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Original Investigation

Spine and Peripheral Nerves

A New Measurement Technique for Lumbosacral Transitional Vertebra and Anatomic Orientation of Sacrum (Perioperative Indicator for Lumbosacral Surgery)

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ABSTRACT

AIM: To evaluate the orientation of the sacrum, its influence on sagittal balance, and its practical relevance in identifying a sacralized L5 or lumbarized S1 as an lumbosacral transitional vertebrae (LSTV) to help prevent complications.

MATERIAL and METHODS: Lumbosacral vertebral roentgenograms from 633 outpatients who visited our hospital between June 2018 and August 2018 were retrospectively reviewed.

RESULTS: All participants were young males with a mean age of 18.41 years (range 17-21 years). The mean ATA1 distance was 16.84 mm ± 6.28 in the 527 normal cases, 4.21 mm ± 5.32 in the 71 sacralization cases, and 21.17 mm ± 6.68 in the 35 lumbarization cases The angle distribution among the 527 patients with normal anatomy was 10.58° ± 1.3. In the 71 patients with sacralization, the angle was 8.89° ± 1.13. Among the 35 patients with lumbarization, the angle was 9.86° ± 1.76.

CONCLUSION: A new index formula, comprising the Anterior Translational Arch (ATA1) and Anterior Translational Angle (ATA2) is proposed. ATA1 as a distance measurement and ATA2 as an angular measurement were evaluated. These measurements can be easily obtained using either lumbosacral vertebral radiographs or sagittal MRI, owing to the simplicity of the calculation. This allows an easy identification of lumbarization and sacralization.

KEYWORDS: Transitional vertebra, Sacrum, Lumbosacral, Spine, Distance

ABBREVIATIONS: ATA1: Anterior translational arch (distance), **ATA2:** Anterior translational angle, **L5:** Fifth lumbar vertebra, **S1:** First sacral vertebra, **C2:** Second cervical vertebra, **S5:** Fifth sacral vertebra, **LSTV:** Lumbosacral transitional vertebrae, **ROC:** Receiver operating characteristic, **MRI:** Magnetic resonance imaging

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INTRODUCTION

The configuration of the lower lumbar vertebrae and sacrum, along with pelvic orientation and lumbosacral parameters, constitutes the foundation of the vertebral column and play a crucial role in neurosurgical procedures involving this region (14).

The anatomical orientation of the L5 vertebra and the first sacral segment (S1) is primarily influenced by the intervertebral disc and facet joints (13). The structural features of the L5 vertebra and the sacral dome may also contribute to this alignment to some degree. The sacrum is anatomically complex; it is a pyramidal bone formed by the fusion of five sacral vertebrae (17), and it consists of five distinct surfaces: a midline dorsal canal, four ventral sacral foramina, and four dorsal sacral foramina (10). Longitudinally, the sacrum exhibits a curvature with a concave ventral (pelvic) surface and a convex dorsal surface.

The term "lumbosacral transitional vertebrae" (LSTV) refers to a vertebra that is either a "sacralized L5" or a "lumbarized S1." We hypothesized that lumbarization results in the sacral concave surface acquiring a convex contour and that the preoperative identification of the anatomical orientation in this region is of increased importance. This mainly radiological and anatomical study aimed to determine the orientation of the S1 vertebral body in the context of sagittal balance assessment and to explore its practical application in identifying sacralized or lumbarized S1 segments as LSTV, to prevent surgical complications.

MATERIAL and METHODS

Subjects

All participants in the study were healthy individuals undergoing medical evaluation as pilot candidates to obtain the required certification for eligibility. Lumbosacral vertebral roentgenograms from 633 outpatients who visited our hospital between June 2018 and August 2018 were retrospectively reviewed by two senior surgeons, each blinded to the other's assessments. These radiographic images were compared with sacral vertebrae classified as anatomically normal, sacralized, or lumbarized. Patients presenting with low back pain, radiculopathy, or both were excluded from the study.

Ethical approval for this study was granted by the Ethics Committee of the University of Health Sciences Türkiye, Diskapi Yildirim Beyazit Training and Research Hospital (March 08, 2021- Approval code: 106/07). Consent was not required because this study involved no human subject.

Imaging Methods

Lumbosacral vertebral roentgenograms were obtained from all subjects. The lumbosacral region was imaged in the "supine" position for both anteroposterior and neutral lateral radiographic views. The L5 and S1 vertebrae were identified by a radiologist. For lateral imaging, the patient was positioned on the table in a lateral decubitus position, with the vertebral column centered on the table. Radiolucent pillows were used, if necessary, to ensure that the vertebral column remained parallel to the table surface. In the digital X-ray system, the central portion of the detector was positioned 6 cm above the iliac crest. The patient's arms were extended forward and placed on either side of the head. Gonadal shielding was applied for male patients. The distance between the X-ray tube and the film was maintained at 100 cm.

Initially, all cases were categorized into three groups by radiologists: a normal group (control), a sacralization group (study group 1), and a lumbarization group (study group 2), based on the type of sacral transition present.

We aimed to propose a new index formula to assist in identifying sacralization or lumbarization. To achieve this, we devised a simple calculation by measuring angles and distances between lines drawn in accordance with sacral anatomy, in order to assess differences between sacralized and lumbarized vertebrae.

Measurement Methods

Anteroposterior and lateral radiographs of the entire spine were obtained from all participants using the standard techniques previously described. All radiographs were interpreted by a single radiologist with 18 years of experience in conventional radiography. Radiographic assessments and morphometric measurements were carried out using a picture archiving and communication system (Extreme PACS, Ankara, Turkey). The initial radiographic evaluation focused on vertebral identification and numbering. The total number of vertebrae was determined by summing the cervical, thoracic, and lumbar segments located above the sacrum. The first seven vertebrae were identified as cervical vertebrae, those bearing ribs directly beneath them were classified as thoracic vertebrae, and the vertebrae without ribs below those were classified as lumbar vertebrae. The first non-rib-bearing vertebra was designated as L1. A fifth lumbar vertebra that displayed characteristics of the adjacent sacral segment was classified as sacralized, whereas a first sacral vertebra showing characteristics of the adjacent lumbar segment was classified as lumbarized. The total vertebral count was documented. Using the lateral projections as the reference standard, we measured the "Anterior Translational Arch (ATA1)" as a distance and the "Anterior Translational Angle (ATA2)" as an angular value.

Measurement method for ATA1

The method for measuring the distance in millimeter (mm) referred to as ATA1 is illustrated in Figure 1. ATA1 represents the distance between the midpoint of the line connecting the anterior margins of the superior end of the first sacral vertebra and the inferior end of the last sacral vertebra (blue line) and the anterior surface of the sacral slope (yellow line) (Figure 1A).

Measurement method for ATA2

The method for measuring the angle in degree (°) (ATA2) is shown in Figure 1A. A transverse line was drawn through the superior endplate of the first sacral vertebra (S1) to identify the midpoint of its anteroposterior dimension (red line). A second line was then drawn from this midpoint to the anterior margin of the inferior end of the last sacral vertebra (green line). The ATA2 angle was defined as the angle formed between the line connecting the anterior margins of the superior end of the first and the inferior end of the last sacral vertebrae (blue line) and the green line was termed as the ATA2 angle (Figure 1B).

Statistical Analysis

All statistical analyses were performed using SPSS version 22 (IBM Corp., Armonk, NY, USA) and Jamovi version 2.6.22. The Shapiro-Wilk test was employed to assess the normality of data distributions. Group differences were analyzed using the Kruskal-Wallis H test. In cases where the overall test was statistically significant, post hoc pairwise comparisons were conducted using the Dwass-Steel-Critchlow-Fligner method to identify specific group differences. Logistic regression analysis was used to evaluate the association between vertebral variation types (sacralization and lumbarization) and radiographic measurements (ATA1 and ATA2). Since the study cohort consisted exclusively of asymptomatic male patients aged 17-21 years, the models did not include additional covariates such as age or anthropometric variables, to avoid over-adjustment in a demographically homogeneous sample.

When compared with individuals without anatomical variations, the distance value was found to be a statistically significant risk factor in patients with lumbarization or sacralization. In individuals with sacralization, distance values significantly decreased compared to those with normal vertebral anatomy (OR = 0.74; 95% CI: 0.69-0.78), whereas in lumbarization cases, distance values significantly increased (OR = 1.13; 95% CI: 1.06-1.19). ROC analysis was used to identify the optimal cutoff value for the distance measurement based on the x-axis (1-specificity) or y-axis (sensitivity) in relation to the presence of lumbarization or sacralization. A similar ROC analysis was also performed for the "angle measurement" to determine the appropriate cutoff value.

RESULTS

All participants were young males with a mean age of 18.41 years (range 17-21 years) (Table I). None of the subjects were older than 21 years, and none reported back pain, radiculopathy, or both. A total of 527 cases were identified as anatomically normal sacra. On anteroposterior radiographs, 35 cases were confirmed as lumbarization, indicated by the presence of 6 lumbar vertebrae; on lateral lumbosacral radiographs, these cases showed a convex ventral sacral surface. Additionally, 71 cases were confirmed as sacralization, indicated by 6 sacral vertebrae on anteroposterior views and a concave ventral surface on lateral lumbosacral radiographs. These cases were classified as transitional vertebrae.

The mean ATA1 distance was 16.84 mm ± 6.28 in the 527 normal cases (Figure 2A), 4.21 mm ± 5.32 in the 71 sacralization cases (Figure 3A), and 21.17 mm ± 6.68 in the 35 lumbarization cases (Figure 4A). The differences among the three groups were statistically significant ($p < 0.05$). Pairwise comparisons also showed statistically significant differences (sacralization < normal; normal < lumbarization; sacralization < lumbarization; $p < 0.05$) (Table II).

The angle distribution among the 527 patients with normal anatomy was 10.58° ± 1.3 (Figure 2B). In the 71 patients with

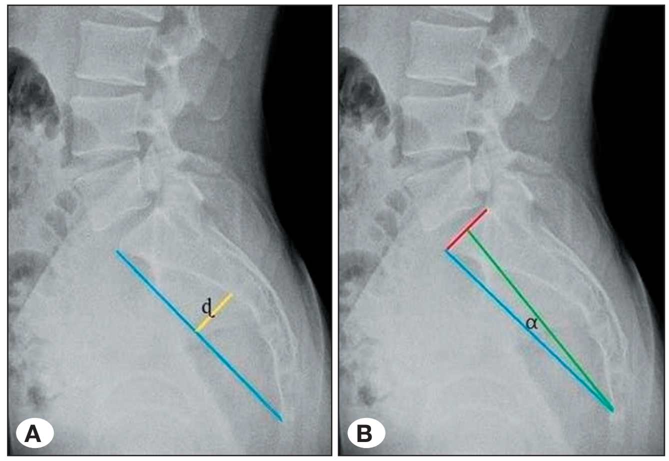

Figure 1: Lateral lumbosacral radiograph demonstrating the measurement methods of "ATA1" distance (d) in "mm" **(A)** and "ATA2" angle (α) in "degree °" **(B)**.

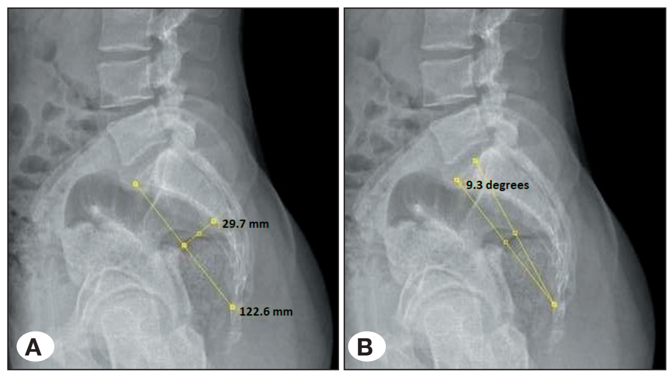

Figure 2: Lateral lumbosacral radiograph of a 20-year-old man with normal alignment of the lumbosacral segments. The measurement of the ATA1 and ATA2 are shown in **(A)** and **(B)**, respectively.

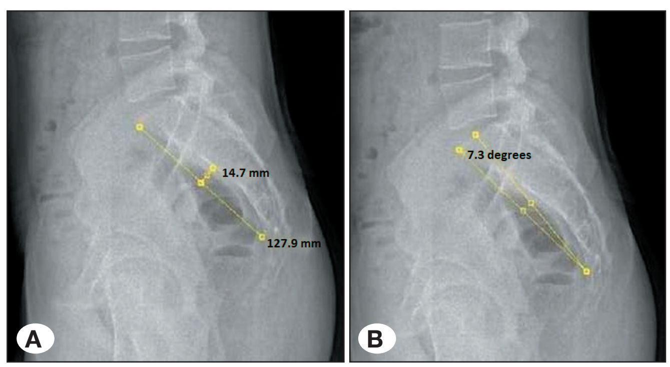

Figure 3: Lateral lumbosacral radiograph of a 20-year-old man with sacralization. The measurement of the ATA1 and ATA2 are shown in **(A)** and **(B)**, respectively.

sacralization, the angle was 8.89° ± 1.13 (Figure 3B). Among the 35 patients with lumbarization, the angle was 9.86° ± 1.76 (Figure 4B). The difference among the three groups was statistically significant ($p < 0.05$). Pairwise comparisons also showed statistically significant differences (sacralization < lumbarization; sacralization < normal; lumbarization < normal; $p < 0.05$) (Table III).

Angle measurements in sacralization cases were significantly lower than in the normal vertebral anatomy group (OR = 0.28; 95% CI: 0.21-0.38), corresponding to an approximately 72% reduction. In lumbarization cases, angle values were also reduced (OR = 0.64; 95% CI: 0.48-0.84), indicating a 36% decrease compared to the normal group. Distance values showed differential patterns: in sacralization, distance decreased (OR = 0.74; 95% CI: 0.69-0.78), reflecting a 26% reduction, whereas in lumbarization, distance increased (OR = 1.13; 95% CI: 1.06-1.19), corresponding to a 13% increase. These results suggest that both distance and angle values are significant predictors of anatomical variation (Table IV).

Table I: The Mean Age of the Cases was 18.41 Years

	Patients' age	
Vertebrae	**Mean (years)**	**Range (years)**
Normal (n=527)	18.46	17-21
Sacralization (n=71)	18.53	17-20
Lumbarization (n=35)	18.25	18-19

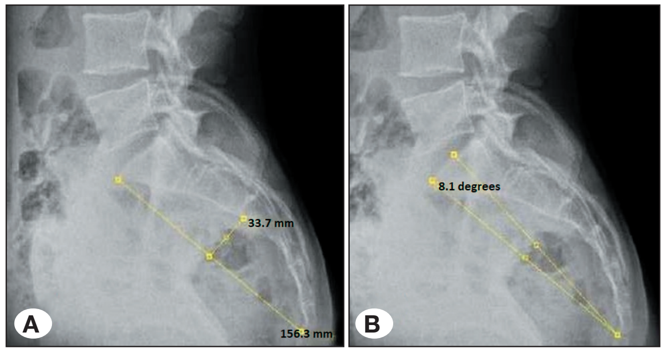

Figure 4: Lateral lumbosacral radiograph of a 19-year-old man with lumbarization. The measure-ment of the ATA1 and ATA2 are shown in **(A)** and **(B)**, respectively.

Table II: The Properties of 633 Cases of Distance Value

	Vertebrae							
ATA1	**Normal [1] (n=527)**		**Sacralization [2] (n=71)**		**Lumbarization [3] (n=35)**		**Total (n=633)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Distance (mm)	16.84	6.28	4.21	5.32	21.17	6.68	15.66	7.48
p-value (general)	0.0001* ($p_{1\&2}$<0.001**; $p_{1\&3}$<0.001**; $p_{2\&3}$<0.001**;							

*ATA1: Anterior Translational Arch, SD: standard deviation, *Kruskal Wallis H Test, ** Dwass-Steel-Critchlow-Fligner*

Table III: The Properties 633 Patients with Angle Values

	Vertebrae							
ATA2	**Normal [1] (n=527)**		**Sacralization [2] (n=71)**		**Lumbarization [3] (n=35)**		**Total (n=633)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Angle (°)	10.58	1.30	8.89	1.13	9.86	1.76	10.35	1.42
p-value (general)	0.0001* ($p_{1\&2}$<0.001**; $p_{1\&3}$<0.03**; $p_{2\&3}$<0.01**;							

*ATA2: Anterior Translational Angle, SD: standard deviation Kruskal Wallis H Test, ** Dwass-Steel-Critchlow-Fligner*

Table IV: Association of Sacralization/Lumbarization with Distance and Angle

					95% Confidence Interval	
Predictor	**Estimate**	**SE**	**p-value**	**Odds ratio**	**Lower**	**Upper**
Distance[1]	-0.30	0.029	**<0.001**	0.74	0.69	0.78
Distance[2]	0.12	0.031	**<0.001**	1.13	1.06	1.19
Angle[1]	-1.27	0.15	**<0.001**	0.28	0.21	0.38
Angle[2]	-0.45	0.15	**0.002**	0.64	0.48	0.84

SE: Standard Error, Estimates represent the log odds of comparison: 1 = Sacralization vs. Normal, 2 = Lumbarization vs. Normal.

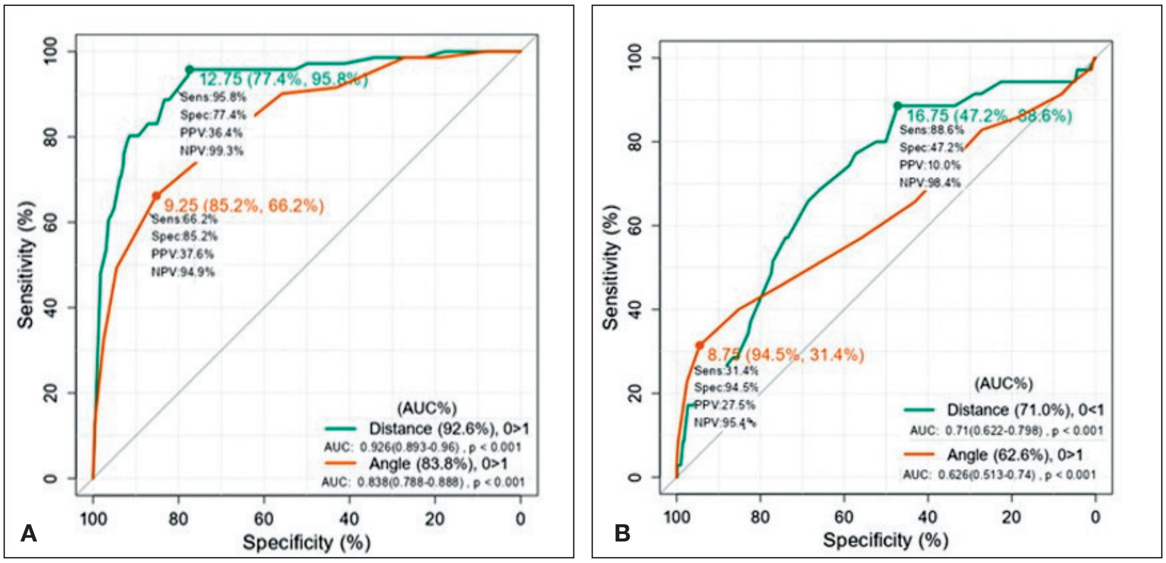

Figure 5: ROC Curves: **A)** sacralization vs. normal; **B)** lumbarization vs. normal.

ROC analysis revealed that distance values had a higher diagnostic accuracy than angle measurements for detecting sacralization (AUC = 0.926) and lumbarization (AUC = 0.710). The optimal cut-off point for distance in sacralization cases was 12.75 mm, with a sensitivity of 95.8% and specificity of 77.4%, while for lumbarization cases, the cut-off was 16.75 mm with moderate sensitivity (47.2%) and high specificity (88.5%) (Figure 5).

DISCUSSION

The sacrum is an anatomically complex and variable structure. Its ventral surface is concave in both vertical and horizontal planes and is smoother compared to the dorsal surface. The first sacral vertebral body is the largest and is most commonly utilized for dorsal or iliosacral screw fixation. A thorough understanding of sacral anatomy is essential for proper lumbosacral orientation and the management of spinal disorders. LSTV are relatively rare in the general population, though in some instances, the condition may be inherited. The relationship between low back pain and the presence of LSTV was initially described by Bertolotti in 1917, and the condition is sometimes termed "Bertolotti's syndrome" (12). This association was later questioned by Elster (4). Nevertheless, subsequent studies have reported a higher-than-expected prevalence of LSTV among patients undergoing imaging for back pain or surgery for a herniated disc (5).

The most reliable method for identifying an LSTV is through lumbosacral radiographs with vertebral counting beginning at the T12 level. However, in cases where MRI is performed without accompanying plain radiographs, careful attention must be paid to the presence of LSTV, and additional knowledge and techniques may be required for accurate identification (6). Correct spinal segmentation is crucial to avoid surgical errors, as the majority of such mistakes have been associated with patients presenting with segmental anomalies, including LSTVs (15). Accurately identifying vertebral levels is essential to localize the pathology precisely and to prevent level-related errors. Lian et al. proposed that whole-spine imaging with caudal counting from C2 represents the gold standard (8). Nonetheless, this approach is often impractical. Frequently, lumbar spine MRI is interpreted without access to plain radiographs, either because they were not performed or are unavailable. There remains no consensus on the definition of LSTV (1). Techniques such as counting from C2 downward, from S5 upward, or using anatomical landmarks like the aortic bifurcation, the right renal artery, and the iliolumbar ligament have been described. However, ATA1 and ATA2 measurements, as introduced in our study, have not been previously evaluated.

Identifying LSTV on MRI can be challenging. When LSTV is suspected, it is important to determine whether it represents a "sacralized L5" or "lumbarized S1." Incorrect identification of disc levels may lead to surgery being performed at the wrong site (9). Zhou et al. examined how variations affect the selection of the sacral endplate in LSTV cases and noted that no standardized approach exists for measuring sagittal alignment in these patients (16).

Additionally, MRI findings have demonstrated that the disc space between an LSTV and the sacrum is significantly narrower than that of a normal lumbosacral intervertebral disc space (11). To address abnormalities associated with lumbarization, it is advisable for patients suspected of having sacral anomalies to undergo an anteroposterior sacral view via conventional radiography, as was done in our study.

Castellvi et al. identified LSTV based on the morphology of the transverse processes (2), while Desmond and Buirski used the presence of disc material on T2-weighted MRI for classification (3). O'Driscoll et al. defined sacral morphology by examining whether residual disc material existed between the uppermost sacral segment (S1) and the rest of the sacrum (12). Hughes and Saifuddin recommended obtaining both

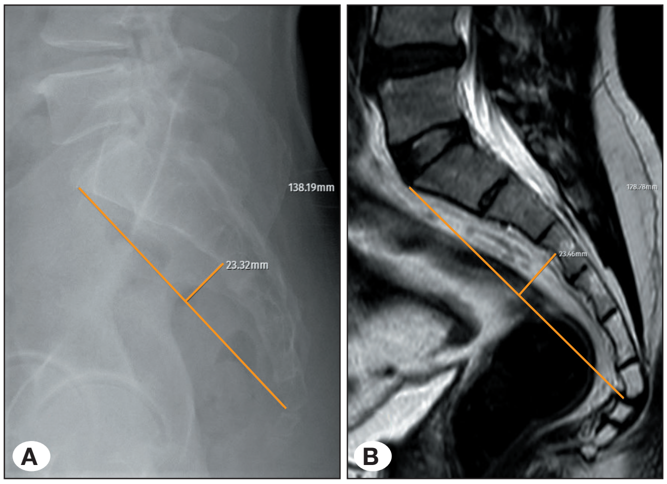

Figure 6: Lateral lumbosacral radiogram **(A)** and T2-weighted magnetic resonance mid-sagittal image of the lumbosacral vertebrae **(B)** of a patient with sacralization. The measurement of the ATA1 on radiograph and magnetic resonance image is shown in **(A)** and **(B)**, respectively.

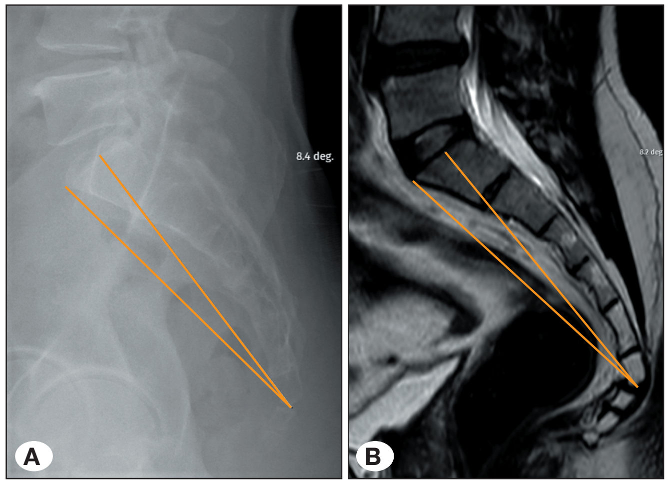

Figure 7: Lateral lumbosacral radiogram **(A)** and T2-weighted magnetic resonance mid-sagittal image of the lumbosacral vertebrae **(B)** of a patient with sacralization. The measurement of the ATA2 on radiograph and magnetic resonance image is shown in **(A)** and **(B)**, respectively.

sagittal MRI and lateral plain radiographs before surgery (7). In the present study, we relied solely on lateral plain radiographs to confirm the presence of LSTV based on observed ventral sacral convexity. While some prefer using sagittal MRI images for straightforward measurements, we believe that X-ray imaging provides clearer visualization of bone structure and definition. However, when we adapted the measurement criteria to MRI, we found that the results were similar to those obtained from plain radiographs (Figure 6,7).

The anatomical reference points used for the new measurement method in this study included the sacral endplate, the midpoint of the anteroposterior dimension of the S1 vertebra, the angle formed by the line connecting the anterior margins of the upper end of the first and the lower end of the last sacral vertebrae, and the anterior longitudinal line of the S1-S5 vertebrae. These landmarks are easily identifiable using fluoroscopy, both before and during surgery. It is proposed that the ATA1 and ATA2 indices could serve as alternatives to conventional reference lines, particularly in situations where identifying the full lateral spine from C2 to S5 is challenging. The clinical reflection of these findings is of great importance in daily practice. Because the effect of providing the general sagittal balance of the spine and restoring lumbar lordosis on surgical outcomes is now accepted by all spine surgeons. Lumbar lordosis is no longer viewed as a static parameter as it once was. Lumbar lordosis is rather a dynamic parameter that can change both the peak and the diameter of the lordosis circle, that is, the characteristic of the lordosis curve, with the number of lumbar vertebrae of the patient, in other words, the presence of lumbarization or sacralization. In addition, the orientation and dome shape of the sacrum are among the parameters that should be taken into consideration in the restoration of lordosis. This condition reveals the importance of considering ATA1 and ATA2 parameters in daily spine surgery practice.

A potential limitation of this method is that image clarity may be compromised in obese patients. The clinical implications of this anatomical and radiologic study are crucial during the preoperative evaluation phase. By design, this is an anatomo-radiologic study proposing practical indicators aimed at preoperative level identification and mitigating wrong-level surgery. Although the study is based on radiologic parameters, it provides a radiologic definition that will minimize potential complications in lumbar surgery. Although there are no direct clinical outcome data, this can be acknowledged briefly as a limitation with a suggestion for future validation studies.

CONCLUSION

The most critical complications when interpreting MRI in patients with LSTV is the possibility of surgery being performed at the wrong spinal level. Furthermore, precise identification and numbering of the thoracolumbar transition vertebrae are essential for the accurate planning of transpedicular stabilization procedures. This underscores the importance of detecting LSTV. In cases where ventral sacral convexity raises suspicion of LSTV, we emphasize the importance of obtaining lateral plain radiographs preoperatively. The ATA1 and ATA2 measurements are simple, practical, and effective tools that may support the development of a clinical consensus. We believe this contribution addresses a critical need in daily surgical practice, particularly given the lack of a widely accepted standard approach. Careful radiological assessment is especially crucial in facilities that do not use neuronavigation and continue to perform stabilization and fusion using the freehand technique, where this method and its measurements may help avoid numerous surgical errors.

A special tribute is due to someone no longer with us: Mustafa Kemal Ataturk, the founder of the Republic of Türkiye—affectionately remembered as "ATA" by the Turkish people—whose vision made it possible for Türkiye to emerge as a modern nation. If scientific endeavors continue in this country today, it is thanks to the foundation he laid.

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Declarations

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Availability of data and materials: The datasets generated and/or analyzed during the current study are available from the corresponding author by reasonable request.

Disclosure: The authors declare no competing interests.

AUTHORSHIP CONTRIBUTION

Study conception and design: CA, AG
Data collection: AG, AE
Analysis and interpretation of results: MO, AMS
Draft manuscript preparation: CA
Critical revision of the article: UE
Other (study supervision, fundings, materials, etc...): n/a
All authors (CA, AG, AE, MO, AMS, UE) reviewed the results and approved the final version of the manuscript.

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