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The implications of sacralized transitional vertebra on spinal alignment.

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Conflicts of interest:

The authors have no conflict of interest to declare relatively to this study.

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ABSTRACT

Study design: Retrospective study of a multicentric prospective database.

Objective: This study aimed to determine, in a cohort of healthy volunteers, the impact of sacralized lumbo-sacral transitional vertebra (LSTV) on spinal alignment according to its grade, particularly regarding lumbar lordosis magnitude and distribution, and the implications for spinopelvic parameters measurement.

Summary of Background Data: There is little data regarding spinopelvic alignment assessment in LSTV patients.

Methods: This study included healthy volunteers with full-body stereoradiographs in free-standing position aged over 18. Castellvi grade, pelvic parameters (measured on S1 and L5), L1-S1 lumbar lordosis (LL) and segmental lordosis for each disc and vertebral body, thoracic

kyphosis, cervical lordosis, lower limb, and global alignment parameters were assessed. Castellvi I and II were considered as Low-grade and Castellvi III and IV as High-grade LSTV. Alignment parameters between No-LSTV, Low- and High-grade LSTV were compared. Propensity score matching was used to match PI in No-LSTV and Low-grades. Spinopelvic parameters measured on S1 in No-LSTV group and on L5 in High-grade were compared.

Results: 713 subjects were included, of whom 23 Low-grades and 27 High-grades. Mean pelvic incidence was 51.0±11.0° and mean age was 37.5±16.2 years. LL distribution was different between groups, with an apex and inflexion point significantly higher in High-grade (*p<0.001*). Kyphosis in the LSTV segment was compensated for by a steeper increase of LL above L5 in the High-grades. Low-grades and PI-matched No-LSTV presented similar alignment parameters. There were minor differences in parameters measured on S1 in No-LSTV and no L5 in High-grades.

Conclusion: Subjects with low-grade LSTV present similar alignment as PI-matched No-LSTV subjects, and S1 should be taken as reference to measure spinopelvic parameters. High-grade LSTV subjects have kyphotic L5-S1 segment with more cranial lumbar apex and thoracolumbar inflexion point. In these subjects, spinopelvic parameters should be measured on L5.

KEY POINTSMETHODS

- Spinal alignment in sacralized lumbo-sacral transitional vertebra (LSTV) patients must be assessed according to its grade.

- On average, low-grade sacralization subjects have greater pelvic incidence than No-LSTV cohort.
- After matching for pelvic incidence, low-grade and No-LSTV subjects present similar alignment, indicating that parameters should be measured using S1.
- High-grade subjects have a kyphotic LSTV segment with cranial shift of lumbar apex and thoracolumbar inflexion point.
- Comparing spinopelvic parameters measured on S1 in the No-LSTV group and measured on L5 in the high-grade LSTV group showed minor differences, indicating that parameters should be measured on L5 in high-grade subjects.

INTRODUCTION

Sagittal alignment assessment has become essential in the management of spinal conditions, for adult spinal deformity correction but also short fusions [1,2]. Most published articles assume five lumbar vertebrae, and guidance is limited for patients presenting lumbosacral transitional vertebrae (LSTV) in terms of physiological alignment and the way it should be assessed. LSTV are frequent, estimated at around 10 to 15% of the general population [3]. They can be of two types: L5 sacralization or S1 lumbarization, leading to 4-vertebra or 6-vertebra lumbar spine, respectively. Castellvi *et al.* proposed a classification in four grades of these anomalies, taking into account the degree of LSTV fusion to the sacrum, and their bi- or unilaterality feature [4] (**Figure 1**).

Although generally asymptomatic, these anomalies can have repercussions on daily life as they have been associated with an increased risk of low back pain. Indeed, according to Farshad *et al.*, more cephalad adjacent disc degeneration was noted in patients with lumbosacral transitional vertebra compared with control subjects [5]. In addition, it has been demonstrated that types II, III and IV were associated with lumbar disc and facet joint degeneration at all levels between L2 and L5 [6]. These skeletal anomalies are also associated with musculature changes. Becker *et al.* reported that lower volume of paraspinal and trunk muscles and increased fatty changes in patients with LSTV correlated with Castellvi's classification grades [7].

The presence of a lumbosacral transitional anomaly can be challenging if surgical treatment is indicated. Such anomalies can lead to mistakes when counting the spinal level to

treat, intraoperatively or during preoperative planning according to Nakagawa *et al.* [8]. Thus, these authors recommended routine full-spine X-rays to decrease that risk. Further, spinopelvic measurement in LSTV patients remains unclear. Several studies attempted to determine if pelvic parameters should be measured using the S1 plateau or the upper endplate of L5 fused to the sacrum, in patients with sacralization. However, to our knowledge, there is no data in the literature regarding the other spinopelvic parameters and global alignment assessment in LSTV patients.

This study aimed to determine, in a cohort of healthy volunteers, the impact of sacralized transitional vertebra on spinal alignment according to its grade, particularly in terms of lumbar lordosis magnitude and distribution, and the implications for pelvic parameters measurement.

METHODS

Population

This multicentric study included healthy volunteers from previous studies, aged above 18 years [9–12]. Volunteers presented no major pain in the spine, hip, or knee. Exclusion criteria were any musculoskeletal deformity, scoliosis with a Cobb angle >15°, isthmic or degenerative spondylolisthesis, history of spinal surgery, hip, or knee replacement. All participants had a full-body biplanar radiograph (EOS™ system, Alphatec, CA, USA) in free-standing position (in upright position, fingers positioned on the cheeks or clavicles, and one foot slightly forward) [13]. This study was approved by regional ethics committees (approval N° 6001 and 6061 C.P.P. Ile-de France VI and FM 312 ethical committee at the Saint-Joseph University, Beirut). All participants provided their informed written consent.

Parameters

Demographic parameters including age, sex, height, weight, and body mass index (BMI) were collected. LSTV subjects were categorized as "lumbarization" or "sacralization", after counting the vertebrae down from C2: LSTV subjects with 6 and 4 lumbar vertebrae respectively (T12 may not have a rib). All LSTVs were then further graded according to Castellvi's classification (**Figure 1**).

Spinopelvic and lower limb three-dimension reconstructions were performed by a specifically trained physician, according to previously validated semi-automated methods [14,15]. First the spinal line from C3 to L5 was drawn by the user on the anteroposterior and lateral views. The software then generated a 3D spine reconstruction and retro-projected the 3D models of the vertebra on the radiographs. This model was then manually adjusted by the user to precisely fit vertebral contours visible on the radiographs. Similarly, the 3D models of the pelvis and lower limbs were carried out.

In case of sacralization, the L5 body and L5-S1 transitional disc were taken into account within the sacralized complex (**Figure 2**). All radiographic data were computed from the 3D reconstructions. Parameters affected by LSTV, hereafter marked with an asterisk, were measured twice: the standard way, measured using S1 plateau, and the alternative way using the upper endplate of the fused L5 vertebra. The latter is denoted by adding "_L5" after parameter designation (e.g., PI_L5). The following parameters were measured:

- Pelvic parameters: pelvic incidence* (PI), pelvic tilt* (PT) and sacral slope* (SS) [16] (**Figure 2**).
- Spinal parameters: each disc and vertebral body angulation in the lumbar spine was measured. Lumbar functional units were defined as the vertebral body and the underlying disc. The maximum lordosis* (LLmax) was measured from the upper

endplate of thoraco-lumbar inflexion vertebra to the S1 endplate, distal lumbar lordosis* (LLdist) was measured from the upper endplate of lumbar apex to S1 endplate, and proximal LL (LLprox) was measured from inflexion point upper endplate to the upper endplate of the lumbar apex (**Figure 2**). L1-S1, T12-L5, L4-S1, and L1-L4 were also measured.

Thoracic kyphosis (TK) was measured from the upper endplate of T1 to the upper endplate of L1, further divided into proximal (T1-T5), middle (T5-T9) and distal regions (T9-L1). Cervical lordosis was measured from the upper endplate of C3 to the upper endplate of T1.

- Alignment parameters: Sagittal vertical axis (SVA), T1 pelvic angle* (TPA), spino-sacral angle* (SSA), T1 spino-pelvic inclination (T1SPi) and sagittal odontoid-hip axis angle (ODHA) [17]. PI-LL mismatch* was measured the standard way, and the alternative way by calculating the difference between PI_L5 and T12-L5 lordosis.
- Lower limb parameters: Sacro-femoral angle* (SFA), Knee flexion angle (KFA), Ankle flexion angle (AA) and Pelvic shift (PSh) [18]. These parameters result from the left and right lower limbs values mean.

Statistical analysis

All variables were tested for normality using Shapiro-Wilk's. First, a global description of the cohort was made, with parameters expressed by their means ± standard deviations (SD). By convention, lordosis is expressed by negative values as opposed to kyphosis which is given with positive ones.

Castellvi I and II were considered as low-grade and Castellvi III and IV as high-grade LSTV. Comparisons between the three groups (No-LSTV, low-grade and high-grade) were performed using Pearson's χ^2 test for categorical variables, and Kruskal-Wallis test for

numeric variables. Post-hoc analyses using pairwise Wilcoxon tests with Bonferroni correction were carried out to identify significant differences between each pair of groups.

Further pairwise analysis comparing No-LSTV subjects with Low-grade and High-grade sacralization subjects was performed after matching PI of No-LSTV subjects with that of sacralization subjects, using a propensity score. Last, spinopelvic parameters measured on S1 in No-LSTV group and on L5 in high-grade LSTV were compared.

All statistical analyses have been carried out using RStudio (version 2024.04.1+748). with p-values lower than 0.05 considered significant.

RESULTS

Cohort description

This study included 713 subjects, with 50.6% of females and an average age of 37.5±16.2 years and BMI of 24.5±4.4 $kg.m^{-2}$. Mean PI was 51.0±11.0° and mean L1-S1 lordosis was -57.7±11.5°. There were 10.1% (n=72) of subjects with LSTV, including 7.0% (n=50) with sacralization and 3.1% (n=22) with lumbarization. The distribution of Castellvi's grade among subjects with L5 sacralization is given in **Table 1**.

How do spino-pelvic parameters differ with sacralization grade?

Subjects were comparable in the three groups of sacralization grade in terms of demographics (**Table 2**). Pelvic tilt, PI, and PI_L5 increased significantly with LSTV grade (**Table 2**). PT_L5 was significantly greater in high-grade LSTV subjects (8.9±7.1°) than in no-LSTV subjects (4.8±5.6°, *p=0.02*). Lumbar lordosis magnitude significantly differed between the groups, with greater L1-S1 lordosis, L1-L4 and maximum lordosis found in high-grade LSTV subjects (**Table 2**). L4-S1 lordosis was significantly lower in high-grade LSTV subjects (*p=0.008*).

High-grade LSTV subjects presented alteration of global alignment with greater proximal TK than low-grade subjects (*p=0.03*) and decreased lower TK compared to No-LSTV subjects (*p=0.04*) (**Table 3**).

Normative values for PI-LL mismatch, SVA, TPA, SSA and their alternatives measured on L5 are given in **Table 3**. There were no significant differences between the groups in terms of cervical curvature and lower limb parameters (pelvic shift, knee and ankle angles, *not shown*).

How does lumbar distribution differ with sacralization grade?

Lordosis distribution was also different between groups, with an apex significantly higher in high-grade LSTV: 63% in L3 and 30% in L4 versus 26% in L3 and 70% in L4 among low-grade subjects, and 6% in L3 and 77% in L4 in no-LSTV (*p<0.001*). Similarly, most frequent location of the thoracolumbar inflexion point was L1 in No-LSTV subjects (36%), while it was in T12 in low-grade subjects (56.5%). In the high-grade group, one third of subjects had an inflexion point at T11 (**Figure 3**).

L5 functional unit lordosis accounted for 39.7% of L1-S1 lordosis in no-LSTV subjects, versus 33.1% in low-grade and 10.2% in high-grade subjects (**Figure 4**) (*p<0.001*). Conversely, L4 functional unit contribution to L1-S1 lordosis was the highest in high-grade group (38.6% versus 26.2% and 25.6% in low-grade in No-LSTV groups, respectively).

Accordingly, looking at the cumulative contribution of each disc and vertebral body to L1-S1 lordosis exhibited different patterns between the groups (**Figure 5**). Notably, kyphosis in the LSTV segment was compensated for by a steeper increase of LL above L5 in the High-grade LSTV group.

How to measure alignment in sacralization subjects?

After matching PI of No-LSTV with low-grade and high-grade sacralization subjects respectively, some similarities were highlighted. There were no significant differences in all the spinopelvic alignment parameters studied between low-grade and PI-matched No-LSTV subjects (**Table 4**). These results indicate parameters should be measured on S1 in low-grade sacralization subjects.

High-grade sacralization subjects had significantly greater L1-L4 and lower L4-S1 lordosis than PI-matched No-LSTV subjects. However, both groups presented similar distal and proximal LL. Lumbar apex was mainly located at L4 in the No-LSTV group while it was preponderantly located at L3 in the High-LSTV group ($p=0.001$). In total, the lumbar alignment of High-grade sacralization subjects was comparable to high-PI No-LSTV subjects with a cranial shift of one vertebra (**Table 4**).

Subsequent analysis was performed comparing spinopelvic parameters measured on S1 in the whole No-LSTV group and measured on L5 in the high-grade LSTV group (**Table 5**). Although significant, the difference in mean SS versus SS_L5 was of 1°. L3-L5 lordosis in high-grade LSTV was higher than L4-S1 lordosis in No-LSTV (-41.4±6.4° versus -36.6±7.1° respectively, $p<0.001$). There were no significant differences in PI, PT, lumbar lordosis, LLmax and global alignment (**Table 5**). Despite minor differences, these results indicate parameters should be measured on L5 in high-grade sacralization subjects.

DISCUSSION

While not well documented in literature, this study sheds light on spinal alignment in subjects with sacralization-type LSTV. Our results highlighted that pelvic parameters values were greater if measured on S1 endplate than on L5. Individuals with sacralization had

different alignment than No-LSTV subjects, with greater PI, more cranial and greater lumbar lordosis. This difference was more pronounced with high-grade sacralization subjects. Indeed, after matching for PI, alignments were similar between No-LSTV and low-grade sacralization subjects, while alignment of high-grade group was comparable of high-PI No-LSTV subjects with a cranial shift of one vertebra. These results indicate that spinopelvic parameters should be measured using S1 in low-grade LSTV subjects whereas L5 should be taken as reference in high-grade individuals. To our knowledge, there is no such thorough description in literature of spinopelvic alignment in patients with sacralization, and further assessment according to Castellvi grade. Normative values are provided for pelvic parameters, segmental, regional and total lumbar lordosis as well as the locations of lumbar apex and inflexion point. These results are useful to determine alignment goals when lumbar fusion is to be undertaken in patients with sacralization.

Subjects with high-grade sacralization exhibited a kyphotic L5-S1 transitional disc, with an alteration of the whole thoraco-lumbar alignment. In compensation, these subjects presented greater lordosis above, especially at the L4-L5 and L3-L4 levels, along with decreased lower TK. Accordingly, lumbar apex and inflexion point were more proximal, by one level on average, in subjects with sacralization, especially of high-grade. This finding is particularly relevant to adjust correction towards increased lordosis when performing short fusion in patients with high-grade sacralization.

Increased lordosis at these levels could increase the stress on the facet joints and may lead to degeneration. Accordingly, Hanhivaara *et al.* described a higher rate of facet degeneration at L4-L5 on CT-scans in patients with LSTV than in controls [6]. Another explanation to this adjacent degeneration could be the increased motion at the cranial adjacent segment of LSTV, as exhibited by Becker *et al.* [19]. Last, the lower muscle volume and greater

muscle degeneration in the trunk and lumbar muscles could also play a role in adjacent degeneration [7].

Great caution is called for when performing correction-fusion surgery in sacralization patient as the distribution of spinal curvatures is also altered by the LSTV. In this study, lumbar lordosis and pelvic parameters (whether measured on S1 or L5) were significantly greater in subjects with LSTV. These findings are in accordance with Jacob *et al.* who found greater LL, PI and PT (measured on S1) in LSTV patients compared to controls [20]. This discrepancy is explained by the significant shorter size of sacra in patients with sacralization compared to normal ones if fused L5 is not taken into account, as per Mahato *et al.*'s study [24]. Consequently, measuring alignment in LSTV patients remains challenging. Tatara *et al.* concluded that if PI was too low when measured on L5 (LSTV), S1 should be then taken as reference [21]. Ani *et al.* recommended to use S1 to assess spino-pelvic parameters as L5-parameters underestimated deformity and showed weaker correlation with health-related quality of life scores in a population of adult spinal deformity (ASD) patients [22]. Zhou *et al.* drew the same conclusion in non-ASD patients [23].

Interestingly, this study demonstrated that sagittal alignment of subjects with sacralization was dependent on the LSTV grade. Thus, subjects with Low-grade sacralization presented similar alignment to No-LSTV group with matched PI measured on S1. The high-grade sacralization group exhibited significant variation in alignment with a cranial shift of lumbar lordosis, of one vertebra on average, to compensate for a kyphotic L5-S1 segment within the sacralized complex. These subjects presented higher lumbar apex and thoracolumbar inflexion point, with a lower T9-L1 kyphosis and greater middle thoracic kyphosis. Nevertheless, these subjects presented similar LL magnitude compared to No-LSTV group with high PI (measured on S1). In contrast with previous literature data, these

results suggest to measure pelvic parameters using the S1 plateau for low-grade LSTV and L5 for high-grade. Indeed, the complete fusion of the L5-S1 segment in high-grade sacralizations leads to a cranial shift of lumbosacral junction from S1 plateau to L5 upper endplate.

Limitations

A larger sample size would have enabled a more detailed description by Castellvi type and PI group among sacralization subjects, as well as analysis in subjects with lumbarization. There were no CT-scan images available for these healthy volunteers, to help better grading of LSTV according to Castellvi's classification.

CONCLUSION

This study highlighted the greater PI and the specific sagittal alignment in subjects with a sacralization of L5, and its relationship with sacralization grade. Subjects with low-grade LSTV present similar alignment as PI-matched No-LSTV subjects, and S1 should be taken as reference to measure spinopelvic parameters. High-grade LSTV subjects have kyphotic L5-S1 segment with more cranial lumbar apex and thoracolumbar inflexion point. In these subjects, spinopelvic parameters should be measured on L5. Normative values for each disc and vertebral body are also provided to help surgeons define alignment goals when performing fusion in patients with sacralization.

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Figure 1: Castellvi's classification of LSTV. Type I: dysplastic enlarged transverse process (TP), Type II: pseudo-articulation between TP and sacrum, Type III: fusion with the sacrum, Type IV: fusion on one side and pseudo-articulation on the other. A: unilateral lesion, B: bilateral lesion.

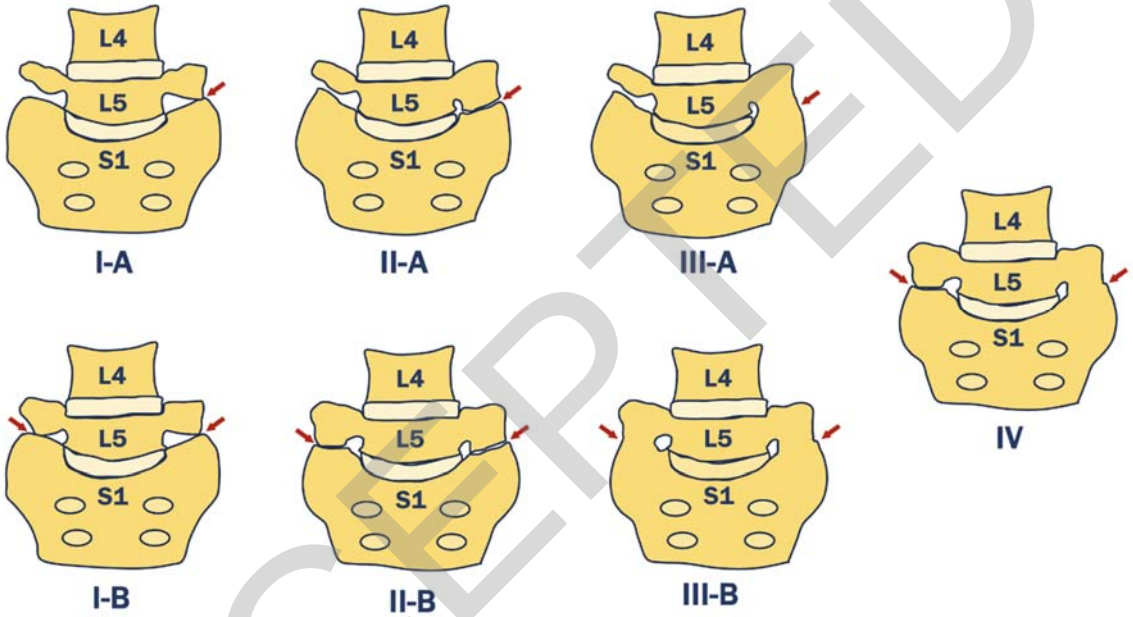


Figure 2: The same lateral X-ray illustrating PI, PT, LLdist and LLprox measurement (*on the left*), and PI_L5, PT_L5 and T12-L5 sagittal Cobb angle (*on the right*).

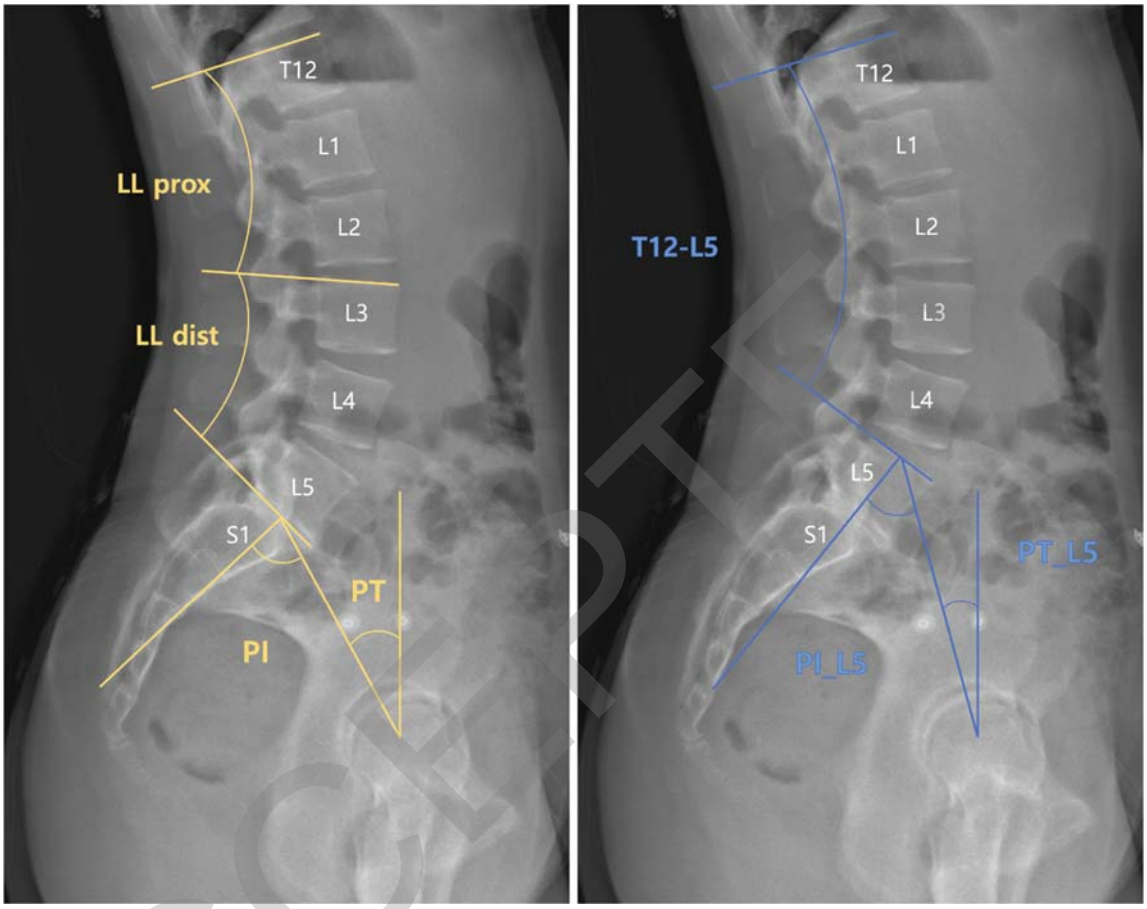


Figure 3: Lumbar apex and inflexion point distribution in each sacralization group. Green: No-LSTV, Orange: Low-grade, Red: High-grade.

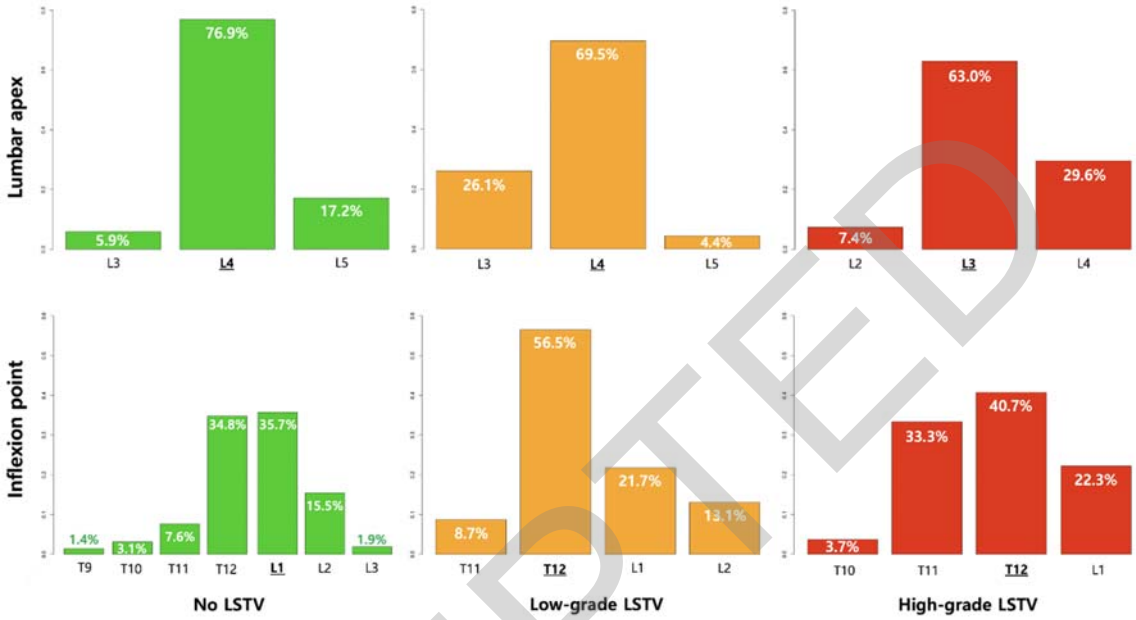


Figure 4: Normative values for sagittal Cobb angle of each lumbar disc and vertebral body, for each LSTV group. Next to the arrows are reported the contribution of each functional unit (vertebra + underlying disc). Blue arrows denote significant differences in functional unit contribution to LL between contiguous groups, with respective p-values reported above.

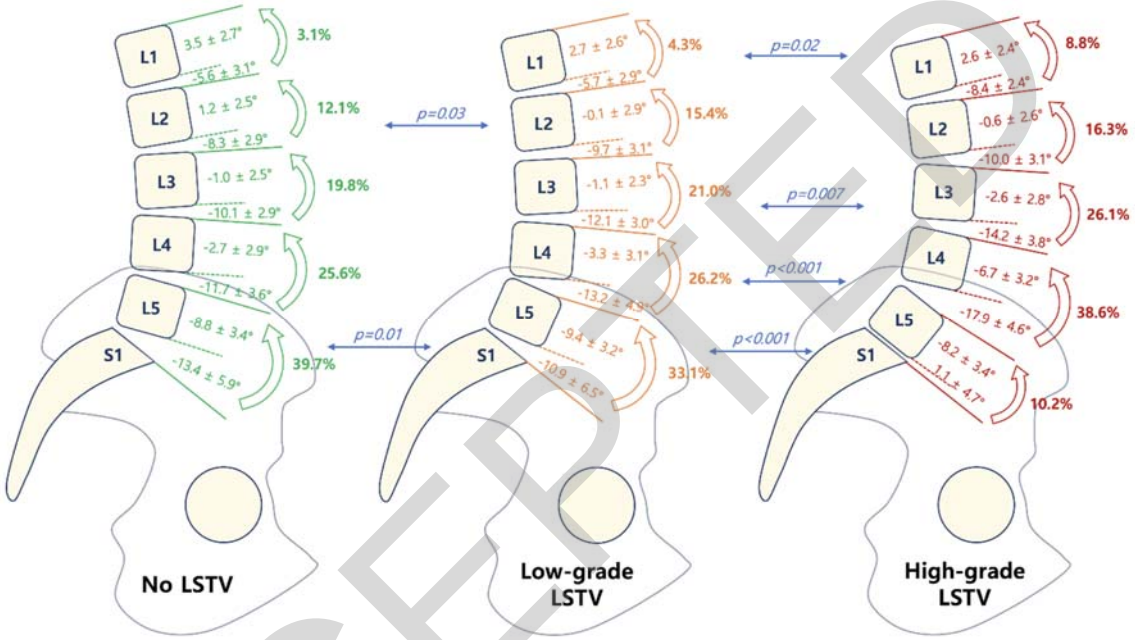
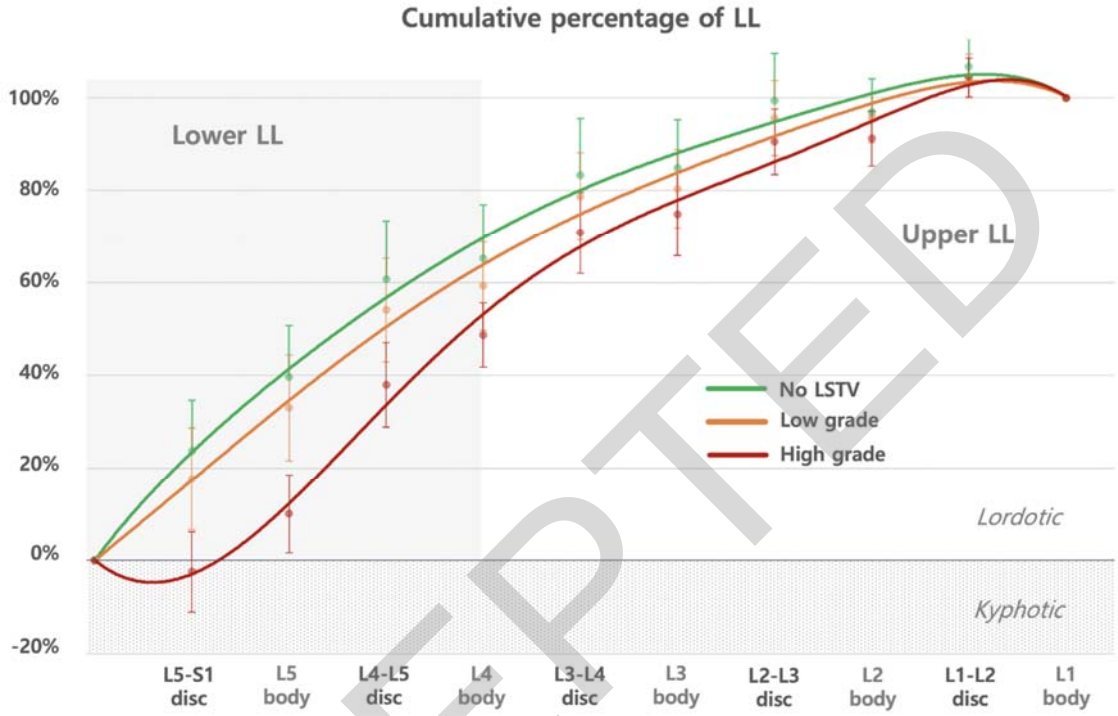


Figure 5: Mean cumulative contribution of each disc and vertebral body to the L1-S1 lordosis for each sacralization group. Green: No-LSTV, Orange: Low-grade, Red: High-grade.



Sacralization	n	%
1a	10	20
1b	3	6
2a	6	12
2b	4	8
3a	7	14
3b	20	40
4	0	0
Total low-grade	23	46
Total high-grade	27	54
Total	50	100

Table 1: Distribution of Castellvi's grades among sacralization subjects.

	No-LSTV	Low-grade	High-grade	*p-value*
Demographics				
Age (years)	37.4 ± 16.1	35.7 ± 15.6	38.3 ± 17.3	*0.96*
BMI ($Kg.m^{-2}$)	24.6 ± 4.5	23.3 ± 3.8	24.0 ± 4.7	*0.37*
Sex (females)	50.9%	39.1 %	59.3%	*0.36*
Pelvic parameters				
PI	49.3 ± 9.5	59.9 ± 7.7	70.2 ± 11.7	*<0.001**
PI_L5	20.7 ± 8.2	29.7 ± 9.2	46.1 ± 14.8	*<0.001**
PT	11.2 ± 6.7	15.1 ± 7.6	22.7 ± 7.7	*<0.001**
PT_L5	4.8 ± 5.6	5.4 ± 6.5	8.9 ± 7.1	*0.03**
SS	38.1 ± 8.0	44.8 ± 7.1	47.4 ± 7.7	*<0.001**
SS_L5	15.9 ± 7.8	24.3 ± 9.1	37.2 ± 10.9	*<0.001**
Lumbar lordosis parameters				
LL max (°)	-59.7 ± 11.0	-63.9 ± 10.3	-68.5 ± 10.6	*<0.001**
L1-S1 (°)	-57.0 ± 11.2	-62.8 ± 10.6	-64.8 ± 10.6	*<0.001**
T12-L5 (°)	-34.3 ± 11.2	-42.4 ± 12.5	-60.3 ± 8.8	*<0.001**
L1-L4 (°)	-20.4 ± 8.4	-25.9 ± 8.4	-33.2 ± 6.5	*<0.001**
L4-S1 (°)	-36.6 ± 7.1	-36.8 ± 6.8	-31.7 ± 7.1	*0.008**

Table 2: Demographics, pelvic parameters, and lumbar lordosis parameters in the three groups of sacralization grade. Significant p-values are denoted with an asterisk.

	No LSTV	Low grade	High grade	*p-value*
Thoracic kyphosis				
T1-L1	50.9 ± 10.8	49.3 ± 12.7	52.7 ± 8.5	*0.49*
T1-T5	19.6 ± 8.0	17.6 ± 6.2	22.9 ± 7.6	*0.04**
T5-T9	23.5 ± 7.1	24.8 ± 7.4	26.0 ± 4.8	*0.04**
T9-L1	7.9 ± 7.5	6.9 ± 7.1	3.9 ± 7.0	*0.03**
Alignment				
PI-LL	-7.7 ± 9.6	-2.9 ± 9.5	5.3 ± 9.4	*<0.001**
PI-LL_L5	-13.6 ± 9.3	-12.7 ± 9.2	-13.8 ± 14.1	*0.52*
T1SPi	-5.7 ± 2.4	-5.0 ± 2.8	-5.5 ± 2.1	*0.36*
SVA	-13.5 ± 23.6	-1.1 ± 27.2	8.5 ± 19.3	*<0.001**
SVA_L5	-20.4 ± 23.7	-12.6 ± 25.0	-12.6 ± 18.3	*0.06*
TPA	5.5 ± 6.5	10.1 ± 7.2	17.3 ± 7.0	*<0.001**
TPA_L5	-0.9 ± 5.4	0.4 ± 5.8	3.4 ± 6.3	*0.004**
SSA	131.4 ± 8.7	136.3 ± 7.4	137.5 ± 8.3	*<0.001**
SSA_L5	110.6 ± 8.7	118.0 ± 8.9	130.5 ± 10.9	*<0.001**

Table 3: Thoracic kyphosis and global alignment parameters in the three groups of sacralization grade. Significant p-values are reported with an asterisk.

MATCHING	**No LSTV**	**Low-grade**	***p-value***	**No-LSTV**	**High-grade**	***p-value***
Demographics						
n	23	23	-	26	26	-
Age	43.3 ± 17.0	35.7 ± 15.6	*0.09*	40.4 ± 14.6	37.4 ± 17.2	*0.49*
BMI	29.0 ± 9.7	23.3 ± 3.8	*0.02**	24.3 ± 4.0	24.0 ± 4.8	*0.74*
Females	44%	39.10%	*1*	62%	57.70%	*1*
Spinopelvic parameters						
PI	59.9 ± 7.7	59.9 ± 7.7	-	68.2 ± 9.2	69.7 ± 11.7	-
PI_L5	28.1 ± 8.0	29.7 ± 9.2	*0.63*	32.8 ± 9.4	46.1 ± 15.1	*<0.001**
SS	42.8 ± 7.6	44.8 ± 7.1	*0.54*	49.5 ± 9.0	47.2 ± 7.8	*0.46*
PI-LL	-1.2 ± 10.8	-2.9 ± 9.5	*0.24*	-1.4 ± 11.0	5.4 ± 9.6	*0.04**
PI-LL_L5	-10.5 ± 11.6	-12.7 ± 9.2	*0.41*	-12.2 ± 11.2	-13.9 ± 13.4	*0.96*
SVA	-5.9 ± 18.9	-1.1 ± 27.2	*0.66*	-9.6 ± 23.1	10.0 ± 17.9	*<0.001**
TPA	10.9 ± 6.3	10.1 ± 7.2	*0.49*	12.3 ± 5.7	17.2 ± 7.2	*0.03**
T1SPi	-6.1 ± 2.3	-5.0 ± 2.8	*0.23*	-6.3 ± 2.6	-5.3 ± 1.9	*1*
SSA	135.1 ± 7.8	136.3 ± 7.4	*0.81*	141.9 ± 10.3	137.1 ± 8.1	*0.08*
LL max	-62.9 ± 11.8	-63.9 ± 10.3	*0.91*	-70.8 ± 13.5	-68.2 ± 10.6	*0.53*
LL prox	-24.5 ± 7.8	-23.5 ± 6.8	*0.97*	-26.4 ± 7.0	-23.8 ± 6.6	*0.19*
LL dist	-38.3 ± 8.1	-40.4 ± 8.6	*0.55*	-44.4 ± 11.1	-44.5 ± 10.9	*0.86*
L1-S1	-61.1 ± 11.9	-62.8 ± 10.6	*0.72*	-69.6 ± 14.3	-64.3 ± 10.5	*0.21*
L1-L4	-23.2 ± 8.7	-25.9 ± 8.4	*0.42*	-27.6 ± 9.5	-33.1 ± 6.6	*0.02**
L4-S1	-37.9 ± 6.6	-36.8 ± 6.6	*0.4*	-42.0 ± 10.1	-31.2 ± 6.8	*<0.001**
T1-L1	50.1 ± 11.1	49.3 ± 12.7	*0.56*	49.2 ± 12.3	52.5 ± 8.6	*0.29*
T1-T5	20.2 ± 10.8	17.6 ± 6.2	*0.6*	17.6 ± 8.5	22.6 ± 7.6	*0.03**
T5-T9	23.7 ± 9.5	24.8 ± 7.4	*0.21*	24.2 ± 6.6	26.1 ± 4.8	*0.32*
T9-L1	6.2 ± 6.2	6.9 ± 7.1	*0.97*	7.3 ± 7.9	3.8 ± 7.1	*0.22*
CL	-8.1 ± 12.6	-8.4 ± 13.1	*0.53*	-2.5 ± 11.1	-10.3 ± 11.7	*0.03**
Lumbar apex						
L1	0.0%	0.0%		0.0%	0.0%	
L2	0.0%	0.0%		0.0%	7.7%	
L3	8.7%	26.1%	*0.27*	19.2%	65.4%	*0.001**
L4	82.6%	69.6%		76.9%	26.9%	
L5	8.7%	4.4%		3.9%	0.0%	

Table 4: Description of spinopelvic parameters and lumbar apex location after matching PI of No-LSTV with Low-grade and High-grade sacralization subjects, respectively. Significant p-values from Wilcoxon tests are denoted with an asterisk. *CL = cervical lordosis.*

	No LSTV		High-grade	*p-value*
PI	49.3 ± 9.5	**PI_L5**	46.1 ± 14.8	*0.32*
PT	11.2 ± 6.7	**PT_L5**	8.9 ± 7.1	*0.12*
SS	38.1 ± 8.0	**SS_L5**	37.2 ± 10.9	*<0.001**
L1-S1	-57.0 ± 11.2	**T12-L5**	-60.3 ± 8.8	*0.13*
L4-S1	-36.6 ± 7.1	**L3-L5**	-41.4 ± 6.4	*<0.001**
L1-L4	-20.4 ± 8.4	**T12-L3**	-18.9 ± 8.1	*0.36*
TPA	5.5 ± 6.5	**TPA_L5**	3.4 ± 6.3	*0.11*
SSA	131.4 ± 8.7	**SSA_L5**	130.5 ± 10.9	*0.92*
SVA	-13.5 ± 23.6	**SVA_L5**	-12.6 ± 18.3	*0.62*
PI-LL	-7.7 ± 9.6	**PI-LL_L5**	-13.8 ±14.1	*<0.001**
LL max	-59.7 ± 11.0	**LL max_L5**	-61.5 ± 9.5	*0.15*
LL dist	-35.1 ± 8.4	**LL dist_L5**	-37.4 ± 10.6	*0.27*

Table 5: Comparison of spinopelvic parameters measured on S1 in No-LSTV subjects (*on the left*) and the equivalent parameters measured on L5 in High-grade LSTV subjects (*on the right)*. Significant p-values from Wilcoxon tests are denoted with an asterisk.