The T1 Pelvic Angle, a Novel Radiographic Measure of Global Sagittal Deformity, Accounts for Both Spinal Inclination and Pelvic Tilt and Correlates with Health-Related Quality of Life

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Background: Adult spinal deformity is a prevalent cause of pain and disability. Established measures of sagittal spinopelvic alignment such as sagittal vertical axis and pelvic tilt can be modified by postural compensation, including pelvic retroversion, knee flexion, and the use of assistive devices for standing. We introduce the T1 pelvic angle, a novel measure of sagittal alignment that simultaneously accounts for both spinal inclination and pelvic retroversion. The purpose of this study was to investigate the relationship of the T1 pelvic angle and other established sagittal alignment measures and to correlate these parameters with health-related quality-of-life measures.

Methods: This is a multicenter, prospective, cross-sectional analysis of consecutive patients with adult spinal deformity. Inclusion criteria were adult spinal deformity, an age of greater than eighteen years, and any of the following: scoliosis, a Cobb angle of ≥20°, sagittal vertical axis of ≥5 cm, thoracic kyphosis of ≥60°, and pelvic tilt of ≥25°. Clinical measures of disability included the Oswestry Disability Index (ODI), Scoliosis Research Society (SRS)-22, and Short Form-36 (SF-36) questionnaires.

Results: Five hundred and fifty-nine consecutive patients with adult spinal deformity (mean age, 52.5 years) were enrolled. The T1 pelvic angle correlated with the sagittal vertical axis ($r = 0.837$), pelvic incidence minus lumbar lordosis ($r = 0.889$), and pelvic tilt (0.933). Categorizing the patients by increasing T1 pelvic angle (<10°, 10° to 20°, 21° to 30°, and >30°) revealed a significant and progressive worsening in health-related quality of life ($p < 0.001$ for all). The T1 pelvic angle and sagittal vertical axis correlated with the ODI (0.435 and 0.455), SF-36 Physical Component Summary (–0.445 and –0.458), and SRS (–0.358 and –0.383) ($p < 0.001$ for all). Utilizing a linear regression analysis, a T1 pelvic angle of 20° corresponded to a severe disability (an ODI of >40), and the meaningful change in T1 pelvic angle corresponding to one minimal clinically important difference was 4.1° on the ODI.

continued

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A commentary by **Joshua M. Pahys, MD,** is linked to the online version of this article at jbjs.org.

Conclusions: The T1 pelvic angle correlates with health-related quality of life in patients with adult spinal deformity. The T1 pelvic angle is related to both pelvic tilt and sagittal vertical axis; however, unlike sagittal vertical axis, it does not vary on the basis of the extent of pelvic retroversion or patient support in standing. Since the T1 pelvic angle is an angular and not a linear measure, it does not require calibration of the radiograph. Thus, the T1 pelvic angle measures sagittal deformity independent of many postural compensatory mechanisms, and it can be useful as a preoperative planning tool, with a target T1 pelvic angle of <14°.

Level of Evidence: Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

The importance of the sagittal plane in adult spinal deformity has been well established as a cause of severe pain and disability. The prevalence of spinal deformity in the U.S. population has been estimated to be as high as 60%, and the rate of adult spinal deformity increases with age[1]. With the aging of our population and the rising functional expectations of our elderly patients, optimizing quality of life is an issue of increasing concern. A recent study has shown that adult spinal deformity impacts health status as much as cancer, diabetes, and heart disease[2]. Glassman et al. demonstrated that sagittal spinal alignment was much more important than coronal deformity when correlated with significant disability by validated outcome measures[3]. Their study has become the classic reference that established the sagittal vertical axis as the primary measure of sagittal deformity. Other studies have proposed sagittal parameters such as the T1 spinopelvic inclination or T1 tilt, which is prevalent in the spinal deformity literature of Europe[4-8]. With adult spinal deformity, pelvic tilt is another important parameter indicative of pelvic compensation, and increasing pelvic tilt correlates with increasing disability[4,9]. Last, a spinopelvic relationship, the mismatch between pelvic incidence minus lumbar lordosis, is an integral factor that is very useful in intraoperative planning of lumbar flatback deformity correction[4,9]. Schwab et al. advanced a classification system of adult spinal deformity centered around the sagittal vertical axis, pelvic tilt, and pelvic incidence minus lumbar lordosis to capture all potential parameters that determine the clinically relevant descriptors of spinal deformity[10,11].

We introduce the T1 pelvic angle, a novel angular measure of global sagittal spinal deformity. The T1 pelvic angle is the angle subtended by a line from the femoral heads to the center of the T1 vertebral body and a line from the femoral heads to the center of the superior sacral end plate (Fig. 1). The T1 pelvic angle combines information from both the sagittal vertical axis and pelvic tilt simultaneously to more directly measure the geometry of global spinal deformity. For an individual patient, sagittal vertical axis and pelvic tilt are interrelated in the sense that the magnitude of the one affects that of the other (Fig. 2). This interplay is modulated further by patient compensatory mechanisms such as knee flexion and pelvic retroversion to maintain global standing alignment and horizontal gaze[12-14]. Since the T1 pelvic angle accounts for both spinal inclination and pelvic tilt simultaneously, it is less affected by such variations in standing compensation (Fig. 3).

The purpose of this study was to investigate the utility of the T1 pelvic angle in measuring the magnitude of global sagittal spinal deformity and to investigate its correlation with health measures and other radiographic parameters of sagittal spinopelvic alignment in patients with adult spinal deformity.

Materials and Methods

Study Design

This study is a multicenter, prospective cross-sectional analysis of patients with adult spinal deformity conducted through the International Spine Study Group (ISSG), a collaboration of spine surgeons from eleven sites across the United States. Institutional review board approval was obtained at each site for the patient enrollment and data collection protocols. Inclusion criteria for enrollment were an age of more than eighteen years and a radiographic diagnosis of adult spinal deformity defined as at least one of the following: coronal Cobb angle of ≥20°, sagittal vertical axis of ≥5 cm, pelvic tilt of ≥25°, or thoracic kyphosis of ≥60°. For the present study,

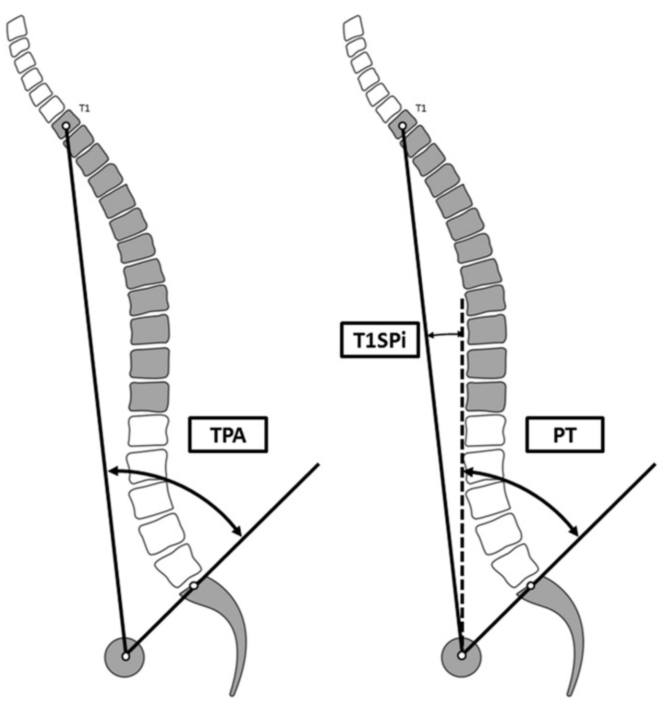

Fig. 1

T1 pelvic angle (TPA), a novel radiographic parameter that accounts for both global malalignment and compensation through pelvic retroversion. The T1 pelvic angle is defined as the angle between the line from the femoral head axis to the centroid of T1 and the line from the femoral head axis to the middle of the S1 superior end plate. The T1 pelvic angle is the sum of the T1 spinopelvic inclination (T1SPi) and the pelvic tilt (PT).

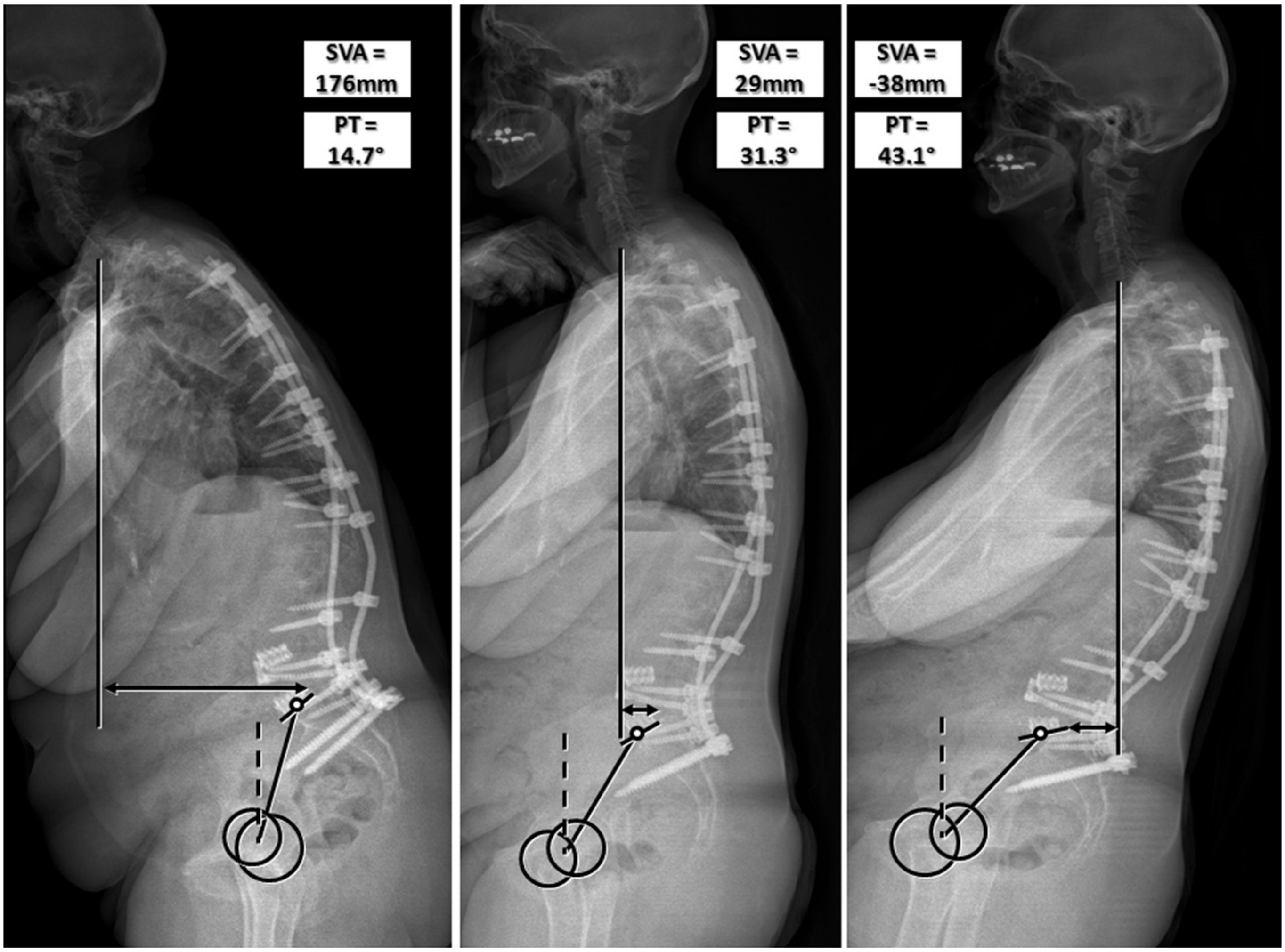

Fig. 2

The variability of the sagittal vertical axis (SVA) in a single patient with different degrees of pelvic retroversion. The image to the left shows the alignment with no pelvic compensation, the middle image is the patient's usual standing alignment with moderate pelvic compensation, and the image to the right shows the patient flexing her knees to maximize her pelvic retroversion. PT = pelvic tilt.

all subjects had 36-in (91-cm) radiographs of the spine, made with the patient standing, and health-related quality-of-life data available at baseline.

Radiographic Analysis and Data Collection

Data collection at baseline included standardized health-related quality-of-life questionnaires as well as clinical, demographic, and radiographic information. Basic demographic and clinical data included patient age, sex, body mass index (BMI), and Charlson comorbidity index (CCI)[15].

All subjects had 36-in (91-cm) spinal radiographs, made with the patients standing and free of any external support. All radiographic measurements were performed at a central location (New York University) using standard techniques for established parameters. Radiographic analysis was performed on baseline radiographs using a dedicated and validated software program (SpineView; ENSAM, Paris, France)[16,17]. Measurements were performed by a trained member of the research staff at the primary study site and then were reviewed by the senior author (V.L.) for accuracy. Radiographic parameters recorded included the T1 pelvic angle, sagittal vertical axis, T1 spinopelvic inclination, pelvic tilt, and pelvic incidence minus lumbar lordosis.

Health-related quality-of-life assessment tools included the Oswestry Disability Index (ODI)[18], Scoliosis Research Society (SRS)-22[19], and Short Form (SF)-36[20] questionnaires. Two standard summary scores were calculated on the basis of the SF-36, the Physical Component Summary (PCS) and the Mental Component Summary (MCS). The SRS-22 provides a summary score and multiple subdomains, including activity, pain, appearance, mental health, and satisfaction.

Statistical Analysis

Correlations were assessed both within radiographic parameters and between radiographic parameters and health-related quality-of-life scores, with a focus on the T1 pelvic angle. Subjects were stratified into four groups on the basis of an increasing magnitude of the T1 pelvic angle (<10°, 10° to 20°, 21° to 30°, and >30°). These groups were compared in terms of sagittal vertical axis, pelvic tilt, pelvic incidence minus lumbar lordosis, and ODI scores using analysis of variance (ANOVA) tests with post hoc comparisons.

To assess the reliability of the new measure, five observers measured the T1 pelvic angle, sagittal vertical axis, pelvic tilt, and pelvic incidence in twenty sample cases on two separate occasions. The observers consisted of five researchers (three research fellows and two orthopaedic residents) with experience doing spine measurements. The interobserver and intraobserver reliability was assessed with an absolute agreement intraclass correlation coefficient (ICC)

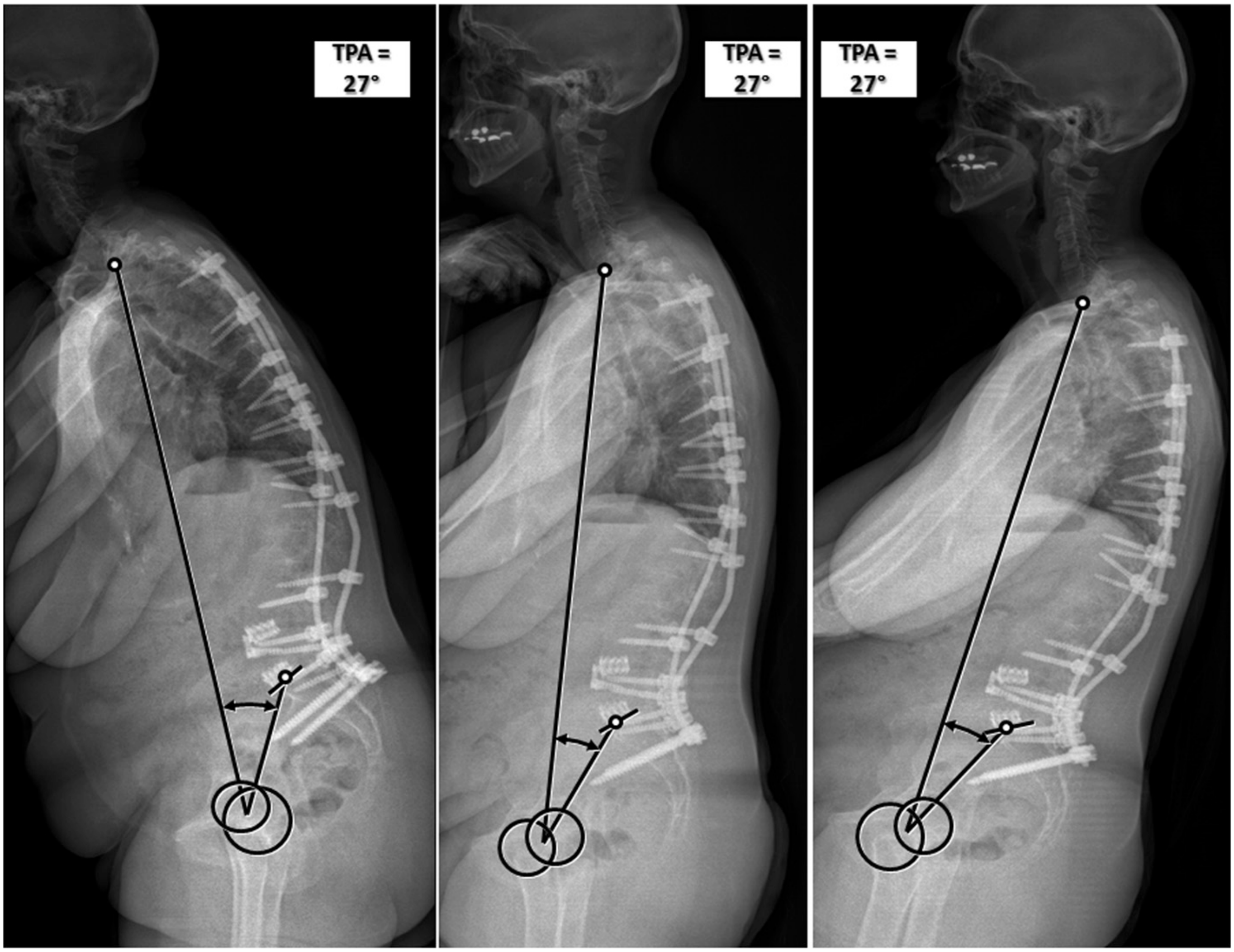

Fig. 3
The consistency of the T1 pelvic angle (TPA) in the same patient despite varying degrees of pelvic retroversion and knee flexion.

analysis using a two-way random effects model. Agreement was classified as excellent for an ICC of >0.75.

A stepwise linear regression was performed on the entire population with the ODI score as the dependent variable and the T1 pelvic angle as the independent variable. This result was used to calculate the T1 pelvic angle value corresponding to severe disability (ODI of >40) and meaningful change (minimal clinically important difference [MCID]) (corresponding to ODI change = 15). Where appropriate, significance was set at $p < 0.05$. The combined impact of the T1 pelvic angle and pelvic tilt was assessed in predicting increasing disability on the basis of the ODI using linear regression analysis.

Patients with deformity who had not undergone spine surgery were compared with those who had prior spine surgery with respect to alignment parameters and health-related quality of life using the unpaired t test. A linear regression analysis controlling for the T1 pelvic angle was also performed, comparing the patients with spinal deformity who had not undergone surgery and those who had prior spine surgery.

Source of Funding
This study was supported by the International Spine Study Group and was partially funded by a grant from DePuy Spine and the Scoliosis Research Society.

Results

Patient Group

A total of 559 subjects met the inclusion criteria. Nine patients were excluded because the upper thoracic spine was not visible on the radiographs and the T1 pelvic angle could not be measured. The mean age (and standard deviation) was 52.5 ± 16 years (range, 18.4 to 86.2 years), and the mean BMI was 26 kg/m^2. The mean Charlson comorbidity score[21] was 1.2 ± 1.5. Eighty-six percent of the patients were female, and 31% had prior spine surgery. The mean patient-reported outcomes (Table I) were 31.7 points for ODI, 38.5 points for SF-36 PCS, 47.8 points for SF-36 MCS, and 3.2 points for SRS-22. The analysis of the sagittal radiographic parameters (Table II) revealed that the study group encompassed a large variability of sagittal profiles as illustrated by the range of variation and the coefficient of variation. A summary of the analysis of the sagittal deformity by SRS-Schwab is depicted in a chart (see Appendix).

TABLE I Demographic Information and Baseline Health-Related Quality of Life for the 559 Subjects

Parameter*	Mean	Standard Deviation	Min.	Max.	Coefficient of Variation†
Age *(yr)*	52.5	16	18.4	86.2	0.3
BMI *(kg/m^2)*	26.0	6.3	15.0	70.2	0.24
Charlson Comorbidity Index *(points)*	1.2	1.5	0	8	1.25
Oswestry Disability Index *(points)*	31.7	20.7	0.0	92.0	0.65
SF-36 *(points)*					
PCS	38.5	11.4	13.1	64.8	0.3
MCS	47.8	12.6	8.1	72.5	0.26
SRS *(points)*					
Activity	3.4	1.0	1.2	5.0	0.29
Pain	3.0	1.0	1.0	5.0	0.33
Appearance	2.9	0.9	1.0	5.0	0.31
Mental health	3.6	0.9	1.0	5.0	0.25
Total	3.2	0.8	1.1	5.0	0.25

*BMI = body mass index, SF-36 = Short Form-36, PCS = Physical Component Summary, MCS = Mental Component Summary, and SRS = Scoliosis Research Society. †Coefficient of variation is the standard deviation divided by the mean.

Correlations Analysis (Table III)

The T1 pelvic angle was highly correlated with sagittal vertical axis (r = 0.837), pelvic tilt (r = 0.933), pelvic incidence minus lumbar lordosis (r = 0.889), and T1 spinopelvic inclination (r = 0.589). In terms of health-related quality of life, the T1 pelvic angle correlated with ODI (r = 0.435), SF-36 PCS (r = –0.445), and SRS-22 total (r = –0.358) scores. These associations were similar to those for sagittal vertical axis, pelvic tilt, pelvic incidence minus lumbar lordosis, and T1 spinopelvic inclination. All the reported correlations were significant at the $p < 0.05$ level.

Analysis by Increasing T1 Pelvic Angle (Table IV)

The stratification by increased T1 pelvic angle revealed that there were 167, 187, 118, and eighty-seven subjects in the groups with a T1 pelvic angle of <10°, 10° to 20°, 21° to 30°, and >30°, respectively. Moving from the <10° group to the >30° group, there was progressive worsening in sagittal vertical axis, pelvic tilt, and pelvic incidence minus lumbar lordosis, as well as in ODI (ANOVA, $p < 0.001$ for all) (Fig. 4, Table IV).

Reliability Analysis

The interobserver and intraobserver reliability of the T1 pelvic angle measure had excellent agreement (ICC = 0.980 and 0.902, respectively). It compared favorably with the interobserver and intraobserver reliability for the sagittal vertical axis (0.995 and 0.917), pelvic tilt (0.959 and 0.853), and pelvic incidence (0.909 and 0.866).

TABLE II Sagittal Radiographic Parameters for the 559 Study Patients

Parameter	Mean	Standard Deviation	Min.	Max.	Coefficient of Variation*
T1 pelvic angle *(deg)*	17.3	13.1	−9.0	69.3	0.8
Thoracic kyphosis† *(deg)*	−32.0	16.4	−95.2	6.8	−0.5
Lumbar lordosis† *(deg)*	45.8	19.2	−17.2	92.4	0.4
Sagittal vertical axis *(deg)*	35.2	65.2	−120.3	325.9	1.9
T1 spinopelvic inclination *(deg)*	−3.1	4.9	−13.8	21.2	−1.5
Pelvic tilt *(deg)*	20.5	11.0	−6.0	68.1	0.5
Pelvic incidence *(deg)*	54.1	13.1	12.0	97.8	0.2
Pelvic incidence minus lumbar lordosis *(deg)*	8.3	19.6	−40.9	68.0	2.3

*Coefficient of variation is the standard deviation divided by the mean. †A negative sign denotes a kyphotic curvature.

TABLE III Correlations Between Radiographic Parameters and Health-Related Quality-of-Life Scores Among the 559 Study Patients*

		Short Form-36		Scoliosis Research Society-22				
	ODI	PCS	MCS	Activity	Pain	Appearance	Mental	Total
T1 pelvic angle	0.435†	−0.445†	−0.144†	−0.400†	−0.355†	−0.319†	−0.171†	−0.358†
Sagittal vertical axis	0.455†	−0.458†	−0.172†	−0.407†	−0.338†	−0.362†	−0.201†	−0.383†
Pelvic tilt	0.353†	−0.368†	−0.095‡	−0.329†	−0.296†	−0.248†	−0.121‡	−0.284†
Pelvic incidence minus lumbar lordosis	0.424†	−0.445†	−0.152†	−0.401†	−0.359†	−0.292†	−0.178†	−0.354†
T1 spinopelvic inclination	0.379†	−0.372†	−0.175†	−0.338†	−0.294†	−0.301†	−0.188†	−0.325†

*All are significant at $p < 0.05$. ODI = Oswestry Disability Index, PCS = Physical Component Summary, and MCS = Mental Component Summary. †Denotes significant differences with $p \le 0.001$. ‡Denotes significant differences with $p < 0.05$.

Linear Regression

The linear relationship between T1 pelvic angle (TPA) and ODI was used to generate a linear regression model leading to the following equation ($r = 0.435$ and $r^2 = 0.19$):

$$TPA = 8.647 + 0.273^{*}ODI$$

Based on this result, the T1 pelvic angle value corresponding to the cutoff of severe disability—i.e., an ODI of 40[18]—was 20°; the T1 pelvic angle corresponding to one MCID (i.e., an ODI change of 15 points) was 4.1°. An ODI of 20 points, which is considered to be the cutoff for minimal disability, corresponded to a T1 pelvic angle of 14°[18]. An ODI of 0 points corresponded to a T1 pelvic angle of 8°.

In an effort to evaluate the combined impact of T1 pelvic angle and pelvic tilt on ODI, a second linear regression model with a stepwise condition was generated using ODI as a

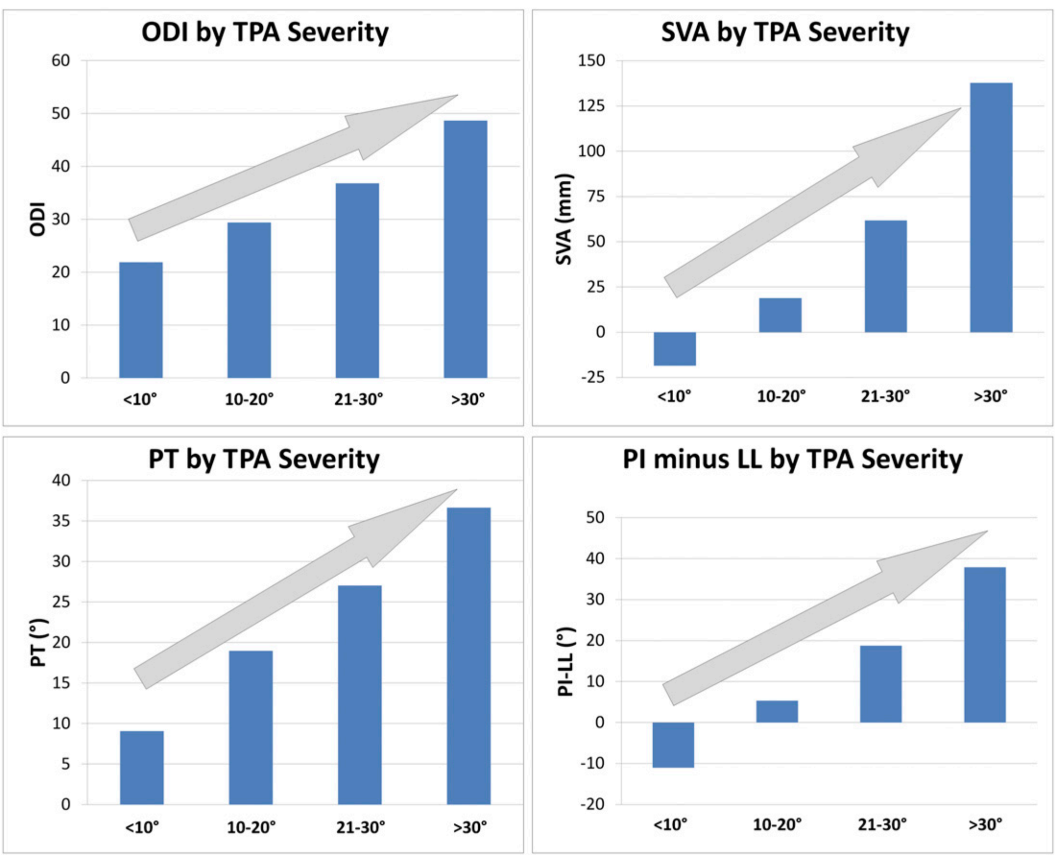

Fig. 4

The mean ODI (Oswestry Disability Index), SVA (sagittal vertical axis), PT (pelvic tilt), and PI-LL (pelvic incidence minus lumbar lordosis) for groups by increasing severity of the TPA (T1 pelvic angle).

TABLE IV Comparison of Radiographic Parameters and Oswestry Disability Index Scores for the Four Groups According to T1 Pelvic Angle

T1 Pelvic Angle Group	No.	Sagittal Vertical Angle* *(mm)*	Pelvic Tilt* *(deg)*	Pelvic Incidence Minus Lumbar Lordosis* *(deg)*	Oswestry Disability Index* *(points)*
<10°	167	−19 ± 32.5	9.1 ± 5.5	−11.1 ± 10.1	21.9 ± 17.5
10°-20°	187	19 ± 32.4	19.0 ± 4.1	5.4 ± 9.6	29.4 ± 19.2
21°-30°	118	62 ± 40.3	27.0 ± 4.8	18.7 ± 9.4	36.8 ± 19.9
>30°	87	138 ± 57.3	36.6 ± 8.5	37.9 ± 13.7	48.6 ± 18.5

*For all comparisons, ANOVA had p < 0.001 and all post hoc tests had p < 0.01. The values are given as the mean and the standard deviation.

dependent variable and T1 pelvic angle and pelvic tilt as independent variables. Both independent parameters were significant ($p < 0.001$) and yielded an r of 0.461 ($r^2 = 0.21$). For this model, the analysis of the standardized coefficients (0.8 for T1 pelvic angle and –0.4 for pelvic tilt) revealed that the combined impact of T1 pelvic angle and pelvic tilt predicted increasing ODI disability when the T1 pelvic angle increased with a concurrent decrease of pelvic tilt.

Comparison of Patients with Deformity Who Had Prior Spine Surgery and Those Who Had Not

Compared with the 386 patients with deformity who had not had spine surgery, the 173 patients who had prior spine surgery had larger deformities by T1 pelvic angle (mean, 42.4° versus 28.9°; p < 0.0001) and worse health-related quality of life by ODI (mean, 42.7 versus 26.8 points; p < 0.0001), SF-36 PCS (mean, 32.4 versus 41.2 points; p < 0.0001), SF-36 MCS (mean, 44.4 versus 49.2 points; p < 0.0001), SRS activity (mean, 2.89 versus 3.65 points; p < 0.0001), SRS pain (mean, 2.48 versus 3.65 points; p < 0.0001), SRS appearance (mean, 2.57 versus 3.07 points; p < 0.0001), and SRS mental health (mean, 3.37 versus 3.74 points; p < 0.0001).

In controlling for T1 pelvic angle, comparison of the two groups revealed that the difference in health-related quality of life was maintained with revision patients having worse mean differences for ODI (+9.27 points; p < 0.0001), SF-36 PCS (–4.99 points; p < 0.0001), SF-36 MCS (–3.84 points; p = 0.004), SRS activity (–0.48 point; p < 0.0001), SRS pain (–0.44 point; p < 0.0001), SRS appearance (–0.30 point; p < 0.0001), and SRS mental health (–0.27 point; p = 0.001).

Discussion

Sagittal spinal deformity is a prevalent and disabling condition that has multiple causes such as the degenerative process of aging, iatrogenic postoperative flatback syndrome, posttraumatic kyphosis, and inflammatory arthopathies[22-26].

This study introduces the T1 pelvic angle, a novel angular measure of global sagittal alignment that accounts for both sagittal vertical axis and pelvic tilt simultaneously. Several parameters have been described to measure spinal deformity, and global spinal malalignment correlates with disability by validated health measures[1,3,4,10,27,28]. Glassman et al. showed that among 352 patients with positive sagittal alignment, increasing sagittal vertical axis correlated with pain and poor health-related quality-of-life scores[3]. This relationship was linear, but the correlation coefficient was weak for all health measures (r = 0.281 for sagittal vertical axis and ODI). Lafage et al. found a stronger correlation with T1 spinopelvic inclination or T1 tilt and ODI (r = 0.52, p < 0.001) among 125 patients with adult spinal deformity[4]. They postulated that the difference in the strength of the correlation may have been due to the different patient sample, but also the inherent error in measuring a linear parameter such as the sagittal vertical axis, which requires calibration of the radiograph and can vary widely in a multicenter study. In this regard, the T1 pelvic angle has the advantage of being an angular spinopelvic measure that does not require calibration of the radiograph.

Our study demonstrated that the T1 inclination had the weakest correlation with health-related quality of life compared with that of the T1 pelvic angle and sagittal vertical axis. This contradictory finding with prior studies may be the result of the use of a different patient sample. Unlike the study by Glassman et al.[3], all our radiographic measurements were performed at a single center with substantial image analysis experience using dedicated and validated software to minimize variation in the measurement technique[16,17].

To assess the reliability of the new T1 pelvic angle measure, the T1 pelvic angle, sagittal vertical axis, pelvic tilt, and pelvic incidence were assessed with ICC analysis. The interobserver and intraobserver reliability of the T1 pelvic angle measure was excellent (0.980 and 0.902, respectively) and compared favorably with the interobserver and intraobserver reliability for the sagittal vertical axis (0.995 and 0.917), pelvic tilt (0.959 and 0.853), and pelvic incidence (0.909 and 0.866). While the sagittal vertical axis measure proved to be the most reliable, it is important to note that the radiographs used for this analysis were in DICOM (Digital Imaging and Communications in Medicine) form with linear measurements already embedded in the images; therefore, the linear measurement of the sagittal vertical axis did not require calibration of the radiographs. If calibration of the radiographs had been necessary, this would have added more error to the sagittal vertical axis measure. The angular measures such as the T1 pelvic angle, pelvic tilt, and pelvic incidence do not require calibration.

A reliability analysis of the use of the SpineView software in measuring angular spinal alignment parameters was performed by Champain et al.[16]. They determined that the reproducibility estimator (i.e., the error of an individual radiographic measurement) was 0.1° for T1 inclination and 1.2° for pelvic tilt. Since the T1 pelvic angle is the sum of these two measures, the error of the T1 pelvic angle measurement is 1.3°, which essentially approximates that of the pelvic tilt.

Vialle et al. performed a study of common spinal measurements among asymptomatic subjects[6]. They found a mean T1 tilt (and standard deviation) of –1.35° ± 2.7° and a mean pelvic tilt of 13.2° ± 6.1°. Since T1 pelvic angle is the sum of T1 tilt and pelvic tilt, the mean T1 pelvic angle for the normative population is estimated to be 11.9°.

Lafage et al. demonstrated that increasing pelvic tilt correlated with poor health-related quality of life[4]. Our study confirms this finding and further demonstrates that as global sagittal deformity increases, the increase in the T1 pelvic angle correlates with increasing pelvic tilt (r = 0.933). However, an interesting finding in the study by Lafage et al. was that when the patients who had deformity were subdivided into four groups by high and low pelvic tilt and high and low sagittal vertical axis, the group with the worst ODI had a high sagittal vertical axis and low pelvic tilt. This suggests that patients with larger deformities without the ability to compensate with pelvic retroversion have the worst disability. However, a statistical comparison of the groups was not presented in that study, and this conclusion was not emphasized. This finding was confirmed in the present study with a linear regression analysis demonstrating that when the T1 pelvic angle and pelvic tilt were considered in tandem, an increasing T1 pelvic angle was the primary driver of a worse disability score on the ODI, but concurrent decreasing pelvic tilt also predicted a higher ODI score, with a p value of <0.01 for the model.

This ability to assess the magnitude of sagittal spinal deformity with the T1 pelvic angle separate from pelvic compensation may change the paradigm of how we assess global spinopelvic alignment because, for a given deformity magnitude, a lower pelvic tilt implies decompensation and worse health measures. This explains why pelvic tilt had the weakest correlation coefficient with health-related quality of life of all of the parameters (Table III).

Roussouly and Nnadi described spinopelvic relationships with the use of the spinopelvic angle (SPA) and the spinosacral angle (SSA), angles measured between a line from C7 to the center of the sacral end plate, and a line from the center of the sacral end plate to the femoral heads (SPA), or a line along the end plate (SSA)[29]. These spinopelvic parameters are similar in concept to the T1 pelvic angle; however, these measures decrease as the deformity increases, and pathologic values that correlate with health-related quality of life have not been established. The T1 pelvic angle is intrinsically more intuitive, as it is the sum of T1 inclination and pelvic tilt; as the deformity increases, so does the T1 pelvic angle. It is easy to postulate that an optimal target for pelvic tilt of <20° and a T1 inclination of <0° will yield a T1 pelvic angle of <20° as a target for deformity correction. Indeed, our data show that a T1 pelvic angle of 20° correlated with severe disability according to the ODI score.

By measuring spinal inclination and pelvic tilt simultaneously, the T1 pelvic angle measures the magnitude of spinal deformity independent of pelvic retroversion (Fig. 3). The sagittal vertical axis measure can be diminished by postural compensatory mechanisms such as pelvic retroversion (see Appendix). Thus, a high pelvic tilt can "hide" a larger spinal deformity when only the sagittal vertical axis is considered. Lafage et al. showed that the pelvic tilt must be considered in tandem with the sagittal vertical axis to capture patients with sagittal spinal deformity without a large sagittal vertical axis because of pelvic compensation[4].

In severe sagittal spinal deformities, knee flexion is another compensatory mechanism to affect the magnitude of sagittal vertical axis by allowing for greater pelvic retroversion to bring the head back over the hips and ankles, effectively decreasing the sagittal vertical axis[12-14]. To eliminate the effect of this compensation, it has been suggested that spinopelvic radiographs of patients should be made with the knees extended, a position that may be difficult for patients with a severe deformity to maintain[13]. By contrast, since the T1 pelvic angle is not similarly diminished by pelvic retroversion or knee flexion, patients can stand for the spinopelvic radiograph in a position of comfort to maintain horizontal gaze without concern that the deformities will be underestimated by such compensatory mechanisms. Moreover, the T1 pelvic angle is less affected by patient support in standing. Patients who cannot otherwise stand without any support render measures such as the sagittal vertical axis and pelvic tilt irrelevant because these parameters require the patient to be freestanding. For example, the patient who leans against a walker will have a higher sagittal vertical axis and artificially lower pelvic tilt than expected. In patients who are completely unable to stand, the T1 pelvic angle can be measured in the sitting position, which is not possible for the sagittal vertical axis or pelvic tilt. Finally, since the T1 pelvic angle measurement does not require a radiograph in the standing, unsupported position, it may prove to be a useful measurement on an intraoperative radiograph made with the patient prone to gauge the adequacy of deformity correction. However, additional studies on the applicability of intraoperative T1 pelvic angle measurements and how they relate to the postoperative standing measurements are necessary to gauge its utility in this setting.

Although our investigation is based on prospectively collected data, the primary limitation of the present study is the retrospective design. Moreover, only baseline radiographic and health-related quality-of-life data were analyzed as an introduction to the concept of the T1 pelvic angle. Additional studies with long-term follow-up should be undertaken to analyze the effect of postoperative deformity correction on the T1 pelvic angle parameter as it relates to improvement in health-related quality of life. The strengths of the study include the multicenter design and the use of multiple validated measures of health-related quality of life. Furthermore, all radiographic measures were performed at a single center with extensive experience in image analysis to minimize measurement variation.

In conclusion, we introduce a novel global angular measure of sagittal spinal deformity, the T1 pelvic angle, which correlates with validated health measures. Since it is an angular measure that is not diminished by many postural compensatory mechanisms, the T1 pelvic angle has advantages over established measures of sagittal deformity. Spinopelvic measures such as the T1 pelvic angle can be utilized to analyze the contribution of local or regional deformities on global spinal alignment[30]. Our linear regression analysis demonstrated that a T1 pelvic angle of 14° correlated to an ODI of 20 points, which is a value of minimal disability; thus, the T1 pelvic angle can be utilized as a perioperative tool to gauge the adequacy of global sagittal correction with a target T1 pelvic angle of <14°.

Appendix

eA A figure showing the percentage of patients classified according to the severity of sagittal deformity modifiers in the SRS-Schwab classification system is available with the online version of this article as a data supplement at jbjs.org. ■

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References

1. Schwab F, Dubey A, Gamez L, El Fegoun AB, Hwang K, Pagala M, Farcy JP. Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. Spine (Phila Pa 1976). 2005 May 1;30(9):1082-5.

2. Fu KM, Bess RS, Schwab FJ, Shaffrey CI, Lafage V, Smith JS, Akbarnia BA, Ames CP, Boachie-Adjei O, Burton DC, Hostin R, Hart RA, Kebaish KM, Klineberg EO, Gupta MC, Deviren V, Wood KB. Health impact comparison of different disease states and population norms to adult spinal deformity (asd): a call for medical attention. Spine J. 2012 Sep;12(9):S2.

3. Glassman SD, Bridwell K, Dimar JR, Horton W, Berven S, Schwab F. The impact of positive sagittal balance in adult spinal deformity. Spine (Phila Pa 1976). 2005 Sep 15;30(18):2024-9.

4. Lafage V, Schwab F, Patel A, Hawkinson N, Farcy JP. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. Spine (Phila Pa 1976). 2009 Aug 1;34(17):E599-606.

5. Legaye J, Duval-Beaupère G. Sagittal plane alignment of the spine and gravity: a radiological and clinical evaluation. Acta Orthop Belg. 2005 Apr;71(2):213-20.

6. Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. J Bone Joint Surg Am. 2005 Feb;87(2):260-7.

7. Legaye J, Hecquet J, Marty C, Duval-Beaupere G. Equilibre sagittal du rachis. Relations entre bassin et courbures rachidiennes sagittales en position debout. Rachis. 1993;5(5):215-26.

8. Legaye J, Duval-Beaupère G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J. 1998;7(2):99-103.

9. Lazennec JY, Ramaré S, Arafati N, Laudet CG, Gorin M, Roger B, Hansen S, Saillant G, Maurs L, Trabelsi R. Sagittal alignment in lumbosacral fusion: relations between radiological parameters and pain. Eur Spine J. 2000 Feb;9(1):47-55.

10. Schwab F, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D, DeWald C, Mehdian H, Shaffrey C, Tribus C, Lafage V. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine (Phila Pa 1976). 2012 May 20;37(12):1077-82.

11. Terran J, Schwab F, Shaffrey CI, Smith JS, Devos P, Ames CP, Fu KM, Burton D, Hostin R, Klineberg E, Gupta M, Deviren V, Mundis G, Hart R, Bess S, Lafage V; International Spine Study Group. The SRS-Schwab adult spinal deformity classification: assessment and clinical correlations based on a prospective operative and nonoperative cohort. Neurosurgery. 2013 Oct;73(4):559-68.

12. Obeid I, Hauger O, Aunoble S, Bourghli A, Pellet N, Vital JM. Global analysis of sagittal spinal alignment in major deformities: correlation between lack of lumbar lordosis and flexion of the knee. Eur Spine J. 2011 Sep;20(Suppl 5):681-5. Epub 2011 Aug 26.

13. Morvan G, Mathieu P, Vuillemin V, Guerini H, Bossard P, Zeitoun F, Wybier M. Standardized way for imaging of the sagittal spinal balance. Eur Spine J. 2011 Sep;20(Suppl 5):602-8. Epub 2011 Aug 10.

14. Barrey C, Roussouly P, Perrin G, Le Huec JC. Sagittal balance disorders in severe degenerative spine. Can we identify the compensatory mechanisms? Eur Spine J. 2011 Sep;20(Suppl 5):626-33. Epub 2011 Jul 28.

15. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis. 1987;40(5):373-83.

16. Champain S, Benchikh K, Nogier A, Mazel C, Guise JD, Skalli W. Validation of new clinical quantitative analysis software applicable in spine orthopaedic studies. Eur Spine J. 2006 Jun;15(6):982-91. Epub 2005 Jun 17.

17. Rillardon L, Levassor N, Guigui P, Wodecki P, Cardinne L, Templier A, Skalli W. [Validation of a tool to measure pelvic and spinal parameters of sagittal balance] [French]. Rev Chir Orthop Reparatrice Appar Mot. 2003 May;89(3):218-27.

18. Fairbank JC, Couper J, Davies JB, O'Brien JP. The Oswestry low back pain disability questionnaire. Physiotherapy. 1980 Aug;66(8):271-3.

19. Asher M1, Lai SM, Burton D, Manna B. Spine deformity correlates better than trunk deformity with idiopathic scoliosis patients' quality of life questionnaire responses. Stud Health Technol Inform. 2002;91:462-4.

20. Ware JE Jr1, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care. 1992 Jun;30(6):473-83.

21. Charlson M, Szatrowski TP, Peterson J, Gold J. Validation of a combined comorbidity index. J Clin Epidemiol. 1994 Nov;47(11):1245-51.

22. Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. Spine (Phila Pa 1976). 1997 Oct 15;22(20):2452-7.

23. Potter BK, Lenke LG, Kuklo TR. Prevention and management of iatrogenic flatback deformity. J Bone Joint Surg Am. 2004 Aug;86-A(8):1793-808.

24. Debarge R, Demey G, Roussouly P. Sagittal balance analysis after pedicle subtraction osteotomy in ankylosing spondylitis. Eur Spine J. 2011 Sep;20(Suppl 5):619-25. Epub 2011 Aug 10.

25. Buchowski JM, Kuhns CA, Bridwell KH, Lenke LG. Surgical management of posttraumatic thoracolumbar kyphosis. Spine J. 2008 Jul-Aug;8(4):666-77. Epub 2007 May 30.

26. Illés T, de Jonge T, Domán I, Dóczi T. Surgical correction of the late consequences of posttraumatic spinal disorders. J Spinal Disord Tech. 2002 Apr;15 (2):127-32.

27. Glassman SD, Berven S, Bridwell K, Horton W, Dimar JR. Correlation of radiographic parameters and clinical symptoms in adult scoliosis. Spine (Phila Pa 1976). 2005 Mar 15;30(6):682-8.

28. Schwab F, Farcy JP, Bridwell K, Berven S, Glassman S, Harrast J, Horton W. A clinical impact classification of scoliosis in the adult. Spine (Phila Pa 1976). 2006 Aug 15;31(18):2109-14.

29. Roussouly P, Nnadi C. Sagittal plane deformity: an overview of interpretation and management. Eur Spine J. 2010 Nov;19(11):1824-36. Epub 2010 Jun 22.

30. Protopsaltis T, Bronsard N, Terran J, Smith J, Klineberg E, Mundis G, Kim HJ, Hostin R, Hart R, Ames C, Shaffrey C, Bess S, Schwab F, Lafage V, International Spine Study Group. Cervical sagittal deformity develops after PJK in adult thoracolumbar deformity correction: radiographic analysis utilizing a novel global sagittal parameter, the CTPA. Read at the 20th International Meeting on Advanced Spine Techniques; 2013 Jul 11; Vancouver, Canada. Paper no 65.