Association of the Anatomical Sacral Slope With Lumbar Lordosis and Pelvic Incidence in Female Patients With Developmental Hip Dysplasia: A Retrospective Cross-sectional Study

Norio Imai (imainorio2001@yahoo.co.jp)
Niigata University Graduate School of Medical and Dental Sciences
Hayato Suzuki
Niigata University Graduate School of Medical and Dental Sciences
Atsushi Sakagami
Niigata University Graduate School of Medical and Dental Sciences
Yuki Hirano
Niigata University Graduate School of Medical and Dental Sciences
Naoto Endo
Niigata University Graduate School of Medical and Dental Sciences

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Abstract

Background:The anatomical sacral slope, considered an anatomical pelvic parameter independent of femoral head centers for measurement, was previously described to strongly correlate withpelvic incidenceon two-dimensional examination of normal healthy subjects. However, the associationbetween anatomical sacral slope and pelvic incidence was unclear in patients withdevelopmental dysplasia of the hip. Thecurrent study aimed to examine the association between anatomical sacral slope and other spinopelvic parameters on plain radiographs in female patients with developmental dysplasia of the hip.

Methods:Eighty-four women with developmental dysplasia of the hip were examined. Lumbar lordosis, thoracic kyphosis, pelvic incidence, sacral slope, and anatomical sacral slope, which was deemedthe angle formed by the straight line of the S1 superior endplate and a line at a right angle to the anterior pelvic plane, were determined by plain radiographs. The correlations were examined by Pearson correlation coefficients, and intra- and interrater intraclass correlation coefficients were evaluated forreliability.

Results:A strong association was observed between pelvic incidence and anatomical sacral slope (r=0.725, p<0.001). In addition, the association between anatomical sacral slope and lumbar lordosis wassimilar to that between pelvic incidence and lumbar lordosis (r=0.661, p<0.001 and r=0.554, p<0.001, respectively). The intraraterintraclass correlation coefficient values were 0.869 for anatomical sacral slope and 0.824 for pelvic incidence. Furthermore, the interraterintraclass correlation coefficient values were 0.83 for anatomical sacral slope and 0.685 for pelvic incidence.

Conclusions:We found that the strong association between anatomical sacral slope and pelvic incidence wasequal to that in normal,healthy subjects. The associationbetweenanatomical sacral slope and lumbar lordosis was equal to that between pelvic incidence and lumbar lordosis. Additionally, the intraclass correlation coefficient value foranatomical sacral slope was slightlyhigher than that forpelvic incidence. We thusconclude that anatomical sacral slope can be considered a helpful anatomical pelvic parameter that isasubstitute for pelvic incidence not only in normal subjectsbut also in patients with developmental dysplasia of the hip.

Background

The anatomical sacral slope (a-SS) was established as the angle formed by the straight line of the superior endplate of S1 and a line at a right angle to the anterior pelvic plane (APP), which was established according to the line connecting the middle point of the anterior superior iliac spine (ASIS) of both sides and the pubic symphysis [1–3] (Fig. 1). The a-SS was also considered an anatomical parameter that does not require femoral head measurements as is the case when determining the pelvic incidence (PI). This is advantageous as sometimes the femoral head center is difficult to establish. Previously, we found a close association between PI and a-SS among normal healthy subjects and patients with developmental dysplasia of the hip (DDH) measured using only the three-dimensional (3D) method [1].

Based on previous studies, it was considered that pelvic morphology as well as PI influences sagittal spinal alignment and standing posture [4–6]. In sagittal spinal malalignment, maintaining suitable balance is considered difficult, and it may lead to “hip-spine syndrome” [7].

Several previous studies have described PI and other thoracolumbar spinal and pelvic parameters, such as lumbar lordosis (LL) and sacral slope (SS), as significantly associated on plane radiographs [3, 8, 9]. A larger PI is considered a risk factor for spondylolisthesis, because it seems to lead to anterior deviation of the sagittal vertical axis [10, 11]. Additionally, the discrepancy between PI and LL leads to spinal deformity in adults [12]. Consequently, PI is considered one of the most clinically important parameters and should be evaluated.

Generally, many surgeons evaluate sagittal thoracolumbar spinal alignment and pelvic parameters by two-dimensional (2D) plain radiographs in the standing position [13, 14]. SS and pelvic tilt (PT) are defined as functional parameters, since these angles are influenced by the anteroposterior tilt of the pelvis, that is, anterior or posterior tilt in the sagittal plane in the standing position. On the contrary, PI is deemed an anatomical parameter as it is not influenced by the anteroposterior tilt of the pelvis. SS and PT are known to be related to PI in geometrical relation by the formula PI = SS + PT.

We recently described a similar correlation between PI and a-SS in normal healthy subjects using 2D measurements [3]. Therefore, a-SS is considered useful for estimating PI. Moreover, a-SS seems to be a new pelvic anatomical parameter, independent of the femoral head center for measurements. However, the correlation between PI and a-SS has not been examined in patients with DDH, whose pelvic and/or spinal morphological features may be different from those of normal subjects obtained using 2D measurements.

In this current study, we aimed to examine the association between PI and a-SS using plain radiographs of patients with DDH. We also examined the association between a-SS and LL using 2D measurements.

Methods

Eighty-four women with bilateral DDH who had undergone curved periacetabular osteotomy [15] for treating early stage hip osteoarthritis due to DDH from April 1, 2010, to July 30, 2017 were examined in our hospital. The inclusion criterion was the center-edge angles of the hip joints less than 20°, obtained from the anteroposterior view of the hips on plain radiographs, since these patients seem to have a common morphological characteristic of DDH in their pelvis and might have a common functional alignment in the pelvis and spine. We excluded subjects who had already undergone any hip joint surgery or were evaluated as having Crowe stages 2–4 [16] with regard to subluxation or arthritic change evaluated as Tonnis grades 2–3 [17] observed on plain radiographs of the hip.

The ethical review board of our institution approved this study and waived the need for informed consent because of the retrospective cross-sectional design of the study.

Measurements of pelvic and thoracolumbar parameters

The pelvic parameters PI, SS, and a-SS, and thoracolumbar parameters thoracic kyphosis (TK) and LL, were measured using standing thoracic and lumbar plain radiographs including the pelvis in the standing position. PI was established as the angle formed by the line at a right angle to the superior endplate of S1 at its middle point and the line connecting this point to the axis connecting the bilateral femoral heads (Fig. 1) [13].The SS was established as the angle formed by the straight line of the S1 superior endplate and leveled line at a right angle to the gravitational force direction. PT was established as the angle formed by the straight line connecting the middle point of the S1 endplate to the hip axis and the vertical line parallel to the gravitational force direction (Fig. 1). LL was established as the angle from the line of T12 inferior endplate and the line of the S1 superior endplate (Fig. 2). TK was the angle defined from the line of the T1 superior endplate and the line of the T12 inferior endplate (Fig. 2).

Statistical analysis

We analyzed the data using SPSS software (version 24; SPSS, Inc., Chicago, IL). The associations of PI, SS, a-SS, LL, and TK were evaluated with Pearson's correlation coefficients according to Guilford's definition [18]. We also evaluated the statistical power (type II (ß) error) with a post hoc analysis, with 0.3 as the effect size (d) and 0.05 as type I (α) error, for the correlation analysis. We evaluated the validity of this study by the mean absolute difference (MAD), the variability by standard deviation (SD), and the intrarater and interrater reliability with interclass correlation coefficients (ICCs) with 95% confidential intervals by two-tailed analysis. We measured 1-week intervals twice to determine the intrarater reliability. To assess the interrater reliability, we drew a parallel between the measurements examined by two other observers. We considered statistical significance when a p-value was below 0.05.

Results

The average age and body mass index of the participants were 35.0 ± 9.2 years (range: 20–52 years) and 22.0 ± 2.9 kg/m^2 (range: 16.2–27.8 kg/m^2), respectively.

Table 1 shows the details of the parameters. A close association was observed between PI and a-SS ($r = 0.725$, $p < 0.001$), as defined by Guilford [18] (Table 2). The regression formula was calculated from this correlation as follows: PI = 0.8 × a-SS + 21.

Table 1
The details of spinopelvic and spinal parameters of the 84 patients with DDH

SS	38.5 ± 10.8 (10.0-69.0°)
PT	15.7 ± 7.0 (-8.0-27.0°)
a-SS	40.8 ± 9.4 (20.0-61.0°)
TK	35.0 ± 10.7 (7.0-83°)
LL	55.4 ± 18.4 (3.0-83.0°)

Mean ± standard deviation (range)
PI: pelvic incidence, SS: sacral slope, PT: pelvic tilt, a-SS: anatomical sacral slope, TK: thoracic kyphosis, LL: lumbar lordosis

Table 2
Pearson's correlation coefficients of pelvic and sagittal spinal parameters

	SS	**PT**	**a-SS**	**LL**	**TK**
PI	0.632*	0.341*	0.725*	0.554*	-0.017
SS		-0.229	0.698*	0.827*	0.141
PT			0.128	0.034	-0.068
a-SS				0.661*	0.057

*$p < 0.05$
PI: pelvic incidence, SS: sacral slope, PT: pelvic tilt, a-SS: anatomical sacral slope, TK: thoracic kyphosis, LL: lumbar lordosis

Regarding the association between pelvic and thoracolumbar parameters, a strong association was observed between SS and LL ($r = 0.827$, $p < 0.001$). With regard to the anatomical parameters, the correlation between a-SS and LL was equal to that between PI and LL ($r = 0.554$, $p < 0.001$ and $r = 0.661$, $p < 0.001$, respectively) (Table 2). However, no association was observed between TK and PI, SS, or a-SS. In terms of the power analysis of the correlation, the power value was 0.803. Intrarater MADs ranged from 2.6° for SS to 3.7° for PI, and the smallest ICC was 0.708 for TK (Table 3). With regard to the MADs, intrarater MADs were slightly smaller than the interrater ones (largest MAD was 4.5° for PI), and the smallest ICC was 0.685 for PI (Table 3).

Table 3

Intra- and interrater reliabilities of the measured values

	Intrarater reliability	Interrater reliability
PI	3.7 ± 2.8° (0.824*)	4.5 ± 3.6° (0.685*)
SS	2.6 ± 2.2° (0.869*)	3.5 ± 2.8° (0.712*)
PT	2.9 ± 2.8° (0.842*)	4.0 ± 3.2° (0.697*)
a-SS	2.9 ± 2.6° (0.868*)	3.7 ± 2.7° (0.835*)
TK	3.4 ± 3.0° (0.708*)	3.9 ± 3.8° (0.698*)
LL	3.0 ± 2.4° (0.823*)	3.6 ± 3.8° (0.714*)

Mean absolute difference ± standard deviation (intraclass correlation coefficient)

*$p < 0.05$

PI: pelvic incidence, SS: sacral slope, PT: pelvic tilt, a-SS: anatomical sacral slope, TK: thoracic kyphosis, LL: lumbar lordosis

Discussion

In this study, a strong association was observed between PI and a-SS; consequently, PI was considered to be able to be estimated from a-SS. Moreover, the association between a-SS and LL was similar to that between PI and LL (r=0.661, $p < 0.001$, and $r = 0.554$, $p < 0.001$, respectively). These results were similar to those of a study in patients with DDH using 3D measurements [1] and to results in normal healthy subjects, obtained by 2D measurements [3]. Consequently, the relationships between a-SS and LL and between PI and LL were similar between patients with DDH and normal subjects. The mean values in patients with DDH were as follows: PI, 54.2°; SS, 38.5°; and LL, 55.43°. The measured values of PI, SS, and LL have been described to be within the ranges of 44.6°–57.7°, 32.5°–41.4°, and 48.2°–57.2°, respectively, in normal adults [19, 20]. Formerly, PI had been reported to be strongly correlated to SS, and also to LL in normal women [12]. Our findings were similar to those of previous results [1]. Therefore, the results of this current study are considered valid.

PI-LL discrepancy (PI-LL ≥ 11°) has been described to likely lead to disability in patients with spinal deformities [12]. PI-LL discrepancy reportedly leads to residual symptoms such as lumbago and other disabilities following spinal fusion surgery for lumbar degenerative diseases [21, 22]. Therefore, measuring the exact PI is essential. However, measuring PI requires identifying femoral head centers, which is sometimes arduous, especially in patients with aspherical femoral heads and with subluxation following osteoarthritis of the hip. In these patients, a new parameter, independent of the femoral head, seems to be required.

In this current study, we observed that PI was strongly correlated to a-SS on 2D radiologic measurements. These findings were similar to those of several previous studies that described a strong association between PI and a-SS on 3D measurements in patients with DDH [1]. From these results, PI could be estimated from a-SS with the following regression formula: PI = 0.8 × a-SS + 21. Moreover, this formula is similar to that used in normal subjects: PI = 0.8 × a-SS + 18 [3].

Additionally, the findings that show that a-SS and LL were significantly correlated were similar to those for PI and LL in patients with DDH and in normal subjects [1]. Therefore, a-SS may be useful to estimate PI in normal healthy subjects, as well as in patients with DDH, and may be considered a new anatomical pelvic parameter that is independent of the femoral head center for measurements, because sometimes, measurements involving the femoral head were not suitable, such as in patients with aspherical, flattening, or dislocated femoral heads.

Additionally, interrater and interrater MADs of PI, which included the femoral head center for measurements, were larger than those of a-SS, equal to those in normal subjects [1]. Therefore, a-SS may lead to a higher reliability than PI when using 2D radiological measurements.

The current study had several limitations. First, the sample size was small. However, the power value in the correlation analysis was 0.803; therefore, the sample size of this current study was considered to be large enough by power analysis. Second, the participants of this study were only Japanese subjects. Previously, differences in sagittal thoracolumbar spinal and pelvic parameters among races had been described [23]. Therefore, our findings may be different from those in other races. Further studies are needed to investigate whether this result can be generalized to other populations. Third, only female patients were included. DDH is known to have a female predominance, with a female to male ratio of 9:1 [24]. Furthermore, < 20 male patients have undergone periacetabular osteotomy during the last 10 years in our hospital.

Conclusions

a-SS, a novel parameter, can be considered convenient and can be examined by 2D plain radiographs. Additionally, the association between a-SS and LL was similar to that between PI and LL, and the 2D findings were equal to the 3D findings in patients with DDH [1]. We thus consider that a-SS, which does not require the femoral head center for measurement, is useful and a new suggested anatomical pelvic parameter that may be available instead of PI. Further large-scale studies are required to evaluate the validity and usefulness of a-SS as an anatomical parameter.

The findings of our study suggest that a-SS, which is independent of the femoral head center, could be a useful, new, pelvic, anatomical parameter used instead of PI in patients with DDH.

Abbreviations

2D

two-dimensional; 3D:three-dimensional; APP:anterior pelvic plane; ASIS:anterior superior iliac spine; a-SS:anatomical sacral slope; DDH:developmental dysplasia of the hip; ICCs:interclass correlation coefficients; LL:lumbar lordosis; MAD:mean absolute difference; PI:pelvic incidence; PT:pelvic tilt; SS:sacral slope; TK:thoracic kyphosis

Declarations

Ethics approval and consent to participate:

The ethical review board of our institution approved this study (No. 2017 – 0344) and waived the need for informed consent because of the retrospective, cross-sectional design of the study.

Consent for publication:

Not applicable.

Availability of data and materials:

All data generated or analyzed during this study are included in this published article.

Competing interests:

The authors declare that they have no competing interests.

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Authors' contributions:

Conceptualization & formulation by NI, HS, AS, YH and NE. Investigation and data collection were done by all the authors. NI carried out the statistical analysis. The study was performed under supervision of HS and NE. All authors read and approved the final manuscript.

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Authors' information: Norio Imai, PhD, Professor of Division of Comprehensive Musculoskeletal Medicine, Niigata University Graduate School of Medical and Dental Sciences, Japan. Hayato Suzuki, PhD, Assistant professor of Division of Orthopedic Surgery, Department of Regenerative and Transplant Medicine, Niigata University Graduate School of Medical and Dental Sciences, Japan

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Figures

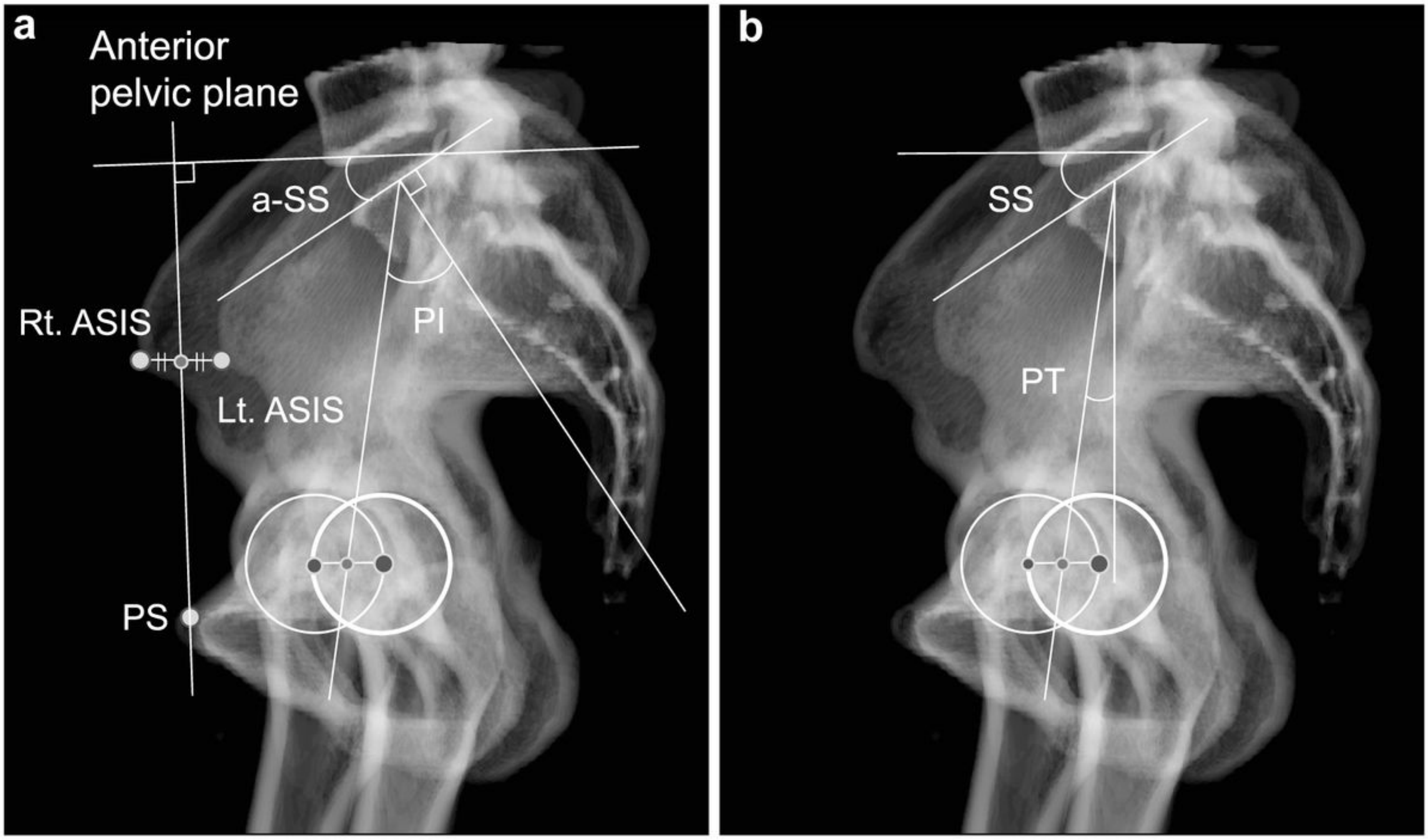

Figure 1

Anatomical and functional parameters of the pelvis A: anatomical parameters, B: functional parameters PI: pelvic incidence; SS: sacral slope, APP: anterior pelvic plane. L- and R-ASIS: left and right anterior superior iliac spine.

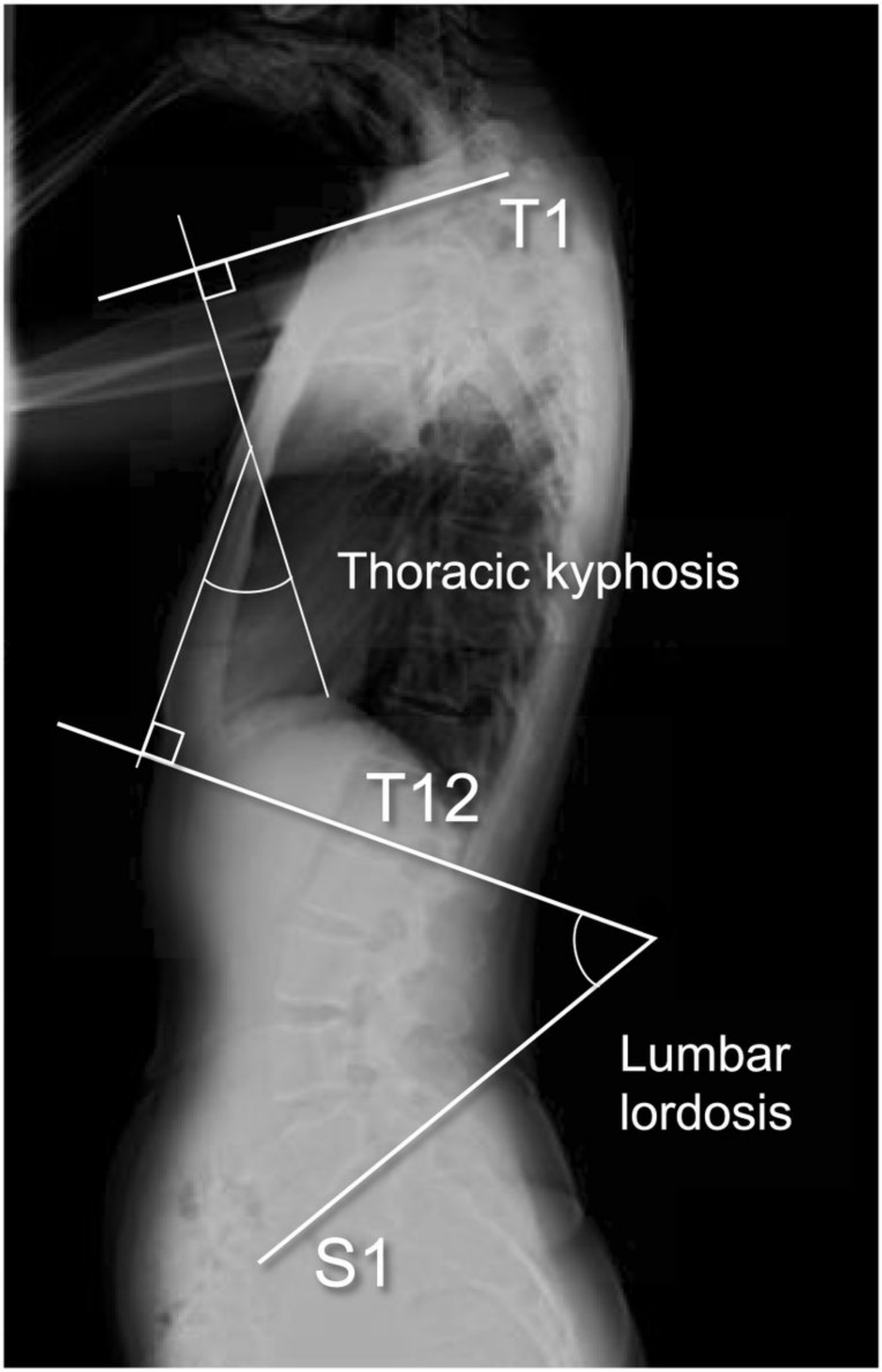

Figure 2

Sagittal thoracolumbar spinal parameters Lumbar lordosis (LL) was established by the T12 inferior end plate and the S1 superior end plate. Thoracic kyphosis (TK) is measured between the T1 superior end plate and the T12 inferior end plate.