Original Article

Effect of lumbosacral transitional vertebra on developmental alterations of the hip: a quantitative investigation of the lumbo-pelvic-hip complex via whole-body computed tomography

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Background: Lumbosacral transitional vertebra (LSTV) is a common spinal variant, with the reported prevalence varying from 8.1% to 36%. LSTV has been shown to alter the lumbo-pelvic parameters and reduce the benefits of total hip arthroplasty, but the specific effects of LSTV on hip development remain unclear. The aim of this study was thus to investigate the impact of LSTV on developmental alterations of the hip.

Methods: A total of 310 individuals were categorized into three groups according to whole-body computed tomography (CT) imaging: a group with sacralization of 23 presacral vertebrae (PSV) (n=102), a group with lumbarization of 25 PSV (n=108), and a normal control group with 24 PSV (n=100). Quantitative parameters of the lumbo-pelvic-hip complex (LPHC) including lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), axial and sagittal acetabular anteversion angle (AAA), center-edge (CE) angle, Sharp angle, and femoral neck-shaft angle (FNSA) were measured and analyzed. Statistical analyses were used to compare the differences of these quantitative parameters among the three groups and to assess the relationship between hip and lumbar-pelvic parameters.

Results: Significant differences between each pair of three groups and the LSTV subgroups were only found in the sagittal AAA (left side: P=0.008; right side: P<0.001), with no differences found for the other parameters. Compared to the normal group (24 PSV), both the 23 PSV and 25 PSV groups exhibited increased values in the sagittal AAA, especially in the right side of the 23 PSV group. Only the sagittal AAA showed low-to-moderate positive correlations with pelvic parameters of PI (r=0.195–0.429; P=0.001–0.08) and PT (r=0.239–0.605; P=0.001–0.03).

Conclusions: Variations of LSTV are correlated with the hip anatomical development via LPHC transmission and may potentially reduce the sagittal acetabular coverage, particularly in the 23 PSV subtype on the right side.

Keywords: Anatomical variation; lumbosacral region; core stability; hip joint; computed tomography (CT)

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Introduction

Lumbosacral transitional vertebra (LSTV) is a common congenital variant of the lumbosacral junction, with its reported prevalence ranging from 8.1% to 36%. LTSV is characterized by either lumbarization of the cranial sacral vertebrae or sacralization of the caudal lumbar vertebrae, accompanied by transverse process hyperplasia (1-4). The presence of LSTV may accelerate the degeneration of the adjacent vertebral appendage, facet joints, and discs, leading to persistent low back pain (5,6). The lumbo-pelvic-hip complex (LPHC) serves as a crucial intermediary, linking the upper and lower extremities, and plays a direct role in energy transfer and maintaining body stability (7,8). The pelvis has been described as an intercalary bone in the LPHC, or a pelvic vertebra, such that pelvic alignment is changed accordingly with the LSTV (9) to exert a downward influence on the hip joint arrangement (10). Muscle tension and weakness also affect the balance of the LPHC and can cause LPHC misalignment and deformity. Hamstring extensibility (HE) is regarded as the primary muscle function essential for pelvis stabilization in the sagittal plane (11). The term hip-spine syndrome is used to describe the clinical manifestations of coexisting degenerative diseases of the hip and spine, suggesting a correlation between the pathological changes in the lumbar spine and the hip (12-14). Patients with lower back pain tend to have a higher risk of hip osteoarthritis compared to healthy individuals when diagnosed using radiographic modalities. In recent years, the effects of hip-spine syndrome in total hip arthroplasty have been extensively investigated, and it has been shown that the decreased range of motion of LPHC increases the risk of implant impingement and displacement after total hip replacement (15). Some syndromes such as femoral acetabular impingement and ischiofemoral impingement can also result in the increased stress and motion of the lumbosacral spine due to its compensating for limited hip motion (16). The identification of coexisting conditions can help guide more accurate treatment and improve long-term clinical outcomes after surgery (17).

A previous study reported that a group patients with LSTV benefited less from hip arthroplasty than did a normal control group (18). Thus far, few studies examining the specific effects of LSTV on hip joints have been conducted, and the related anatomic geometry and biomechanical changes remain unclear. Based on the findings confirming the high co-prevalence of LSTV and hip-spine syndrome, we hypothesized that patients with LSTV may also have other LPHC-related alterations in anatomical geometry including the acetabular version and femoral head coverage.

We aimed to investigate the effect of LSTV on the hip joints by assessing the alignment and balance of the LPHC through retrospectively conduct a large-sample LSTV matched case-control study based on cross-sectional quantitative imaging measurements. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-23-1816/rc).

Methods

Patients

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the local ethics committee of the First Affiliated Hospital of Chongqing Medical University (No. 2021-051). The requirement for individual consent in this retrospective analysis was waived. We retrospectively examined the low-dose whole-body computed tomography (CT) images of 6,097 Han Chinese patients who had undergone positron emission tomography-computed tomography (PET/CT) scans between October 2017 and December 2019. Image analysis was conducted using the Picture Archiving and Communication System (PACS) within the medical institution. Patients with fully validated segmentation anomalies or variations in vertebral number, as determined by gold-standard assessment of whole-body images, were enrolled.

The inclusion criteria were defined as follows: (I) gold standard assessment was conducted and included identification of the number of vertebrae via the precise positioning of the second cervical vertebra from the head laterally and caudally in sequence on the whole spine image. (II) Participants had complete segmental variations of LSTV, including 23 presacral vertebrae (PSV) or 25 PSV subtypes indicative of L5 complete sacralization and S1 complete lumbarization, respectively. The classification of 4 lumbar vertebrae as 23 PSV was based on the identification of the true fifth lumbar vertebra, which exhibits marginal osseous fusion with the sacrum in the sagittal plane despite its square or wedge-shaped outline. Conversely, the designation of the six lumbar vertebra as 25 PSV was considered to be the presence of a well-formed intervertebral disc between the sixth lumbar vertebra and

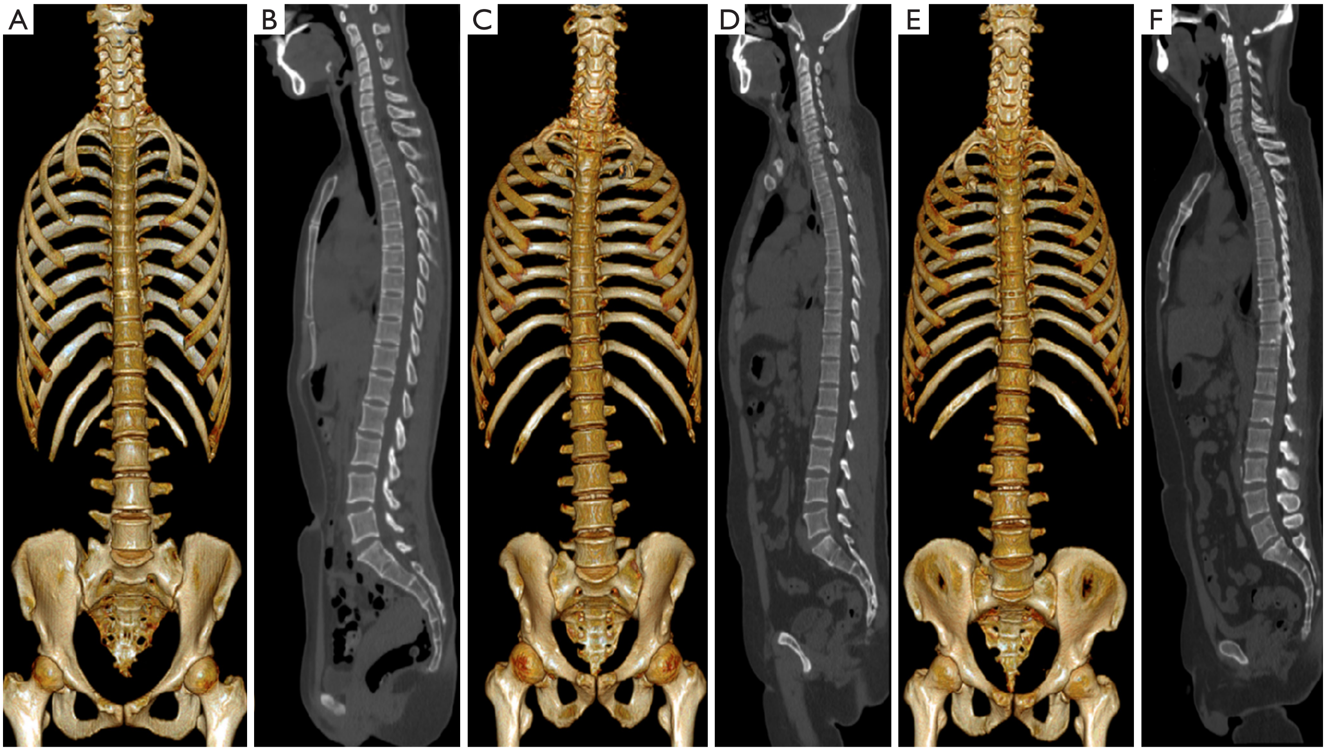

Figure 1 VR and sagittal MPR CT images of the whole spine. (A,B) Images of 23 PSV. (C,D) Images of 24 PSV. (E,F) Images of 25 PSV. VR, volume rendering; MPR, multiplanar reconstruction; CT, computed tomography; PSV, presacral vertebrae.

the uppermost sacral-type segment, without any evidence of marginal fusion. The exclusion criteria were the following: (I) anomalies at the cervicothoracic and/or thoracolumbar junction that impeded the identification of LSTV; (II) primary and secondary malignancies affecting the LPHC; (III) known pathologies involving the sacroiliac and hip joints; (IV) deformities of the LPHC, such as butterfly vertebra, hemivertebra, kyphosis, fusion, scoliosis, ankylosis, and luxation; (V) prior history of LPHC fracture or surgical intervention; (VI) LPHC exhibiting severe degenerative changes; and (VII) incomplete imaging datasets or cases with insufficient clarity for depicting the LPHC.

Combined three-dimensional (3D) volume rendering (VR) and sagittal multiplanar reconstruction (MPR) were applied to count the number of vertebrae and evaluate the variant subtype of LSTV (*Figure 1*). From the total cohort, this investigation enrolled participants with 23 PSV (n=102; 54 males and 48 females; age range 27–88 years; mean age 56 years) and those with 25 PSV (n=108; 62 males and 46 females; age range 24–79 years; mean age 56 years), which were matched in terms of age and gender via propensity-score matching (PSM). A cohort of individuals (n=100) with 24 PSV, age- and gender-matched to two subsets of LSTV, was used as the control group (58 males and 42 females; age range 20–85 years; mean age 59 years). Ultimately, a total of 310 participants were recruited, all of whom were Han Chinese. The study protocol flowchart is presented in *Figure 2*. A portion of the data from these participants has been previously published in other LSTV studies of our team (19).

Acquisition of CT images

The PET/CT images were obtained using a PET/CT scanner (Gemini TF 64, Philips, Amsterdam, the Netherlands). The low-dose CT scans were conducted following a standardized procedure with parameters of 100 mA, 120 kV, matrix size =512×512, and slice thickness =2 mm. Analysis of all low-dose CT images from PET/CT scans was carried out using PACS within our department.

Analysis of CT images

The parameters of the LPHC, including lumbar lordosis

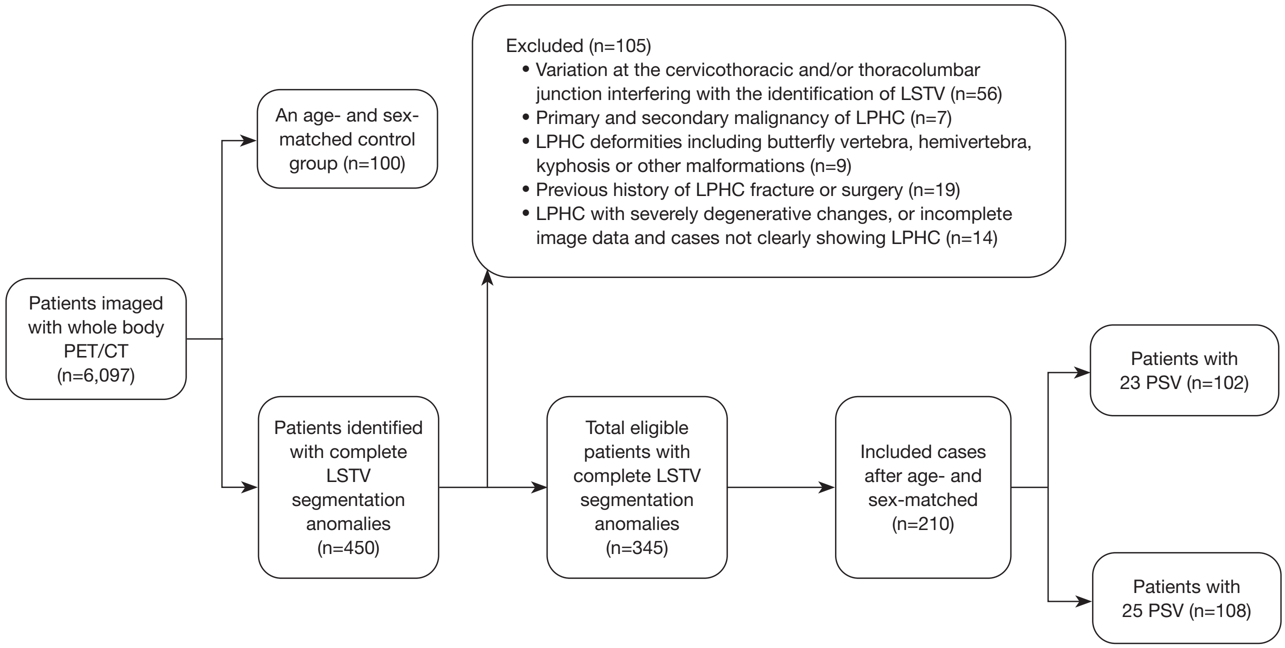

Figure 2 Flowchart of participant inclusion. PET/CT, positron emission tomography-computed tomography; LSTV, lumbosacral transitional vertebra; LPHC, lumbo-pelvic-hip complex; PSV, presacral vertebrae.

(LL), pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), acetabular anteversion angle (AAA), center-edge (CE) angle, Sharp angle, and femoral neck-shaft angle (FNSA), were objectively assessed by two experienced musculoskeletal radiologists (Y.L. and S.Z., with 3 and 5 years of clinical expertise, respectively). Subsequently, one of the radiologists (Y.L.) reassessed the measurements, with a time interval exceeding 4 weeks from the initial evaluation. All data pertaining to the case cohorts were anonymized and pooled together, following which randomized identification numbers were assigned for measurement by the radiologists.

Measurement of the spino-pelvic quantitative parameters including PI, PT, SS, and LL were conducted according to the methods recommended in the literature (20-23). PI is the angle created by the intersection of the line drawn from the center of the femoral heads to the middle of the sacral plate and the line running perpendicular to the middle of the sacral plate. PT is the angle between the vertical line and the line drawn from the center of the femoral heads to the center of the upper sacral endplate. SS is the angle between the tangent line to the superior endplate of S1 and the horizontal line. LL is the angle between tangent lines along the superior endplates of the L1 and S1 vertebrae (*Figure 3A*). Given the potential for measurement level ambiguity arising from the presence of LSTV, all measurements concerning the sacral table were consistently selected at the morphological S1 level, as suggested by previous research findings from our team indicating that the parameters based on the morphological S1 are more stable than are those at the ontogenetical S1 level (24).

Quantitative parameters of the hip included the AAA, CE angle, Sharp angle, and FNSA. The CE angle is the angle formed by drawing a vertical line through the center of the femoral head and a line from the center through the lateral edge of the acetabular roof. The Sharp angle is the angle created between the teardrop line and a line linking the apex of the teardrop to the margin of the acetabular roof. FNSA is the angle formed by the femoral neck axis and femoral long axis. The AAA was measured on the axial and sagittal planes separately to evaluate the acetabular coverage on the two planes. Axial AAA is the angle between a line joining the margins of the anterior and posterior walls of the acetabulum and a line perpendicular to the anterior pelvic plane (APP) (25). Sagittal AAA is the angle between the line between the anterior and posterior edges of the acetabulum and the horizontal line at the sagittal slices from a CT scan at the level of the femoral head center (26).

Due to the variations in pelvic positioning during CT scanning procedures, the original axial images lacked symmetry. Consequently, a redefinition of the standardized

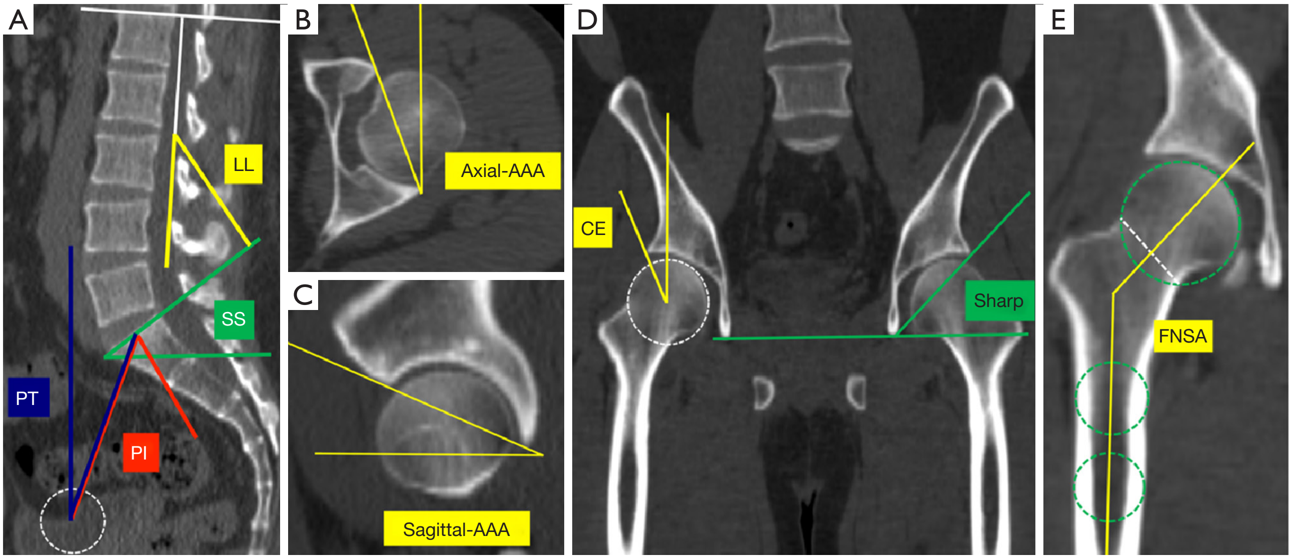

Figure 3 Illustration of the measuring methods of the spino-pelvic-hip parameters. PI (red), PT (blue), SS (green), LL (yellow) (A), axial AAA (B), sagittal AAA (C), CE and Sharp angle (D), and FNSA (E). PI, pelvic incidence; PT, pelvic tilt; SS, sacral inclination; LL, lumbar lordosis; AAA, acetabular anteversion angle; CE, center edge; FNSA, femoral neck-shaft angle.

measurement plane relative to the APP was necessary to mitigate the effects of pelvic positioning. The APP was delineated as the plane exhibiting bilateral visualization of the anterior superior iliac spines (closest to the vertical) and the pubic symphysis (26). The standardized axial plane was defined as the plane perpendicular to the APP, parallel to the teardrop line, and passing through the center of the femoral head (25). Axial AAA was measured on this plane (*Figure 3B*), sagittal AAA was measured on the standardized APP (*Figure 3C*), and CE angle, Sharp angle, and FNSA were measured on a coronal plane aligned parallel to the APP (*Figure 3D,3E*). On sagittal and coronal MPR images, circles were drawn conforming to the femoral head contour to determine the center points for completing the above-mentioned measurements.

Statistical analysis

All statistical analyses were performed using the SPSS 26.0 software (IBM Corp., Armonk, NY, USA). Univariate analysis of variance was used to determine whether the LPHC measured parameters were statistically different among the 23 PSV, 24 PSV, and 25 PSV groups. After the analysis of variance was completed, the effect size and power of the analysis were calculated. The paired *t*-test was employed to examine the disparity between the measurement parameters from the left and right sides. Pearson correlation coefficient was used to ascertain the correlations among spinal, pelvic, and hip parameters and were classified as perfect (1.0), high (0.7–0.9), moderate (0.4–0.6), low (0.1–0.3), and almost no correlation (0–0.1). Intraclass correlation coefficients (ICCs) were used to determine the intra- and interreader agreement of these measurements and were classified as good (>0.75), fair (0.50–0.74), and poor (<0.50). Descriptive statistics are presented as means [with 95% confidence interval (CIs)] for continuous variables. A Bonferroni adjustment was employed to address multiple comparisons across the three groups, with statistical significance determined at a threshold of $P<0.05/n$ (n=3).

Results

Comparison of lumbo-pelvic quantitative parameters among the LSTV subgroups and controls

Statistically significant differences were observed in the PI, PT, SS, and LL values between the control group and the LSTV subgroups ($P\leq0.001$) (*Table 1*). As the number of vertebrae increased, the values of all parameters correspondingly increased in the three groups. The parameters in the 25 PSV group were significantly higher than those of the 24 PSV normal group, while those of

Table 1 Comparison of spino-pelvic-hip parameters among three groups

CT parameter	23 PSV (n=102)	24 PSV (n=100)	25 PSV (n=108)	P value	Power	Effect size
PI	42.1±7.6	48.3±10.4	59.2±11.6	<0.001*	1.000	0.338
PT	5.6±3.7	8.3±5.4	15.6±6.9	<0.001*	1.000	0.378
SS	36.6±6.7	39.9±8.5	43.3±8.7	<0.001*	1.000	0.108
LL	43.9±8.7	45.8±12.0	49.6±11.4	0.001*	0.949	0.048
Sharp angle						
L side	37.9±3.8	37.8±3.5	38.3±3.9	0.65	0.121	0.003
R side	38.4±4.1	38.1±3.7	38.7±3.9	0.63	0.125	0.003
Mean	38.1±3.5	38.0±3.0	38.5±3.4	0.56	0.148	0.004
CE angle						
L side	34.9±6.6	33.6±6.9	34.5±6.6	0.34	0.239	0.007
R side	36.0±6.9	34.8±7.4	35.5±6.6	0.48	0.174	0.005
Mean	35.5±6.1	34.2±6.5	35.0±6.1	0.35	0.235	0.007
FNSA						
L side	139.8±5.9	139.6±5.7	139.6±5.7	0.93	0.061	0.000
R side	136.5±5.9	137.7±5.9	137.0±5.3	0.32	0.248	0.007
Mean	138.2±5.3	138.6±5.2	138.3±4.8	0.82	0.082	0.001
Axial AAA						
L side	20.1±5.9	21.9±5.7	22.0±6.4	0.37	0.222	0.006
R side	23.5±7.0	23.4±5.3	24.7±5.9	0.23	0.313	0.009
Mean	22.2±6.0	22.6±5.0	23.4±5.6	0.33	0.247	0.007
Sagittal AAA						
L side	24.2±7.0	21.2±7.2	22.0±7.1	0.008*	0.800	0.031
R side	27.3±6.1	23.4±6.8	26.0±7.0	<0.001*	0.969	0.054
Mean	25.7±5.9	22.3±6.3	24.0±6.4	0.001*	0.946	0.047

Values are presented as mean ± SD. *, statistical differences are significant (P<0.05) between groups. CT, computed tomography; PSV, presacral vertebrae; PI, pelvic incidence; PT, pelvic tilt; SS, sacral inclination; LL, lumbar lordosis; L, left; R, right; CE, center edge; FNSA, femoral neck-shaft angle; AAA, acetabular anteversion angle; SD, standard deviation.

23 PSV group were significantly lower than those of the normal group.

Comparison of hip quantitative parameters among the LSTV subgroups and control group

Statistically significant differences were only identified for the sagittal AAA values when each pair of the control group was compared with the LSTV subgroups (left side: P=0.008; right side P<0.001). No significant differences were observed for the other parameters, including Sharp angle, CE angle, FNSA, and axial AAA (P=0.23–0.93). Compared to those of the control group, the sagittal AAA values of the bilateral sides in both the 23 PSV and 25 PSV subgroups were all significantly increased. The 23 PSV subgroup showed the highest sagittal AAA values (left side: 24.2°±7.0°; right side: 27.3°±6.1°; mean 25.7°±5.9°) among the three groups, particularly in the right side (*Table 1*). For the bilateral hip parameters in each group, the values of sagittal AAA, axial AAA, and FNSA showed

Table 2 Left-right paired comparisons of hip measurements among three groups

CT parameter	23 PSV (n=102)	24 PSV (n=100)	25 PSV (n=108)
Axial AAA	<0.001*	0.001*	<0.001*
Sagittal AAA	<0.001*	<0.001*	<0.001*
Sharp angle	0.20	0.39	0.27
CE angle	0.06	0.03*	0.03*
FNSA	<0.001*	<0.001*	<0.001*

Values are presented as P values. *, statistical differences are significant (P<0.05) between groups. CT, computed tomography; PSV, presacral vertebrae; AAA, acetabular anteversion angle; CE, center edge; FNSA, femoral neck-shaft angle.

Table 3 Correlation between hip parameter (sagittal AAA) and spino-pelvic measurements in the three groups

Sagittal AAA	PI	PT	SS	LL
23 PSV				
Left	0.195 (0.08)	0.387 (<0.001)*	–0.001 (0.99)	0.011 (0.92)
Right	0.258 (0.02)*	0.239 (0.03)*	0.155 (0.17)	0.178 (0.12)
24 PSV				
Left	0.232 (0.03)*	0.345 (0.001)*	0.066 (0.54)	0.009 (0.93)
Right	0.219 (0.04)*	0.403 (<0.001)*	0.014 (0.89)	–0.033 (0.76)
25 PSV				
Left	0.316 (0.001)*	0.567 (<0.001)*	–0.027 (0.78)	–0.110 (0.26)
Right	0.429 (<0.001)*	0.605 (<0.001)*	0.094 (0.34)	0.040 (0.69)

Values are presented as the correlation coefficient (P value). Pearson correlation coefficient was classified as perfect (1.0), high (0.7–0.9), moderate (0.4–0.6), low (0.1–0.3), and almost no correlation (0–0.1). *, statistical differences are significant (P<0.05) between groups. AAA, acetabular anteversion angle; PI, pelvic incidence; PT, pelvic tilt; SS, sacral inclination; LL, lumbar lordosis; PSV, presacral vertebrae.

significant differences between the left and right sides in all three groups (P≤0.001). Moreover, the CE angle exhibited statistically significant variances among the 24 PSV and 25 PSV subgroups (P=0.03) *Table 2*).

The association of hip measurements and lumbo-pelvic parameters

In the hip measurements, only the sagittal AAA value in all three groups was correlated with the pelvic parameters of PI (P=0.001–0.08) and PT (P=0.001–0.03), but it was not correlated with the spinal parameters of SS (P=0.17–0.99) and LL (P=0.12–0.93). There were weak positive correlations between sagittal AAA and PI (r=0.195–0.429) and moderate positive correlations between sagittal AAA and PT (r=0.239–0.605) (*Table 3*, *Figure 4*). The other hip measurements, including axial-AAA, Sharp angle, CE angle, and FNSA, had no correlations with either spine or pelvis parameters.

Intra- and interreader reliability of quantitative measurements

The ICCs for the intrareader reliability of these quantitative measurements ranged from 0.760 to 0.980, while for inter-reader reliability, the ICCs ranged from 0.782 to 0.968, demonstrating strong consistency both within and between readers (*Table 4*).

Discussion

Morphological changes in the spinal anatomy can alter body kinematics and therefore influence spinal-pelvic-hip alignment (7). In this study, we investigated the specific effect of LSTV variants on hip joints in terms of

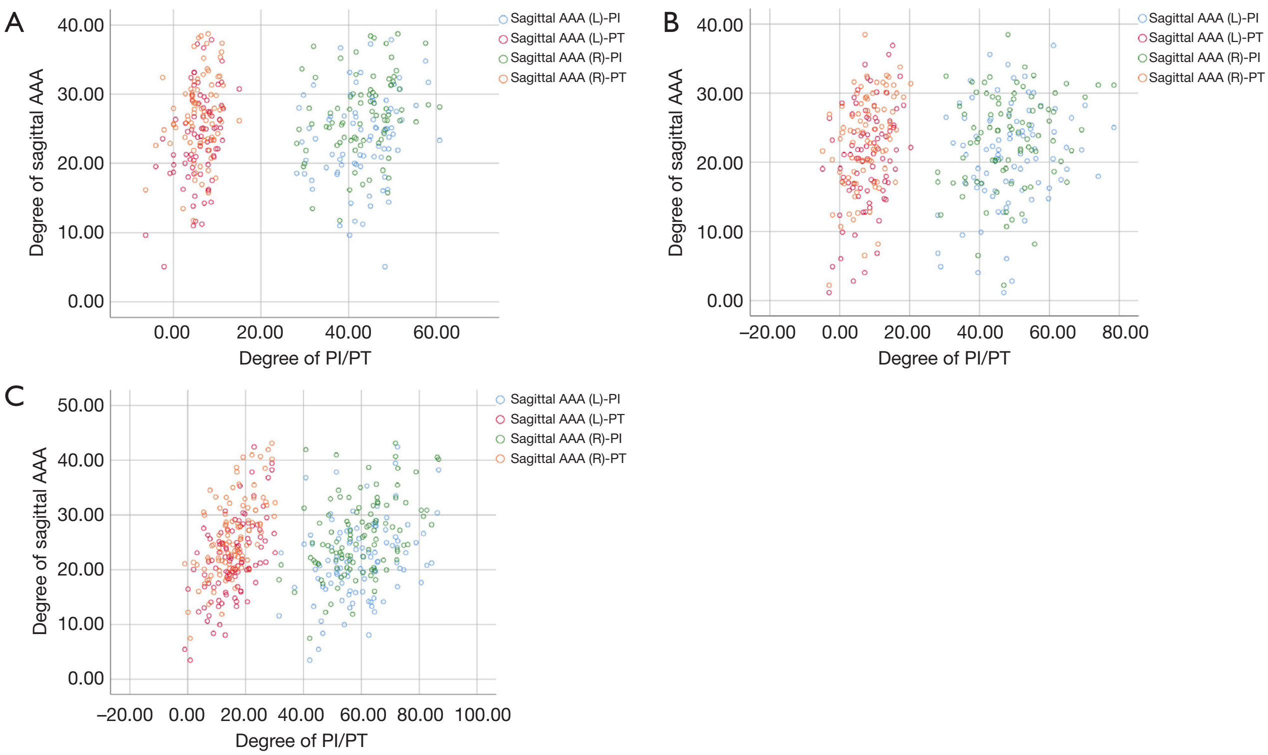

Figure 4 The correlation between sagittal AAA and PI and PT among the 23 PSV, 24 PSV, and 25 PSV groups. (A) The correlation between bilateral sagittal AAA and PI and PT of the 23 PSV group. (B) The correlation between bilateral sagittal AAA and PI and PT of the 24 PSV group. (C) The correlation between bilateral sagittal AAA and PI and PT of the 25 PSV group. The X-axis represents the PI and PT values, while the Y-axis represents the sagittal AAA value. In the scatter plots, bilateral sagittal AAA and PT show more overlap and are closer to a straight line than are sagittal AAA and PI. AAA, acetabular anteversion angle; PI, pelvic incidence; PT, pelvic tilt; L, left; R, right; PSV, presacral vertebrae.

any substantial biomechanical changes. We found that patients with LSTV had corresponding changes in hip anatomical development, specifically reduced sagittal acetabular coverage. To the best of our knowledge, this study represents the largest population-based analysis completed to date on the associations between spino-pelvic-hip alignment parameters and LSTV variants.

All spino-pelvic parameters including PI, PT, SS, and LL in the 25 PSV groups were significantly higher than those of the normal 24 PSV group, while in the 23 PSV group, the values were significantly lower than those of the normal group. These results are consistent with prior studies (27,28). The sacra in the 25 PSV group had a tendency to tilt more anteriorly than did those of the 24 PSV normal group. Previous studies have documented the impact of LSTV on the evaluation of lumbo-pelvic sagittal balance. Kyrölä *et al.* reported that the radiographic spino-pelvic parameters of PI, PT, and LL were higher in a L6 variant group than in a normal L5 group (27). Abola *et al.* screened dry cadaveric specimens via lateral photographs and found that the PI was 38.5° in specimens with 4 lumbar vertebrae and was 46.7° and 47.1° in specimens with 5 and 6 lumbar vertebrae, respectively (28). The different subtypes of LSTV will lead to corresponding alterations of the spinal curvature at the lumbo-sacral junction due to biological adaptation to the weight-bearing capacity to improve spinal stability, which subsequently changes the pelvic parameters (29-31). Muscle tension and weakness can also impact the balance of LPHC and cause LPHC misalignment and deformity. Poor HE has been linked to changes in gait patterns, alterations in lumbopelvic rhythm, and lumbar hyperkyphosis and low back pain. An assistant examiner, such as Lumbosant, can enhance the accuracy of the passive straight leg raise test for evaluating HE (11,32).

The axial AAA showed no significant differences between LSTV subgroups and the normal group, which is consistent with previous studies (25). A CT-based sample study described a range of the axial AAA to be between 13.5 and

Table 4 Intra- and interreader reliability for the measurements of lumbo-pelvic-hip parameters

Variable	ICC (95% CI)	
	Intraobserver reliability	Interobserver reliability
Sagittal AAA	0.968 (0.945–0.981)	0.925 (0.890–0.948)
Axial AAA	0.946 (0.830–0.981)	0.855 (0.765–0.911)
CE angle	0.926 (0.833–0.972)	0.878 (0.834–0.911)
Sharp angle	0.886 (0.778–0.945)	0.878 (0.835–0.926)
FNSA	0.760 (0.564–0.878)	0.782 (0.711–0.866)
PI	0.845 (0.792–0.885)	0.815 (0.754–0.863)
PT	0.980 (0.972–0.985)	0.968 (0.955–0.977)
SS	0.949 (0.929–0.963)	0.942 (0.885–0.966)
LL	0.863 (0.812–0.901)	0.907 (0.647–0.961)

ICCs were used to determine the intra- and interreader agreement of these measurements and were classified as good (≥0.75), fair (0.50–0.74), and poor (<0.50). ICC, intraclass correlation coefficient; CI, confidence interval; AAA, acetabular anteversion angle; CE, center-edge; FNSA, femoral neck-shaft angle; PI, pelvic incidence; PT, pelvic tilt; SS, sacral inclination; LL, lumbar lordosis.

38.7 (25). The numerical values measured in this study based on CT also fall within this range. The sagittal AAA showed increased values on both sides of the 23 PSV and 25 PSV LSTV variants compared to the control group, implying that LSTV can potentially reduce the sagittal acetabular coverage. The orientation of the acetabulum is determined by that of the sagittal spino-pelvic complex. Changes in the number of LSTV variants can affect the flexibility of the spine and lead to changes in the range of motion of the spine (9). According to the flexibility of the spine and hip joint, individuals can be divided into two groups: spine users and hip users (33). Those with flexible lumbar spines (spine users) will decrease the mobility of the hip and protect the joint; on the other hand, those with stiff or fused lumbar spines (hip users) demand higher hip mobility, which may increase the risk of degenerated joints (34). In the presence of sacralization (23 PSV), the curvature of the lumbar spine may reduce and the spino-pelvic complex stiffen; thus, the hip joint needs to be rotated at a larger angle to compensate for the stiffness. At this point, the pelvic retroversion, PT, and sagittal AAA increase, while the SS angle decreases (34-37). When lumbarization occurs, the curvature and the flexibility of the spine may increase. Due to the compensatory effect of the spino-pelvic complex in preventing excessive anteversion, the pelvis is also retroverted, resulting in increased sagittal AAA (35,38) (*Figure 5*).

Other parameters such as Sharp angle, CE angle, and FNSA of the hip joint did not show significant differences between the LSTV subgroups and the normal group, which is partially consistent with previous studies (25,39). The Sharp angle and CE angle reflect the acetabular coverage and inclination on the horizontal plane; however, LSTV mainly impacts the sagittal acetabular alignment. FNSA represents the developmental variation of the femoral neck that does not directly connect with LPHC and possibly transfers a marginal influence from LSTV.

For the left-right paired comparison of the hip quantitative parameters in each group, AAA was measured in axial and sagittal planes, with FNSA showing bilateral asymmetry with significant differences. Both the axial and sagittal AAAs on the right side of the hip were higher than those of the left side, while the FNSA on the left side of the hip was higher than that on the right side. The findings related to bilateral symmetric comparisons of hip joint morphology are controversial, with some studies reporting an association and others not (10,40). Dimitriou *et al.* described patients showing asymmetry in femoral head centers and identified a correlation between the femoral head center and the femoral neck shaft angle (41), which is in line with our findings. These results may be related to the right lower extremity of most people being the predominant side. It is believed that the nature of these data may be explained by the particularities of human growth and development, gait, and the presence of mild osteoarthritis in some patients (42).

In the hip-related parameters measured in this study, only sagittal AAA was shown to have weak-to-moderate correlations with pelvic parameters (PT and PT), but it had no significant correlations with spinal parameters (LL and SS) in those with LSTV. This suggests that the anatomical variations of LSTV indirectly affect the hip joint through the biomechanics of weight transfer at the spino-pelvic-hip complex. As the center of the kinetic chain, this complex is critical to maintaining stability and adjusting balance. Pelvic motion acting as a hinge between the spine and hips is essential to maintaining proper balance during bipedalism. Pelvic rotation is recruited as a compensatory mechanism when spinal malalignment occurs (32,43-45). LSTV is not correlated to other hip measurements that reflect acetabular inclination and coverage of the lateral rim in both acetabular and femoral development, which may also be due to the LSTV mainly affecting the sagittal

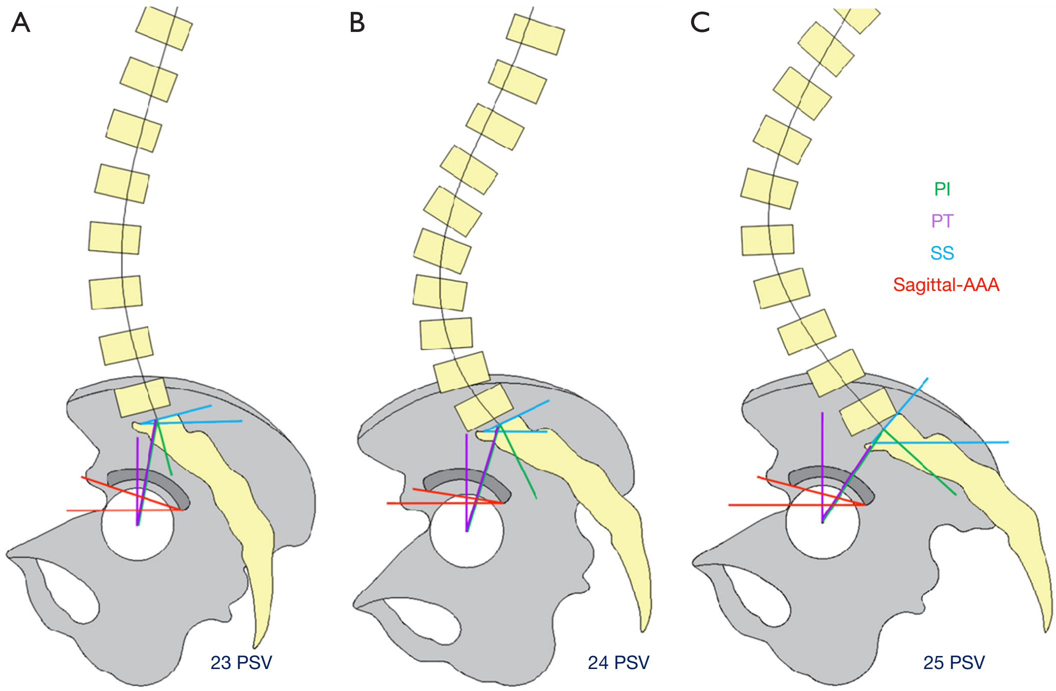

Figure 5 Diagram illustrating the effects of LSTV on pelvic and acetabular alignments. (A) 23 PSV. (B) 24 PSV. (C) 25 PSV. In the presence of 23 PSV, the curvature of the lumbar spine may reduce and the spino-pelvic complex stiffen; thus, pelvic retroversion, PT angle, and sagittal AAA increase, and SS decreases. When 25 PSV occurs, the curvature and the flexibility of the spine may increase. Due to the compensatory effect of the spino-pelvic complex, the pelvis is retroverted, and this results in increased PT and sagittal AAA. PI (green), pelvic incidence; PT (purple), pelvic tilt; SS (blue), sacral slope; AAA (red), acetabular anteversion angle; PSV, presacral vertebrae; LSTV, lumbosacral transitional vertebra.

alignment of LPHC.

This study involved certain limitations which should be mentioned. First, all measurements were based on static imaging in the supine position, which might not fully represent the changes under the weight-bearing condition of LPHC. However, this is similar to surgeon's intraoperative position and may thus be more helpful for orthopedists in preoperative planning. Further research is needed on the load-bearing and dynamic positions in individuals with LSTV. Second, the effect of body mass index (BMI) was not considered. Some studies have shown that a higher BMI contributes to a more retroverted pelvis in a sitting position (46). However, in the literature, the effect of BMI on sagittal spinopelvic alignment is equivocal, with some studies reporting an association and others not (47,48). Third, most of the included patients had a history of tumors, which might have introduced a degree of bias. Fourth, future studies should include younger age groups and examine the role of pelvic and lumbar flexibility exercises. It would be interesting to consider the evaluation of muscle extensibility through the range of motion and its effect on the lumbo-pelvic-hip sagittal complex. In particular, the hamstring muscles play a vital role in sagittal plane pelvic stabilization by modulating anterior PT during dynamic postures and forward trunk flexion.

Conclusions

The variants of LSTV may exert a corresponding influence in the hip anatomical development through LPHC transmission and may potentially reduce the sagittal acetabular coverage, particularly in the 23 PSV subtype with a rightward hip. Therefore, the unique influence of LSTV on the pelvis and hip joint needs to be considered before completion hip of operations so that the implant position can be suitably adjusted.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the local ethics committee of the First Affiliated Hospital of Chongqing Medical University (No. 2021-051). The requirement for individual consent in this retrospective analysis was waived.

References

1. Iplikcioglu AC, Karabag H. A simple method for the selection of valid spinopelvic parameters and lumbar lordosis in patients with transitional lumbosacral vertebrae. Eur Spine J 2024. [Epub ahead of print]. doi: 10.1007/s00586-024-08220-x.
2. Apaydin M, Uluc ME, Sezgin G. Lumbosacral transitional vertebra in the young men population with low back pain: anatomical considerations and degenerations (transitional vertebra types in the young men population with low back pain). Radiol Med 2019;124:375-81.
3. Doo AR, Lee J, Yeo GE, Lee KH, Kim YS, Mun JH, Han YJ, Son JS. The prevalence and clinical significance of transitional vertebrae: a radiologic investigation using whole spine spiral three-dimensional computed tomographic images. Anesth Pain Med (Seoul) 2020;15:103-10.
4. Byvaltsev VA, Kalinin AA, Shepelev VV, Pestryakov YY, Aliyev MA, Hozeev DV, Biryuchkov MY, Kundubayev RA, Riew KD. Prevalence of lumbosacral transitional vertebra among 4816 consecutive patients with low back pain: A computed tomography, magnetic resonance imaging, and plain radiographic study with novel classification schema. J Craniovertebr Junction Spine 2023;14:35-43.
5. Bhagchandani C, Murugan C, Arumugam T, Karuppanan Sukumaran SVA, Shetty AP, Kanna RM, Rajasekaran S. A Whole-Spine Magnetic Resonance Imaging-Based Cross-Sectional Study of the Clinicoradiological Association of Lumbosacral Transitional Vertebra with Degenerative Disc Disease, End Plate Degeneration, Low Back Pain, and Facet Tropism. World Neurosurg 2024;185:e1121-8.
6. Ravikanth R, Majumdar P. Bertolotti's syndrome in low-backache population: Classification and imaging findings. Ci Ji Yi Xue Za Zhi 2019;31:90-5.
7. Wang W, Pei B, Wu S, Lu D, He P, Ma C, Wu X. Biomechanical responses of human lumbar spine and pelvis according to the Roussouly classification. PLoS One 2022;17:e0266954.
8. Fadaei Dehcheshmeh P, Gandomi F, Maffulli N. Effect of lumbopelvic control on landing mechanics and lower extremity muscles' activities in female professional athletes: implications for injury prevention. BMC Sports Sci Med Rehabil 2021;13:101.
9. Di Martino A, Geraci G, Brunello M, D'Agostino C, Davico G, Curreli C, Traina F, Faldini C. Hip-spine relationship: clinical evidence and biomechanical issues. Arch Orthop Trauma Surg 2024;144:1821-33.
10. Attenello JD, Harpstrite JK. Implications of Spinopelvic Mobility on Total Hip Arthroplasty: Review of Current Literature. Hawaii J Health Soc Welf 2019;78:31-40.
11. Cejudo A, Centenera-Centenera JM, Santonja-Medina F. The Potential Role of Hamstring Extensibility on Sagittal Pelvic Tilt, Sagittal Spinal Curves and Recurrent Low Back Pain in Team Sports Players: A Gender Perspective Analysis. Int J Environ Res Public Health 2021;18:8654.
12. Prather H, van Dillen L. Links between the Hip and the Lumbar Spine (Hip Spine Syndrome) as they Relate to Clinical Decision Making for Patients with Lumbopelvic Pain. PM R 2019;11 Suppl 1:S64-72.
13. Diebo BG, Day LM, Lafage R, Passias PG, Paulino CB, Naziri Q, Mont MA, Errico TJ, Schwab FJ, Lafage V. Radiographic Categorization of the Hip-spine Syndrome in the Setting of Hip Osteoarthritis and Sagittal Spinal Malalignment. J Am Acad Orthop Surg 2019;27:659-66.

14. Rodkey DL, Lundy AE, Tracey RW, Helgeson MD. Hip-Spine Syndrome Which Surgery First? Clin Spine Surg 2022;35:1-3.
15. Zagra L, Benazzo F, Dallari D, Falez F, Solarino G, D'Apolito R, Castelli CC. Current concepts in hip-spine relationships: making them practical for total hip arthroplasty. EFORT Open Rev 2022;7:59-69.
16. Hatem M, Martin HD. Low Back Pain Improves After Surgery for Lesser Trochanteric-Ischial Impingement. Arthroscopy 2021;37:1503-9.
17. Mancino F, Cacciola G, Di Matteo V, Perna A, Proietti L, Greenberg A, Ma M, Sculco PK, Maccauro G, De Martino I. Surgical implications of the hip-spine relationship in total hip arthroplasty. Orthop Rev (Pavia) 2020;12:8656.
18. Heaps BM, Feingold JD, Swartwout E, Turcan S, Greditzer HG 4th, Kelly BT, Ranawat AS. Lumbosacral Transitional Vertebrae Predict Inferior Patient-Reported Outcomes After Hip Arthroscopy. Am J Sports Med 2020;48:3272-9.
19. Zhou S, Du L, Liu X, Wang Q, Zhao J, Lv Y, Yang H. Quantitative measurements at the lumbosacral junction are more reliable parameters for identifying and numbering lumbosacral transitional vertebrae. Eur Radiol 2022;32:5650-8.
20. Plachta S, Levine SB, Carlberg K, Cirrincione PM, Vitale M, Lenke LG, Roye BD, Selber PRP. Sagittal spinopelvic alignment in ambulatory persons with cerebral palsy. Spine Deform 2024. [Epub ahead of print]. doi: 10.1007/s43390-024-00866-3.
21. Soydan Z, Bayramoglu E, Altas O, Şen C. Revealing the Effect of Spinopelvic Alignment on Hip Disorders. Clin Med Insights Arthritis Musculoskelet Disord 2023;16:11795441231191790.
22. Knapik DM, Clapp IM, Wichman DM, Nho SJ. Spinopelvic Parameters Do Not Influence Outcomes Following Primary Hip Arthroscopy for the Treatment of Femoroacetabular Impingement Syndrome. Arthrosc Sports Med Rehabil 2023;5:e119-27.
23. Qoreishy M, Movahedinia M, Keyhani S, Salehi B, Goodarzi M, Naghibi B. Evaluation of changes in radiographic spinopelvic parameters after primary total hip arthroplasty and its relationship with short-term patient function. Eur J Orthop Surg Traumatol 2024;34:225-30.
24. Zhou S, Du L, Luo Y, Tang Z, Wang Q, Zhao J, Lv Y, Liu X, Yang H. Effect of lumbosacral transitional vertebrae on sagittal balance of lumbo-pelvic complexity assessed by quantitative whole-body CT imaging. Quant Imaging Med Surg 2023;13:8531-44.
25. Okuzu Y, Goto K, Okutani Y, Kuroda Y, Kawai T, Matsuda S. Hip-Spine Syndrome: Acetabular Anteversion Angle Is Associated with Anterior Pelvic Tilt and Lumbar Hyperlordosis in Patients with Acetabular Dysplasia: A Retrospective Study. JB JS Open Access 2019;4:e0025.
26. Dandachli W, Najefi A, Iranpour F, Lenihan J, Hart A, Cobb J. Quantifying the contribution of pincer deformity to femoro-acetabular impingement using 3D computerised tomography. Skeletal Radiol 2012;41:1295-300.
27. Kyrölä K, Kautiainen H, Ylinen J, Lehtola R, Kiviranta I, Häkkinen A. Spinopelvic Parameters and Sagittal Alignment of Symptomatic Degenerative Adult Spinal Disorder Patients With 6 Lumbar Vertebrae. Clin Spine Surg 2019;32:E43-9.
28. Abola MV, Teplensky JR, Cooperman DR, Bauer JM, Liu RW. Pelvic Incidence in Spines With 4 and 6 Lumbar Vertebrae. Global Spine J 2019;9:708-12.
29. Yan YZ, Wang B, Huang XQ, Ru X, Wang XY, Qu HB. Variation in Global Spinal Sagittal Parameters in Asymptomatic Adults with 11 Thoracic Vertebrae, four Lumbar Vertebrae, and six Lumbar Vertebrae. Orthop Surg 2022;14:341-8.
30. Karabag H, Iplikcioglu AC. Analysis of Spinopelvic Parameters and Lumbar Lordosis in Patients with Transitional Lumbosacral Vertebrae, with Special Reference to Sacralization and Lumbarization. World Neurosurg 2024;183:e900-8.
31. Jacob AM, Yadav SK, Elhence A, Banerjee S, Gahlot N, Gupta S, Rajnish RK, Kantiwal P, Tiwari S. Evaluation of spinopelvic parameters in patients with lumbosacral transitional vertebra: a cross sectional and comparative study. Am J Neurodegener Dis 2023;12:123-32.
32. Santonja-Medina F, Santonja-Renedo S, Cejudo A, Ayala F, Baranda PSD. Straight Leg Raise Test: Influence of Lumbosant and Assistant Examiner in Hip, Pelvis Tilt and Lumbar Lordosis. Symmetry 2020;12:927.
33. Rivière C, Hardijzer A, Lazennec JY, Beaulé P, Muirhead-Allwood S, Cobb J. Spine-hip relations add understandings to the pathophysiology of femoro-acetabular impingement: A systematic review. Orthop Traumatol Surg Res 2017;103:549-57.
34. Pizones J, García-Rey E. Pelvic motion the key to understanding spine-hip interaction. EFORT Open Rev 2020;5:522-33.
35. Chavarria JC, Douleh DG, York PJ. The Hip-Spine Challenge. J Bone Joint Surg Am 2021;103:1852-60.
36. Ohashi M, Hasegawa K, Hatsushikano S, Imai N, Tashi H, Makino T, Minato K, Sato M, Watanabe K. Anatomical

Pelvic Parameters Using the Anterior Pelvic Plane: Normative Values and Estimation of the Standing Sagittal Alignment in Healthy Volunteers. Spine Surg Relat Res 2024;8:97-105.
37. Day LM, DelSole EM, Beaubrun BM, Zhou PL, Moon JY, Tishelman JC, Vigdorchik JM, Schwarzkopf R, Lafage R, Lafage V, Protopsaltis T, Buckland AJ. Radiological severity of hip osteoarthritis in patients with adult spinal deformity: the effect on spinopelvic and lower extremity compensatory mechanisms. Eur Spine J 2018;27:2294-302.
38. Salib CG, Reina N, Perry KI, Taunton MJ, Berry DJ, Abdel MP. Lumbar fusion involving the sacrum increases dislocation risk in primary total hip arthroplasty. Bone Joint J 2019;101-B:198-206.
39. Becker L, Taheri N, Haffer H, Muellner M, Hipfl C, Ziegeler K, Diekhoff T, Pumberger M. Lumbosacral Transitional Vertebrae Influence on Acetabular Orientation and Pelvic Tilt. J Clin Med 2022;11:5153.
40. Mascarenhas VV, Rego P, Dantas P, Castro M, Jans L, Marques RM, Gouveia N, Soldado F, Ayeni OR, Consciência JG. Hip shape is symmetric, non-dependent on limb dominance and gender-specific: implications for femoroacetabular impingement. A 3D CT analysis in asymptomatic subjects. Eur Radiol 2018;28:1609-24.
41. Dimitriou D, Tsai TY, Yue B, Rubash HE, Kwon YM, Li G. Side-to-side variation in normal femoral morphology: 3D CT analysis of 122 femurs. Orthop Traumatol Surg Res 2016;102:91-7.
42. Stătescu C, Stoica D, Georgescu CV, Gavrilă BI, Popescu MN, Trăistaru MR, Căluianu EI, Bălşeanu TA. Osteoarthritis induces gender-related changes in the knee range of motion. Rom J Morphol Embryol 2022;63:449-57.
43. Vaswani R, White AE, Feingold J, Ranawat AS. Hip-Spine Syndrome in the Nonarthritic Patient. Arthroscopy 2022;38:2930-8.
44. Maldonado DR, Mu BH, Ornelas J, Chen SL, Lall AC, Walker-Santiago R, Rosinsky PJ, Shapira J, Domb BG. Hip-Spine Syndrome: The Diagnostic Utility of Guided Intra-articular Hip Injections. Orthopedics 2020;43:e65-71.
45. Harris JD. Editorial Commentary: The Pelvis is the Lowest Vertebral Level: Diagnostic Approach to Hip-Spine Syndrome. Arthroscopy 2022;38:2939-41.
46. Esposito CI, Miller TT, Kim HJ, Barlow BT, Wright TM, Padgett DE, Jerabek SA, Mayman DJ. Does Degenerative Lumbar Spine Disease Influence Femoroacetabular Flexion in Patients Undergoing Total Hip Arthroplasty? Clin Orthop Relat Res 2016;474:1788-97.
47. Bayartai ME, Schaer CE, Luomajoki H, Tringali G, De Micheli R, Sartorio A. Differences in spinal posture and mobility between children/adolescents with obesity and age-matched normal-weight individuals. Sci Rep 2022;12:15570.
48. Schenk P, Jacobi A, Graebsch C, Mendel T, Hofmann GO, Ullrich BW. Impact of Spino-Pelvic Parameters on the Prediction of Lumbar and Thoraco-Lumbar Segment Angles in the Supine Position. J Pers Med 2022;12:2081.

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