Original Article

Effect of lumbosacral transitional vertebrae on sagittal balance of lumbo-pelvic complexity assessed by quantitative whole-body CT imaging

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Background: The variation at the lumbosacral junction certainly results in occult alignment changes in the lumbo-pelvic complexity (LPC). This retrospective case-control study aims to investigate the influences of lumbosacral transitional vertebrae (LSTV) on sagittal lumbo-pelvic balance assessment and provide some recommendations for preoperative imaging evaluation.

Methods: Based on whole-body computed tomography (CT) images, a total of 210 individuals with complete segmentation anomalies of LSTV were included and divided into 23 presacral vertebrae (PSV) (sacralization, n=102), 25 PSV (lumbarization, n=108). The control group with 24 PSV (normal, n=100) was matched by age and gender. Sagittal lumbo-pelvic parameters including pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), sacral table angle (STA), sacral kyphosis (SK), and pelvic radius (PR) were measured at the ontogenetical S1 (Ontog S1) level and the morphological S1 (Morph S1), respectively. These parameters were compared using t-test, Kruskal-Wallis H test and post hoc test. Spearman's rank correlation coefficient and linear regression were used to investigate the association of lumbo-pelvic parameters with LSTV types and measurement levels.

Results: All the parameters at the Ontog S1 differed significantly from those at the Morph S1 (all $P<0.001$). At the Ontog S1 level, PI, PT, SS, and LL were negatively correlated with vertebrae counts; SK and PR were positively correlated with vertebrae counts (all $P<0.001$). Instead, reverse results were obtained at the Morph S1 level. The measurement level and vertebrae counts were independent influence factors for the measurement of PI, PT, SS, SK, and PR (all $P<0.05$). Compared with the measured values of the matched controls, the variability of most lumbo-pelvic parameters (PI, SS, LL, STA, SK, PR values of 25 PSV subgroup, and PI, PT, SS, LL, STA values of 23 PSV subgroup) at the Morph S1 level were significantly smaller than that at the Ontog S1. The measurements of PT, SS, LL, and PR were less influenced by the measurement level and vertebrae counts than those of PI and SK.

Conclusions: Morph S1 is more recommended for the measurements of most lumbo-pelvic parameters

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in patients with LSTV. The parameters (PT, SS, LL, STA, PR) are shown more stable and recommended to help reduce the effects caused by LSTV.

Keywords: Sagittal balance; lumbosacral transitional vertebrae (LSTV); lumbo-pelvic complexity (LPC); lumbo-pelvic parameters

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Introduction

The relation between the spine and the pelvis, also described as lumbo-pelvic balance, has been previously overlooked and gained importance in the analysis of overall sagittal balance in recent decades (1,2). The human spine and pelvis are an anatomical and biomechanical complexity, and bipedalism results in curvatures of the spine and verticalization of lumbo-pelvic complexity (LPC) (3,4). A harmonious relationship involving spine and pelvis anatomy matters in maintaining the biomechanical balance in the sagittal plane with minimum energy expenditure, and the concept "efficiency cone" was put forward (5). Sagittal imbalance contributes to the development and progression of spinal degenerative disease, spondylolysis, deformity, and results in unsatisfying clinical outcomes after spinal surgery (2,6,7).

Lumbosacral transitional vertebra (LSTV) is a common congenital anomaly of the spine with a reported prevalence of 4.0–35.9% (8-12). With one less or more vertebra at the lumbosacral transitional region, some lumbo-pelvic biomechanical mechanisms compensate for maintaining the sagittal balance and improving the weight-bearing capability of LPC. Some investigators have argued that the variation LSTV directly resulted in alterations of lumbo-pelvic morphology and sagittal parameters (13-19). Such changes would bring great challenges to preoperative planning and affect the prognosis of the surgical treatment for the patients requiring restoration of sagittal balance or correction of deformity (16,20,21). It has been reported that there are approximately 50% of patients not obtaining ideal sagittal balance after spinal surgery (22). Due to the alteration of the sagittal profile in the presence of LSTV, normative values of lumbo-pelvic parameters to restore ideal balance may be irreproducible (13,15,16,23-27). Some studies have reported the effects of LSTV on LPC (19,28-32), however, the impacts of different subtypes of LSTV and the related quantitative assessment on sagittal lumbo-pelvic balance are still unclear. To avoid sagittal plane over-correction or under-correction, specific spinal types should be particularly considered when estimating restoration objectives of lumbo-pelvic parameters (26,27,33-35).

This retrospective case-control study on a larger cohort of LSTV individuals with full-spine data was conducted, aiming to investigate the effect of LSTV on the assessment of sagittal lumbo-pelvic balance and provide some recommendations for the preoperative imaging evaluation. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-23-799/rc).

Methods

Individuals

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Ethics Board of the First Affiliated Hospital of Chongqing Medical University and individual consent for this retrospective analysis was waived. We reviewed CT images of 6,097 Chinese patients who underwent whole-body positron emission tomography combined with computed tomography (PET/CT) scans from October 2017 to December 2019. The CT images were acquired on a Gemini TF64 PET/CT Scanner (Philips Healthcare, Best, the Netherlands) with a standardized protocol of 100 mA, 120 kV, matrix size of 512×512, and a slice thickness of 2 mm. First, a musculoskeletal radiologist (SZ, with 3 years of clinical experience) reviewed all whole-spine CT images with 3D volume rendered (VR) and multiplanar reconstruction (MPR) techniques to identify LSTV by using PACS (Carestream Health Inc., Rochester, NY, USA) at our department, and counted the vertebrae from the cervical spine to the most caudal vertebra above the sacrum (*Figure 1A-1C*). Next, the variations of spine and rib, including transitional vertebra at the cervicothoracic, thoracolumbar and lumbosacral junction, cervical rib, and

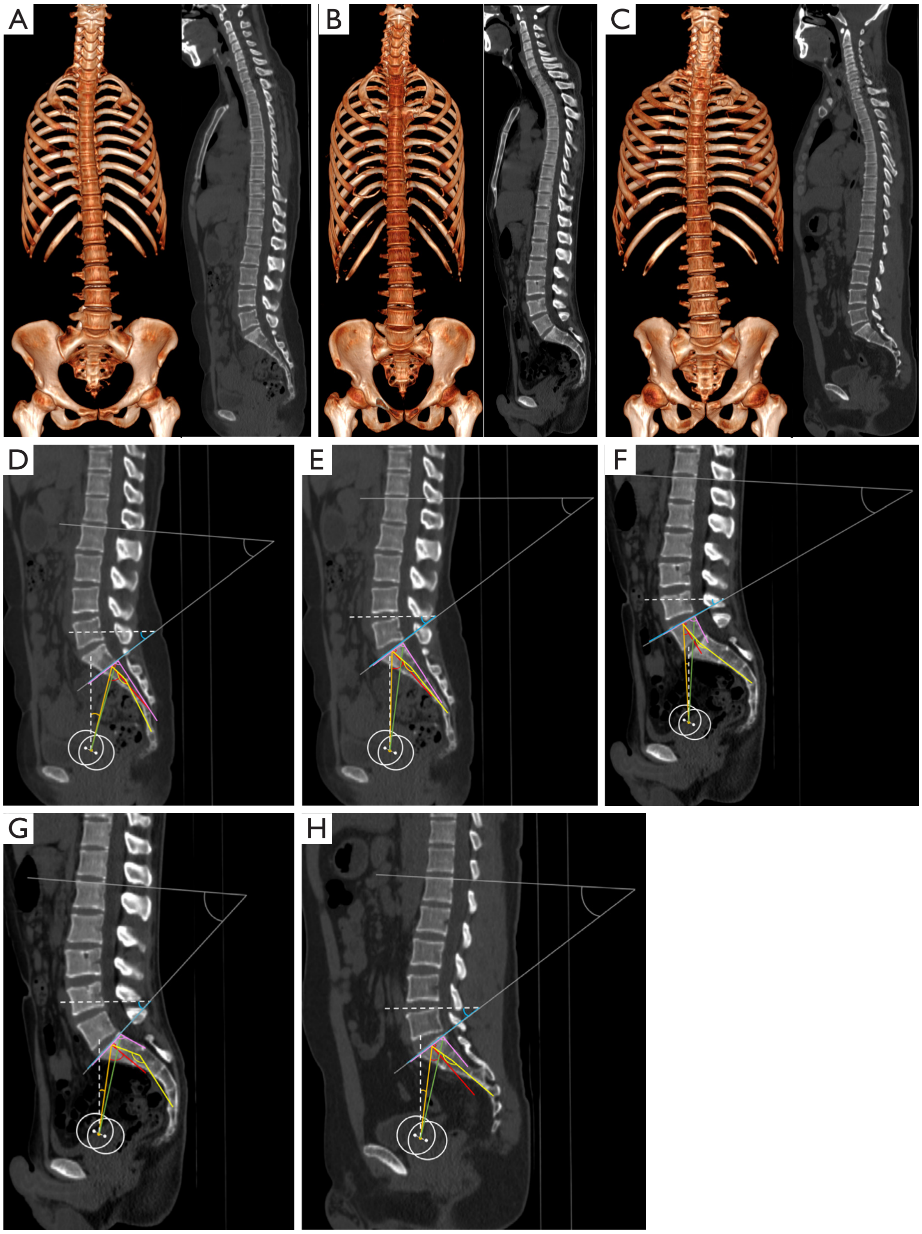

Figure 1 VR and sagittal MPR CT images of the whole spine in the cases with 23 PSV (A,D,E), 25 PSV (B,F,G), 24 PSV (C,H). Illustration of the sagittal lumbo-pelvic parameters' measurements at the Ontog S1 (D,F) and the Morph S1 (E,G) in the cases with 23 PSV and 25 PSV. PSV are enumerated on sagittal MPR whole-spine CT images, and the variations of spine and rib are observed on VR images. PI: the angle between the line perpendicular to the sacral endplate and the line connecting the midpoint of the sacral endplate to that of the bicoxofemoral axis (orange). PT: the angle between a vertical reference line and the line connecting the midpoints of the sacral endplate and the bicoxofemoral axis (red). SS: the angle between a horizontal reference line and the sacral endplate line (blue). LL: the angle between the superior endplate of L1 and that of the sacrum (gray), the number of lumbar vertebrae included in the angle is always five which is counted upward from Ontog S1 and Morph S1, respectively. STA: the angle between the superior endplate of S1 and the posterior edge of the sacrum (purple). SK: the angle between the line connecting the midpoints of S1 and S2 superior endplates and the line connecting the midpoints of S2 superior endplate and S4 inferior endplate (yellow). PR: the distance between the superior posterior corner of S1 and the center of the bicoxofemoral axis (green). The white dotted lines are horizontal and vertical reference lines. VR, volume rendered; MPR, multiplanar reconstruction; CT, computed tomography; PSV, presacral vertebrae; Ontog S1, ontogenetical S1; Morph S1, morphological S1; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; STA, sacral table angle; SK, sacral kyphosis; PR, pelvic radius.

transverse process morphology (Castellvi classification) were recorded (36). Inclusion criteria: individuals with complete segmentation anomalies of LSTV, including 23 and 25 presacral vertebrae (PSV) unrecognizable on lumbar spine images. Exclusion criteria: variation at the cervicothoracic and/or thoracolumbar junction interfering the identification of LSTV; primary and secondary malignancy of spine and pelvis; known diseases of sacroiliac and hip joint; spinal deformities including block vertebra, butterfly vertebra, hemivertebra, kyphosis, and scoliosis; previous history of spinopelvic fracture or surgery; spine and pelvis with severely degenerative changes; incomplete image data and cases not clearly showing vertebra or disc. To date, our data collection of LSTV complete segmentation anomalies included cases with 23 PSV (sacralization, n=211) and 25 PSV (lumbarization, n=239). The cases (n=29) with thoracolumbar transitional vertebra (TLTV) and 23 PSV, and the cases (n=27) with TLTV and 25 PSV were excluded to ensure that segmentation anomalies were only present at the lumbosacral region. In addition, 49 cases were excluded: malignancy of spine and pelvis (n=7); spinal deformities (n=9) including block vertebra (n=1), butterfly vertebra (n=2), hemivertebra (n=1), kyphosis and scoliosis (n=5); previous history of spinopelvic fracture (n=11) or surgery (n=8); spine and pelvis with severely degenerative changes (n=14). From the collection, this study matched 23 PSV (n=102, 54 males and 48 females; age range, 27–88 years; mean age, 56 years) and 25 PSV (n=108, 62 males and 46 females; age range, 24–79 years; mean age, 56 years) by age and gender using propensity-score matching (PSM). And 100 individuals with 24 PSV who were age- and gender-matched with 2 subgroups of LSTV served as controls (58 males and 42 females; age range, 20–85 years; mean age, 59 years). At last, a total of 310 individuals were included and all were Chinese Han population. *Figure 1* shows CT reconstruction images of 23, 24 and 25 PSV (*Figure 1A-1C*) and the measurements of sagittal lumbo-pelvic parameters in the case with 23 PSV (*Figure 1D,1E*), 25 PSV (*Figure 1F,1G*) and 24 PSV (*Figure 1H*). The flow chart of this study is shown in *Figure 2*.

Image assessment

The following lumbo-pelvic parameters, including lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), pelvic radius (PR), sacral slope (SS), sacral table angle (STA), and sacral kyphosis (SK), were measured independently on the midline sagittal reconstruction whole-spine CT image by two musculoskeletal radiologists (LD and SZ, with 5 and 3 years of clinical experience, respectively). All data from the case groups were mixed, and then the randomized ID numbers were distributed to the radiologists for measurements.

The measurement methods are as follows: PI is the angle between the line perpendicular to the superior endplate of S1 passing through its midpoint and the line connecting this point to the center of the bicoxofemoral axis; PT is the angle between a vertical reference line and the line connecting the midpoint of the S1 superior endplate and the bicoxofemoral axis; SS is the angle between the superior endplate of S1 and a horizontal reference line; LL is the angle between the superior endplate of L1 and that of the sacrum; STA is the angle between the superior endplate of S1 and the posterior edge of the sacrum; SK is the angle between the line connecting the midpoints of S1 and S2 superior endplates and the line connecting the midpoints of S2 superior endplate and S4 inferior endplate; PR is the distance between the superior posterior corner of S1 and the center of the bicoxofemoral axis (*Figure 1D-1H*) (1,5,37). For the determination of the bicoxofemoral axis, circles were drawn to adjust over the contour of the bilateral femoral heads on the coronal reconstruction CT image. The projection points of femoral head centers were automatically generated and visualized on all the planes. On the sagittal plane, the bicoxofemoral axis was determined to measure PI, PT, and PR. In two LSTV subgroups, two sets of measurements were performed at the ontogenetical S1 (Ontog S1) (*Figure 1D,1F*) and the morphological S1 (Morph S1) (*Figure 1E,1G*), respectively. For the LL measurement, the number of lumbar vertebrae included in the angle is always five which is counted upward from Ontog S1 or Morph S1, respectively. All the measurements were repeated by one of the radiologists (LD), and the interval between the first and second measurements was 4 weeks.

Statistical analysis

Statistical analyses were performed with the SPSS statistical software program (version 26.0; IBM, Armonk, NY, USA). The demographic data and measurement results were depicted with descriptive statistics. Kolmogorov-Smirnov test was used to test parametric data for normal distribution. In the normal group, *t*-test was used to compare the parameters between males and females. For the measurements at the Ontog S1 and the Morph S1 in the LSTV subgroups, *t*-test was used for statistical analysis of parametric data, and Kruskal-Wallis H test was used for non-parametric data.

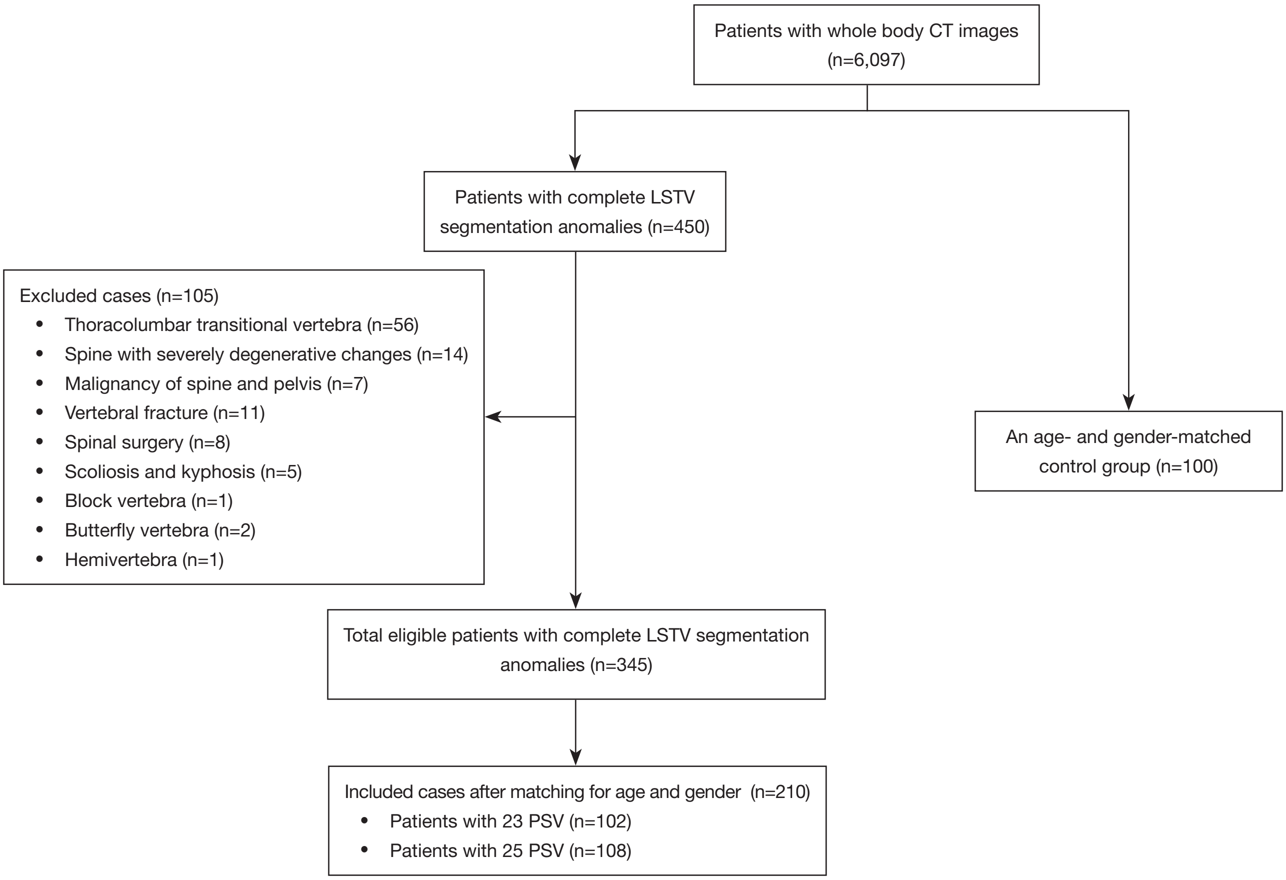

Figure 2 The patient flow chart of the study. CT, computed tomography; LSTV, lumbosacral transitional vertebrae; PSV, presacral vertebrae.

Between subgroups, parameters were compared using post hoc test with adjusted P values according to Bonferroni correction. Spearman's rank correlation coefficient was used for correlation analysis. Linear regression was used to analyze the association of LSTV types and measurement levels with all the parameters by using dummy variables, with the measurements of the control group as references. Intra-class correlation coefficients (ICCs) with a two-way random model were used to determine the intra- and inter-reader agreement of image analysis. Significance was accepted with a P value of less than 0.05 except for the statistical tests with Bonferroni correction.

Results

Intra-group comparisons (effect of measurement levels on lumbo-pelvic parameters)

In the LSTV subgroup with 23 and 25 PSV, lumbo-pelvic parameters measured at the Ontog S1 level significantly differed from those at the Morph S1 (all $P<0.001$). In the 23 PSV subgroup, the Ontog S1 measurements were higher than the Morph S1 in the characteristics of PI, PT, SS, and LL, whereas STA, SK, and PR were in reverse. In the 25 PSV subgroup, the Ontog S1 measurements were higher than the Morph S1 in the characteristics of SK and PR, whereas PI, PT, SS, LL, and STA were in reverse (*Table 1*). In the normal group, there was no difference in all the parameters between males and females (all $P>0.05$).

Inter-group comparisons (effect of LSTV types on lumbo-pelvic parameters)

At the Ontog S1 level, all the lumbo-pelvic parameters showed significant differences between the 23 PSV and 25 PSV subgroups (all $P<0.01$), and the same results were demonstrated at the Morph S1 (all $P<0.001$) (*Figure 3*).

Table 1 Comparisons between lumbo-pelvic parameters measured at two different measurement levels of Ontog S1 and Morph S1 in the two LSTV subgroups and the matched control group

Parameter	Group	Measurement levels	n	Mean (SD)	95% CI	Range	Median (P25, P75)	P value[a]	P value[b]
PI	23 PSV	Ontog S1	102	66.2 (9.0)	64.4–67.9	47.4–90.4	–	<0.001***	<0.001***
		Morph S1	102	42.1 (7.6)	40.6–43.6	20.3–60.8	–		<0.001***
	24 PSV	–	100	48.3 (10.4)	46.2–50.4	28.0–78.5	–	–	–
	25 PSV	Ontog S1	108	28.2 (10.6)	26.1–30.2	6.6–57.8	–	<0.001***	<0.001***
		Morph S1	108	59.2 (11.6)	57.0–61.4	31.6–86.7	–		<0.001***
PT	23 PSV	Ontog S1	102	19.8 (4.6)	18.9–20.7	8.6–32.3	–	<0.001***	<0.001***
		Morph S1	102	5.6 (3.7)	4.8–6.3	–6.4–15.0	–		<0.001***
	24 PSV	–	100	8.3 (5.4)	7.2–9.3	–4.9–24.4	–	–	–
	25 PSV	Ontog S1	108	4.6 (4.9)	3.7–5.5	–7.8–18.7	–	<0.001***	<0.001***
		Morph S1	108	15.6 (6.9)	14.3–16.9	–1.0–30.2	–		<0.001***
SS	23 PSV	Ontog S1	102	45.8 (7.0)	44.5–47.2	28.0–60.7	–	<0.001***	<0.001***
		Morph S1	102	36.6 (6.7)	35.3–37.9	19.1–53.0	–		0.01*
	24 PSV	–	100	39.9 (8.5)	38.2–41.6	18.0–62.4	–	–	–
	25 PSV	Ontog S1	108	–	–	2.3–47.8	22.8 (17.3, 29.0)	<0.001***	<0.001***
		Morph S1	108	43.3 (8.7)	41.7–45.0	13.7–67.7	–		0.007**
LL	23 PSV	Ontog S1	102	53.8 (8.9)	52.0–55.6	29.9–74.3	–	<0.001***	<0.001***
		Morph S1	102	43.9 (8.7)	42.2–45.6	24.2–67.2	–		0.627
	24 PSV	–	100	45.8 (12.0)	43.4–48.2	8.6–78.6	–	–	–
	25 PSV	Ontog S1	108	28.1 (10.7)	26.1–30.2	3.5–62.8	–	<0.001***	<0.001***
		Morph S1	108	49.6 (11.4)	47.5–51.8	13.5–76.5	–		0.033*
STA	23 PSV	Ontog S1	102	92.1 (4.0)	91.3–92.9	77.9–101.0	–	<0.001***	<0.001***
		Morph S1	102	95.8 (5.0)	94.8–96.8	84.5–116.7	–		<0.001***
	24 PSV	–	100	100.4 (5.2)	99.3–101.4	89.8–119.8	–	–	–
	25 PSV	Ontog S1	108	90.5 (3.2)	89.9–91.1	82.1–99.3	–	<0.001***	<0.001***
		Morph S1	108	99.2 (6.4)	98.0–100.4	80.3–118.4	–		0.367
SK	23 PSV	Ontog S1	102	–	–	135.1–176.2	152.9 (149.0, 161.2)	<0.001***	0.001**
		Morph S1	102	–	–	151.3–200.8	176.4 (170.2, 187.8)		<0.001***
	24 PSV	–	100	162.6 (10.6)	160.5–164.7	134.3–184.7	–	–	–
	25 PSV	Ontog S1	108	207.9 (10.9)	205.8–210.0	161.7–230.6	–	<0.001***	<0.001***
		Morph S1	108	–	–	132.6–185.6	154.8 (149.8, 163.1)		<0.001***

Table 1 (*continued*)

Table 1 (*continued*)

Parameter	Group	Measurement levels	n	Mean (SD)	95% CI	Range	Median (P25, P75)	P value[a]	P value[b]
PR	23 PSV	Ontog S1	102	104.4 (7.3)	102.9–105.8	82.0–124.0	–	<0.001***	<0.001***
		Morph S1	102	118.5 (9.2)	116.7–120.4	98.0–151.0	–		<0.001***
	24 PSV	–	100	111.4 (8.0)	109.8–112.9	91.0–129.0	–	–	–
	25 PSV	Ontog S1	108	–	–	100.0–152.0	126.0 (120.0, 132.8)	<0.001***	<0.001***
		Morph S1	108	105.1 (7.9)	103.6–106.6	86.0–124.0	–		<0.001***

[a], comparison between the parameter values at the ontogenetical S1 level and the morphological S1 within each LSTV subgroup; [b], comparison between the parameter values at respective measurement levels of two LSTV subgroups and the control group. *, P<0.05; **, P<0.01; ***, P<0.001. Ontog S1, ontogenetical S1; Morph S1, morphological S1; LSTV, lumbosacral transitional vertebrae; SD, standard deviation; CI, confidence interval; PSV, presacral vertebrae; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; STA, sacral table angle; SK, sacral kyphosis; PR, pelvic radius.

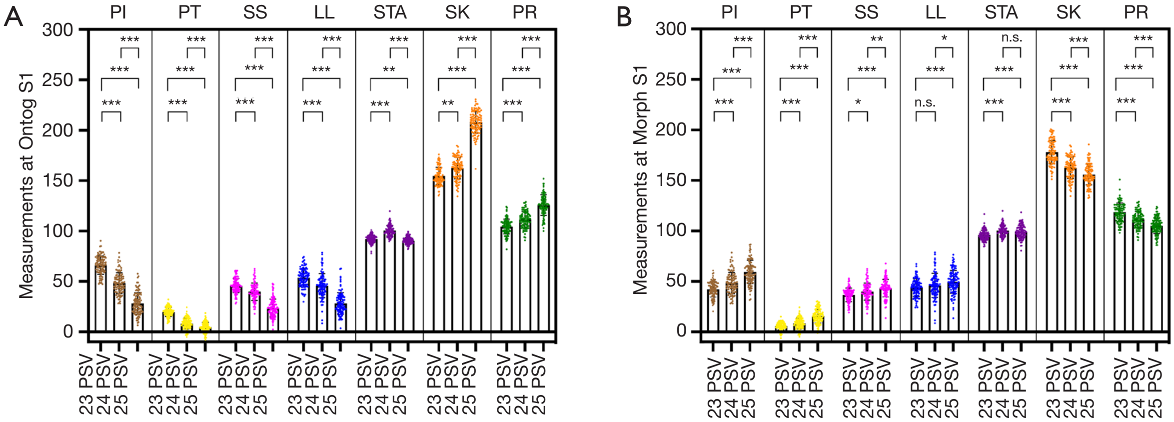

Figure 3 Nested box plot of the lumbo-pelvic parameters' values at the measurement level of Ontog S1 (A) and Morph S1 (B). At the Ontog S1, all parameters were associated with the number of vertebrae and significantly differed among all groups (all P<0.01). Values of the parameters PI, PT, SS, and LL decreased and those of SK and PR increased as the number of vertebrae increased. In contrast, the association of these parameters at the Morph S1 with the number of vertebrae were different. Values of the parameters PI, PT, SS, and LL increased and those of SK and PR decreased as the number of vertebrae increased, though the parameter LL showed no significant difference between individuals with 23 and 24 PSV and STA showed no significant difference between individuals with 24 and 25 PSV. Both at the Ontog S1 and the Morph S1, the parameter STA tended to decrease in two LSTV subgroups when compared with the control group. *, P<0.05; **, P<0.01; ***, P<0.001; n.s., P>0.05. Ontog S1, ontogenetical S1; Morph S1, morphological S1; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; STA, sacral table angle; SK, sacral kyphosis; PR, pelvic radius; PSV, presacral vertebrae; LSTV, lumbosacral transitional vertebrae.

When comparing the parameters measured at the Ontog S1 and the Morph S1 in the two LSTV subgroups with the matched control group respectively, most of them differed significantly (all P<0.05), but not in LL (P=0.627) at the Morph S1 in the 23 PSV subgroup and STA (P=0.367) at the Morph S1 in the 25 PSV subgroup (*Table 1* and *Figure 3*).

The association of LSTV types and measurement levels with lumbo-pelvic parameters

At the Ontog S1 level, the results of correlation analysis showed that there were negative correlations between PI (r_s=−0.850, P<0.001), PT (r_s=−0.762, P<0.001), SS

Table 2 Linear regression results for measurement levels and lumbo-pelvic parameters

Group	PI		PT		SS		LL		STA		SK		PR	
	β value	P	β value	P	β value	P	β value	P	β value	P	β value	P	β value	P
Ontog S1 of 25 PSV	−20.125	<0.001***	−3.665	<0.001***	−16.244	<0.001***	−17.668	<0.001***	−9.855	<0.001***	45.318	<0.001***	14.385	<0.001***
Morph S1 of 23 PSV	−6.163	<0.001***	−2.692	<0.001***	−3.355	0.003**	−1.918	0.193	−4.536	<0.001***	15.512	<0.001***	7.184	<0.001***
Morph S1 of 25 PSV	10.906	<0.001***	7.369	<0.001***	3.407	0.002**	3.848	0.008**	−1.191	0.080	−6.7	<0.001***	−6.297	<0.001***
Ontog S1 of 23 PSV	17.868	<0.001***	11.528	<0.001***	5.915	<0.001***	8.015	<0.001***	−8.249	<0.001***	−7.83	<0.001***	−6.994	<0.001***

β linear correlation coefficient reflecting the change in lumbo-pelvic parameters at different measurement levels relative to the control group. P comparison between different measurement levels of LSTV groups and the control group. **, P<0.01; ***, P<0.001. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; STA, sacral table angle; SK, sacral kyphosis; PR, pelvic radius; Ontog S1, ontogenetical S1; Morph S1, morphological S1; PSV, presacral vertebrae.

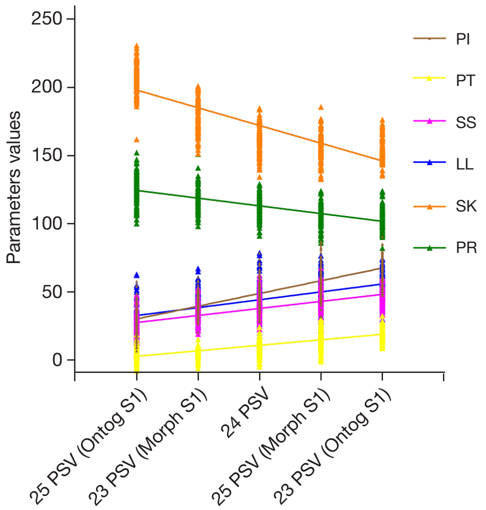

Figure 4 The association of the lumbo-pelvic parameters' values with the number of vertebrae and measurement levels. The linear fitting equations of these parameters showed that the slopes of PI (k=9.335) and SK (k=−12.990) were greater than PT (k=4.028), SS (k=5.155), LL (k=5.765), and PR (k=−5.654), suggesting PI and SK were influenced more by the number of vertebrae and measurement levels, with PT, SS, LL, and PR being relatively more stable in the presence of LSTV. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; SK, sacral kyphosis; PR, pelvic radius; PSV, presacral vertebrae; Ontog S1, ontogenetical S1; Morph S1, morphological S1; LSTV, lumbosacral transitional vertebrae.

(r_s=−0.732, P<0.001), LL (r_s=−0.721, P<0.001) and vertebrae counts; positive correlations between SK (r_s=0.814, P<0.001), PR (r_s=0.718, P<0.001) and vertebrae counts. Instead, reverse results were obtained at the Morph S1, which showed positive correlations between PI (r_s=0.584, P<0.001), PT (r_s=0.600, P<0.001), SS (r_s=0.354, P<0.001), LL (r_s=0.231, P<0.001) and vertebrae counts, and SK (r_s=−0.642, P<0.001), PR (r_s=−0.552, P<0.001) showed negative. No correlation was found between STA values and vertebrae counts both at the Ontog S1 and the Morph S1.

Linear regression results are demonstrated in *Table 2* and *Figure 4*, which show the same tendency as the difference comparison and correlation analysis in the characteristics of these parameter values. The general tendency of PI, PT, SS, and LL in different groups was ordered ascendingly as: Ontog S1 of 25 PSV, Morph S1 of 23 PSV, S1 of 24 PSV, Morph S1 of 25 PSV, Ontog S1 of 23 PSV. In contrast, the opposite tendency of SK and PR was demonstrated when ordered by the above measurement levels. Only the parameter STA showed different results from other parameters. Its measurements at Ontog S1 of 25 PSV, Ontog S1 of 23 PSV, Morph S1 of 23 PSV, Morph S1 of 25 PSV, S1 of 24 PSV, were listed in ascending order. In the cases with 25 PSV, the β absolute values of PI, SS, LL, STA, SK, and PR at the Morph S1 level were less than those at the Ontog S1. In the cases with 23 PSV, the β absolute values of PI, PT, SS, LL, and STA at the Morph S1 were less than those at the Ontog S1 (*Table 2*). Taking only LSTV types as an independent variable, the linear fitting equations showed that the slopes of these parameters at the Ontog S1 were higher than those at the Morph S1 (*Figure 5*). Taking LSTV types and measurement levels as independent variables, the linear fitting equations showed that the slopes of PI (k=9.335) and SK (k=−12.990) were

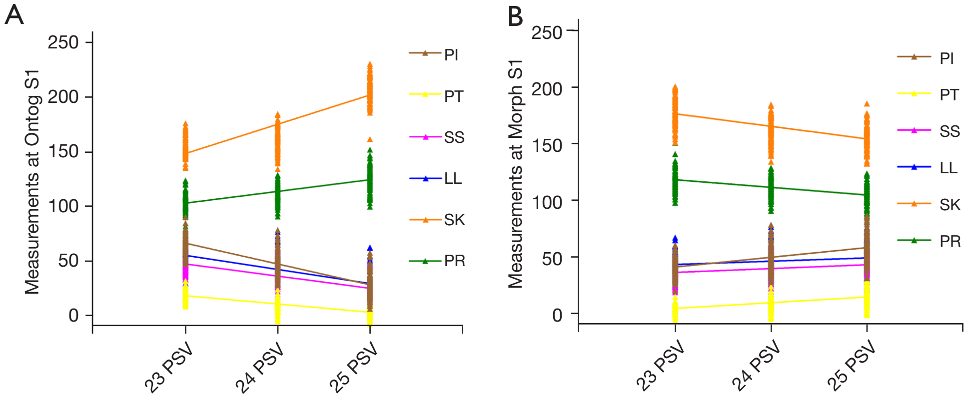

Figure 5 The association of the lumbo-pelvic parameters' values with the number of vertebrae at the measurement level of Ontog S1 (A) and Morph S1 (B), respectively. The linear fitting equations of these parameters showed that the slopes of PI (k=−19.010), PT (k=−7.560), SS (k=−11.130), LL (k=−12.890), SK (k=26.750), PR (k=10.720) at the Ontog S1 were greater than those of PI (k=8.557), PT (k=5.052), SS (k=3.381), LL (k=2.892), SK (k=−11.070), PR (k=−6.737) at the Morph S1. The variability of parameters measurements at the Morph S1 was significantly less than those at the Ontog S1. Ontog S1, ontogenetical S1; Morph S1, morphological S1; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; SK, sacral kyphosis; PR, pelvic radius; PSV, presacral vertebrae.

higher than PT (k=4.028), SS (k=5.155), LL (k=5.765), and PR (k=−5.654) (*Figure 4*).

Intra- and inter-reader reliability

The intra-reader reliability for all lumbo-pelvic parameters measurements was good, with ICCs of more than 0.8. The inter-reader reliability for most lumbo-pelvic parameters measurements was good with ICCs of more than 0.8, except that for STA measurements was moderate or good with ICCs of more than 0.6. The intra- and inter-reader reliabilities of the ICCs for the quantitative measurements are also demonstrated in *Table 3*.

Discussion

To our knowledge, this is the largest population study that investigates the influence of LSTV on lumbo-pelvic parameter characteristics. This study demonstrated that the variation of LSTV and the related measurement levels could affect the evaluation of sagittal balance. Different measurement levels bring about significantly different results, which possibly provide misguidance for preoperative assessment and cause over-correction or under-correction during spinal surgery. The findings of this article recommended the appropriate measurement level and the stable lumbo-pelvic parameters, to provide some help for the comprehension of variability in sagittal balance evaluation and restoration in LSTV individuals.

For a variety of spinal pathologies, assessing sagittal balance is a major factor in determining the health-related quality of life and preventing mechanical complications postoperatively (1,5,20). A few studies on normal subjects with different ages (38-40), genders (38,40-42), and ethnicities (38,42-46) have been conducted, but controversy remains concerning these factors. Similar to some investigations (38,40,44,47), our results of the controls showed that lumbo-pelvic parameters did not vary with sex. Compared with previous studies on the Chinese population, PI, PT, and LL values of the controls in our study were within the reference range given by Zhu *et al.* (44), and PI, PT, SS, and LL values were comparable with another study by Ru *et al.* (39). The above findings remind us that the spinal balance should not be judged by a single parameter, but coherence among these parameters should be taken into consideration preoperatively. Individual evaluation and correction strategy is needed to ensure optimum clinical outcomes for each patient with different conditions.

The presence of LSTV leads to confusing measurement level selections. We found that all the lumbo-pelvic parameters at the Ontog S1 level significantly differed from those at the Morph S1. All the parameters measured at the Ontog S1 and most of them at the Morph S1 were shown to be significantly different among the two LSTV subgroups and the controls. The influence of LSTV on sagittal balance assessment has been reported in previous studies. Kyrölä *et al.*

Table 3 Intra- and inter-reader reliability for the lumbo-pelvic parameters' measurements

ICCs	Parameter	23 PSV		24 PSV	25 PSV	
		Ontog S1	Morph S1		Ontog S1	Morph S1
Intra-reader coefficients (95% CI)	PI	0.911 (0.817–0.957)	0.944 (0.887–0.973)	0.974 (0.946–0.988)	0.980 (0.959–0.991)	0.993 (0.980–0.997)
	PT	0.972 (0.942–0.986)	0.968 (0.933–0.985)	0.982 (0.963–0.992)	0.971 (0.939–0.986)	0.984 (0.967–0.992)
	SS	0.972 (0.942–0.986)	0.939 (0.878–0.971)	0.971 (0.939–0.987)	0.984 (0.960–0.993)	0.993 (0.977–0.997)
	LL	0.965 (0.929–0.983)	0.974 (0.947–0.988)	0.876 (0.757–0.939)	0.967 (0.933–0.984)	0.991 (0.982–0.996)
	STA	0.816 (0.649–0.908)	0.906 (0.809–0.954)	0.808 (0.637–0.904)	0.825 (0.664–0.912)	0.899 (0.800–0.950)
	SK	0.911 (0.822–0.956)	0.955 (0.908–0.978)	0.980 (0.959–0.991)	0.955 (0.907–0.978)	0.978 (0.955–0.990)
	PR	0.987 (0.974–0.994)	0.993 (0.979–0.997)	0.988 (0.975–0.994)	0.983 (0.965–0.992)	0.971 (0.939–0.986)
Inter-reader coefficients (95% CI)	PI	0.904 (0.806–0.953)	0.829 (0.671–0.915)	0.940 (0.879–0.971)	0.950 (0.896–0.976)	0.923 (0.727–0.971)
	PT	0.950 (0.888–0.977)	0.981 (0.943–0.992)	0.945 (0.888–0.973)	0.974 (0.945–0.988)	0.981 (0.959–0.991)
	SS	0.941 (0.880–0.972)	0.964 (0.926–0.983)	0.966 (0.930–0.984)	0.957 (0.910–0.979)	0.932 (0.860–0.967)
	LL	0.957 (0.911–0.979)	0.944 (0.830–0.977)	0.858 (0.700–0.933)	0.944 (0.884–0.973)	0.929 (0.855–0.966)
	STA	0.653 (0.381–0.819)	0.830 (0.676–0.915)	0.734 (0.514–0.863)	0.875 (0.736–0.941)	0.639 (0.166–0.842)
	SK	0.904 (0.798–0.955)	0.938 (0.861–0.972)	0.886 (0.775–0.944)	0.959 (0.915–0.981)	0.889 (0.686–0.954)
	PR	0.984 (0.965–0.992)	0.987 (0.972–0.994)	0.898 (0.794–0.951)	0.985 (0.969–0.993)	0.987 (0.972–0.994)

ICC, intra-class correlation coefficient; PSV, presacral vertebrae; Ontog S1, ontogenetical S1; Morph S1, morphological S1; CI, confidence interval; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; STA, sacral table angle; SK, sacral kyphosis; PR, pelvic radius.

found that the radiographic parameters of L6 variant differed from the control group; PI, PT, and LL of L6 sacrum were significantly higher than those of L6 endplate (25). These findings were comparable with our results. However, Haffer *et al.* reported that there was a significant difference only in the STA but not in PI and PR when comparing 6 lumbar vertebrae (measurement level L6) with the controls, and there was a significant difference in PI and STA but not in PR when comparing 6 lumbar vertebrae (measurement level S1) with the controls (15). Their findings were not completely consistent with our study, which might be due to the small sample size (n=11 for 6 lumbar vertebrae). A cadaveric study (Caucasian and African American) included cases with 4 lumbar vertebrae (n=54) and 6 lumbar vertebrae (n=23) (14). It revealed that PI significantly decreased in subjects with 4 lumbar vertebrae, but not in subjects with 6 lumbar vertebrae (14). On the other hand, our results showed significant differences regarding PI values among all the groups. As shown in these conflicting results, variations of sagittal alignment can be seen among different LSTV study populations. It reminds surgeons of the necessity to differentiate patients on the basis of their conditions including the lumbo-pelvic variation, sagittal shape, age, ethnicity and so on when assessing sagittal spinal alignment.

Our results showed that the sagittal lumbo-pelvic parameters were associated with both vertebrae counts and sacral table location. The differences of PI, SS, LL, STA, SK, and PR values between 25 PSV and the controls at the Morph S1 level were less than those at the Ontog S1. Besides, the differences of PI, PT, SS, LL, STA between 23 PSV and the controls at the Morph S1 were less than those at the Ontog S1. This suggested how to select the vertebra as sacral plateau for measurements in cases with different LSTV types. Recently, there have been several studies on the measurement level selection. Zhou *et al.*

measured lumbo-pelvic parameters at cephalad and caudal sacral endplates and found that pelvic parameters (PI, PT, SS) and regional lumbar parameter (LL) were significantly different (16), which was comparable to our study. Some authors explored the mathematical relationships among these parameters at upper and lower transitional vertebra (24). These studies can help spine surgeons better understand the nuances for restoring proper alignment during spinal surgery and avoid measuring multiple parameters repeatedly.

In our study, the linear fitting equations of these parameters showed that PI and SK measurements were more influenced, with PT, SS, LL, and PR measurements being relatively more stable (*Figure 4*). Therefore, PT, SS, LL, STA, and PR measurements are more reliable and recommended for the initial assessment of sagittal balance. Interestingly, another finding was that the parameter STA measurements at the Ontog S1 and the Morph S1 of 23 and 25 PSV subgroups were all lower than that of the control group. This may indicate that the reference value of STA is lower than the normative value range if LSTV is present without considering the sacral table location. In addition, the parameters other than STA showed excellent intra- and inter-reader reliabilities, providing reproducibility in sagittal balance evaluation between readers. The measurements of STA showed moderate inter-reader reliability, possibly because of the effect of vertebral osteoproliferation on defining the posterior edge of the sacrum.

This study has several limitations. First, the sagittal lumbo-pelvic balance should not be limited to structural analysis under static conditions. Further research is needed on biomechanical analysis and dynamic changes of the LPC in LSTV individuals, including flexion, extension, lateral bending, and axial rotation. The second one is about the position of this study, which only reflects the supine position and the surgeon's intraoperative perspective. Some of the lumbo-pelvic parameters alter with the position, thus the parameters characteristics of the present study may not be readily transferred to other positions. More image data in standing and sitting positions need to be verified and investigated. Third, clinical data on body mass index (BMI) were not documented in this study. The influence of obesity on the sagittal lumbo-pelvic balance assessment cannot be ruled out.

Conclusions

Special consideration of the presence and classification of LSTV are necessary in the preoperative planning of restoring sagittal lumbo-pelvic balance. For LSTV individuals, Morph S1 is recommended for the measurements of most lumbo-pelvic parameters, and PT, SS, LL, STA, PR are shown to be more stable parameters concerning the effect caused by LSTV.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-23-799/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-799/coif). The authors have no conflicts of interest to declare.

Ethical Statement: Photographs are completely unidentified and there are no details on persons mentioned within the text. 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. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Ethics Board of the First Affiliated Hospital of Chongqing Medical University and individual consent for this retrospective analysis was waived.

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