The Lumbar Pelvic Angle (LPA), 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: 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 HRQOL, but it may not be measureable on all intraoperative x-rays. In patients with prior interbody fusion at L5-S1, the plane of the S1 endplate can be blurred, creating error in PI-LL measure. The Lumbar Pelvic Angle (LPA) is more readily measured on intraoperative imaging than the TPA.

Methods: ASD patients were included with either coronal Cobb angle >20°, SVA>5 cm, thoracic kyphosis>60°, or PT >25°. Measures of disability included ODI, SRS and SF36. Baseline and 2-yr follow-up radiographic and HRQOL outcomes were evaluated. Linear regressions compared LPA with radiographic parameters and HRQOL.

Results: 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), SF36 PCS (-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°.

Conclusions: 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 less than 7.2°. LPA predicts global alignment as it correlates with baseline and 2 year TPA and SVA. Along with the CTPA and TPA, LPA completes the fan of spinopelvic alignment.

Key Words: Lumbar Pelvic Angle, T1-Pelvic Angle, Health Related Quality of Life, Intraoperative Planning, Interbody Fusion, Adult Spinal Deformity Surgery, Radiographic Parameters, Patient Reported Outcomes, Sagittal Malalignment, Global Spinopelvic Alignment, Thoracolumbar Surgery

Level of Evidence: 3
INTRODUCTION

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 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.8 The PI-LL parameter has been shown to be an invaluable perioperative tool for correction of lumbar flatback deformity since 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 prior 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 measurements.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. 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.

**MATERIALS AND METHODS**

**Study Design**

This study is a multicenter, prospective data analysis of patients with adult spinal deformity conducted through the International Spine Study Group (ISSG), a collaboration of spine surgeons from 11 sites across the United States. Institutional Review Board approval was obtained at each site prior to 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°, sagittal vertical axis (SVA) ≥ 5cm, pelvic tilt (PT) ≥ 25°, or thoracic kyphosis ≥ 20°.
(TK) ≥ 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, gender, body mass index (BMI), and Charlson Comorbidity Index (CCI).\textsuperscript{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).\textsuperscript{11,12} Radiographic parameters included L1-Pelvic-Angle (LPA), T1-Pelvic-Angle (TPA), Sagittal Vertical Axis (SVA), T9 Pelvic Angle (T9PA), T1 and T9 Spino-pelvic Inclination (T1SPi and T9SPi), Pelvic Tilt (PT) and Pelvic Incidence minus Lumbar Lordosis (PI-LL).

Health-related quality of life (HRQOL) outcomes included the Oswestry Disability Index (ODI), Scoliosis Research Society (SRS)-22, and Short Form (SF)-36 questionnaires.\textsuperscript{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 orthopaedic surgeons, all with experience 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 3 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 in order 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**

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**Demographics**

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 to 86 years), and the mean BMI was 26 kg/m². The mean Charlson Comorbidity Index score was 1.26 (SD = 1.5). Among
the patients, 83% were female and 33% had prior 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°-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, ANOVA 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), T1 Pelvic Angle (0.965 and 0.936), Sagittal Vertical Axis (0.996 and 0.996), and Pelvic Tilt (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:
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.\textsuperscript{1-6} Along with the recognition that sagittal spinal mal-alignment 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 adult spinal deformity.\textsuperscript{1-5} These efforts have culminated in the description of the SRS Schwab classification of adult spinal deformity, within which the sagittal modifiers command the lead role in delineating spinal deformity as they are most highly correlated with health related quality of life measures.\textsuperscript{5}
The pelvic incidence minus lumbar lordosis (PI-LL) measure has been shown to correlate with HRQOL measures while also proving to be a valuable tool for perioperative planning.\textsuperscript{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.\textsuperscript{2,9} To assess the reliability of the new L1 Pelvic Angle, the novel measure and the Pelvic Incidence, T1 Pelvic Angle, Sagittal Vertical Axis, and Pelvic Tilt 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), T1 Pelvic Angle (0.980 and 0.902), sagittal vertical axis (0.995 and 0.917), and pelvic tilt (0.959 and 0.853). Moreover, in cases where a prior or subsequent interbody 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 Pelvic Incidence minus Lumbar Lordosis.

The T1 Pelvic angle (TPA) is a global thoracolumbar deformity measure that has been shown to correlate with HRQOL in adult spinal deformity patients.\textsuperscript{2} It allows for the measurement of the geometry of the spinopelvic deformity separate from pelvic and lower extremity compensation. Unlike the Sagittal Vertical Axis (SVA) and the Pelvic Tilt (PT), the TPA can be measured in various patient positions, including prone on an operating room table.\textsuperscript{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 (LPA), the lumbar component of the TPA. Since 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 flatback deformity including preoperative, intraoperative, and postoperative LPA measurements.

While significant correlations were identified between LPA and all the baseline and 2-year postoperative health related quality of life 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 while LPA measures lumbo-pelvic mal-alignment. 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.

While 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 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 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.
REFERENCES:


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.
Figure 2: The mean Oswestry Disability Index (ODI), SF-36 Physical component Score (PCS), Pelvic Tilt (PT), Pelvic Incidence minus Lumbar Lordosis (PI-LL), Sagittal Vertical Axis (SVA) and T1 Pelvic Angle (TPA) by increasing severity of the Lumbar Pelvic Angle (LPA).
Figure 3: Relationships between the T1 Pelvic Angle (TPA), Lumbar Pelvic Angle (LPA), and T9 Pelvic Angle (T9PA).
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 prior L2 to S1 fusion. T1 Pelvic Angle (TPA) and L1 Pelvic Angle (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°.
Table 1: Means, standard deviations (SD), minimum (min), maximum (max), and coefficients of variation (CV) of sagittal alignment parameters for the cohort at baseline. PT = pelvic tilt; PI = pelvic incidence; PI-LL = pelvic incidence minus lumbar lordosis; T9SPI = T9 spinopelvic inclination; T1SPI = T1 spinopelvic inclination; SVA = sagittal vertical axis; TPA = T1 pelvic angle; T9PA = T9 Pelvic Angle; LPA = lumbar pelvic angle. All measurements in degrees except SVA (mm).