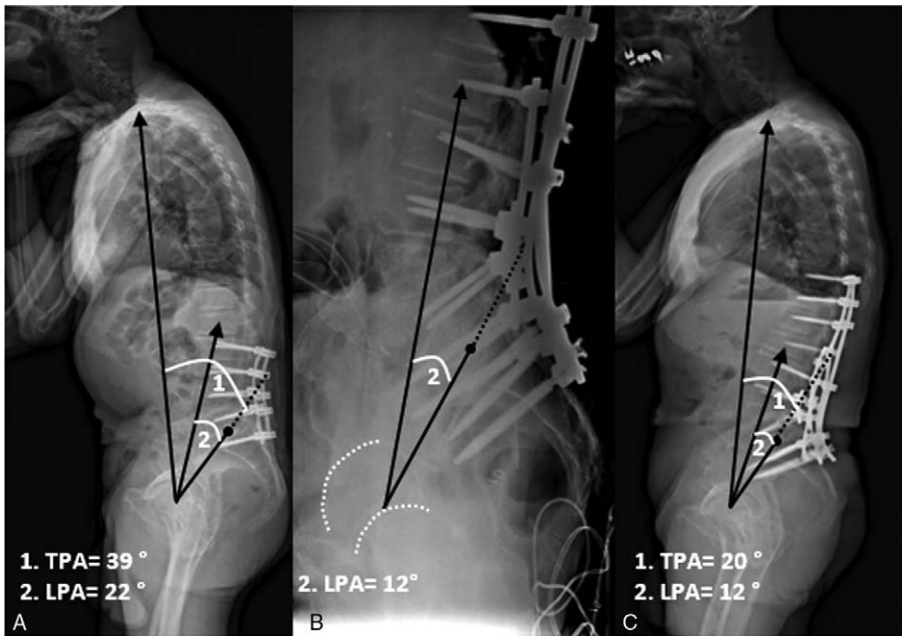

Figure 4. Representative illustrative case with preoperative (**A**) intraoperative (**B**), and postoperative (**C**) radiographs of a 72-year-old male undergoing sagittal spinal correction for lumbar flatback deformity resulting from a previous L2 to S1 fusion. TPA and LPA are labeled and measured. Following an L4 PSO, the intraoperative x-ray demonstrates correction of the LPA from 22° to 12°. The postoperative x-ray demonstrates global correction of the deformity with a TPA improvement from 39° to 20°. LPA indicates lumbar pelvic angle; TPA, T1 pelvic angle.

TABLE 3. Baseline and 2-year Correlations Between Sagittal Alignment Parameters and Health-Related Quality of Life Measures

Correlations Between Sagittal Alignment Parameters and Health-related Quality of Life Measures									
		Baseline				2-y Follow-up			
		ODI	SF-36 PCS	SF-36 MCS	SRS-22 Total	ODI	SF-36 PCS	SF-36 MCS	SRS-22 Total
PT	*r*	0.349*	−0.357*	−0.076†	−0.284*	0.198*	−0.195*	0.008	−0.101†
PI-LL	*r*	0.423*	−0.434*	−0.128*	−0.354*	0.249*	−0.235*	−0.062	−0.179*
SVA	*r*	0.468*	−0.465*	−0.169*	−0.393*	0.322*	−0.317*	−0.099	−0.239*
TPA	*r*	0.447*	−0.450*	−0.130*	−0.371*	0.280*	−0.274*	−0.044	−0.178*
T9PA	*r*	0.398*	−0.396*	−0.126*	−0.327*	0.251*	−0.232*	−0.050	−0.147†
LPA	*r*	0.290*	−0.282*	−0.108†	−0.231*	0.165†	−0.143†	−0.037	−0.070

MCS, mental component score; ODI, Oswestry Disability Index; PCS, physical component score; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SF-36, Short Form-36; SRS-22, Scoliosis Research Society 22; SVA, sagittal vertical axis; T1SPi, T1 Spinopelvic Inclination; T9SPi, T9 spinopelvic inclination; TPA, T1 pelvic angle.

**Denotes significance with $P < 0.001$.*

†Denotes significance with $P < 0.05$.

TABLE 4. Values for the PT, PI-LL, SVA, TPA, T9PA, and LPA Corresponding to Severe Disability (ODI = 40) and Mild Disability (ODI = 20)

Disability and Corresponding Radiographic Parameter Values		
	ODI = 40	ODI = 20
PT	22.6	18.8
PI-LL	12.6	4.2
SVA	51.0	19.1
TPA	20.6	14.7
T9PA	12.1	7.4
LPA	10.1	7.2

LPA, L1 pelvic angle; ODI, Oswestry Disability Index; PI-LL, pelvic incidence minus lumbar lordosis; PT, pelvic tilt; SVA, sagittal vertical axis; T9PA, T9 pelvic angle; TPA, T1 pelvic angle

methods of assessing deformity correction. The strengths of the study are its multicenter design and the use of multiple validated health assessment measures.

With spinopelvic measures like the TPA and LPA, the geometry of sagittal spinal deformity can be dissected to component parts, much like the spokes of a wheel or the slats of a hand-held fan: the TPA measures global thoracolumbar deformity and the LPA accounts for the lumbar component of spinopelvic alignment. LPA is more accessible than current intraoperative measures of correction, and is capable of assessing good correction. Furthermore, LPA correlated to expected improvement in HRQL measures, demonstrating its utility in assessing improvement following deformity correction surgery. Future studies should assess LPA in an intraoperative setting as a tool to predict ultimate global standing alignment.

➢ Key Points

- ❑ This study introduces the LPA, the lumbar component of the TPA.
- ❑ LPA correlates with TPA, PI-LL, and HRQOL in ASD patients.
- ❑ LPA predicts global alignment, as it correlates with baseline and 2-year TPA and SVA.
- ❑ LPA may be utilized as an intraoperative measurement tool to gauge correction and predict global postoperative alignment.

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