



IMPACT OF SACRAL MORPHOLOGICAL PARAMETERS ON L4-5 AND L5-S1 INTERVERTEBRAL DISC DEGENERATION: THE ROLE OF SACRAL TABLE ANGLE

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ABSTRACT

Objective: This study aims to investigate the correlation between sacral morphological parameters and degeneration of the L4-5 and L5-S1 discs, with particular emphasis on STA and SI.

Materials and Methods: This retrospective cohort study includes patients who were admitted with back pain and/or radicular pain. Degeneration at L4-5 and L5-S1 was evaluated using Pfirrmann grading on lumbar magnetic resonance imaging. Pfirrmann grades 1-2 were considered non-degenerative, while Pfirrmann grades 3-5 were considered degenerative. Pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), LL distribution index (LLDI), sacral inclination (SI), and sacral table angle (STA) were measured from standing lumbosacral X-rays.

Results: Ninety consecutive patients were included and the mean age was 47.42±9.84. Fifty-four patients were female and 36 were male. Disc degeneration was observed at L4-5 in 44 patients (48.9%) and at L5-S1 in 47 patients (52.2%). Degeneration at both disc levels was observed in 38 patients. PI, PT, and SS were significantly higher, whereas LLDI, SI, and STA were significantly lower in patients with two-level disc degeneration. There was no statistically significant difference in LL between the degenerative and non-degenerative groups. SI was negatively correlated with Pfirrmann grades in both L4-5 and L5-S1. STA showed a stronger negative correlation with Pfirrmann grades at both levels. The intensity of degeneration was inversely correlated with STA. The mean STA values were 105.09±3.09° in no degeneration, 100.01±4.00° in single-level degeneration and 95.85±4.17° in two-level degeneration groups.

Conclusion: Sacral morphology shows significant association with lower lumbar disc degeneration. A lower STA value is associated with increased disc degeneration at the L4-L5 and L5-S1 levels. STA may be a morphological parameter reflecting the biomechanical environment of the lumbosacral junction.

Keywords: Lumbar disc degeneration, sacral table angle, sacral inclination, lumbar lordosis, sacral morphology

INTRODUCTION

The complex interactions between spinal curvatures and pelvis are crucial in determining the sagittal alignment of the spine. The concept of “pelvic vertebra” as proposed by Dubousset et al.⁽¹⁾ led to a novel viewpoint for the determination of sagittal profile. Pelvic incidence (PI) is a fixed anatomical parameter that dictates the amount and distribution of lumbar lordosis (LL) necessary for maintaining balanced posture⁽²⁻⁵⁾. It facilitates the determination of the relative position of the sacral plate in relation to the femoral heads⁽⁶⁾. PI is a fundamental measure in surgical planning, especially when predicting the optimal LL. However, very little is known for the components and contributors of PI, which may be related to the variations in sacropelvic anatomy⁽⁷⁾. In addition to PI, the

specific characteristics of sacral morphology are increasingly recognized as important factors influencing biomechanical loading at the lumbosacral junction^(4,5,8).

Several authors proposed different parameters that described the sacral geometry. The sacral slope (SS) and sacral inclination (SI) are positional parameters that may be influenced by postural alterations, and the PI and sacral table angle (STA) are fixed bony anatomical parameters⁽⁸⁾. The STA indicates the orientation of the superior sacral endplate and has been linked to stress related conditions such as spondylolysis and spondylolisthesis⁽⁹⁾. Despite the rising interest in this area, the role of STA in lumbar disc degeneration remains largely unexplored. This study investigates the relationship between the sacral morphological parameters and their impact on the disc degeneration in the lower lumbar segments.

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MATERIALS AND METHODS

Study Design and Patient Population

This retrospective observational study included patients that admitted with a low back pain with/without radicular pain. Patients with previous lumbar surgery, spinal trauma, congenital vertebral anomalies, spinal infection, inflammatory spondyloarthropathy, history of spinal trauma and/or fracture, neoplastic disease, scoliosis exceeding 10°, severe spinal stenosis, high-grade spondylolisthesis, lumbosacral transitional anomaly or inadequate radiographic quality were excluded to minimize potential confounding factors affecting spinopelvic alignment. Only examinations with complete radiologic datasets were included in the final analysis. Following application of the eligibility criteria, 90 patients were enrolled for statistical evaluation. Informed consent was obtained from patients and that the ethical approval for this study was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital Ethical Committee (approval no: 318, date: 23.10.2025).

Radiographic Assessment

In all patients, lumbar magnetic resonance imaging (MRI) was obtained to evaluate the disc degeneration and to determine if there was a disc herniation. Lumbar MRI examinations were independently reviewed to determine the degree of intervertebral disc degeneration at the L4-L5 and L5-S1 levels. Degeneration severity was classified according to the Pfirrmann grading system, a validated MRI-based classification based on disc signal intensity, nucleus-annulus distinction, disc structure, and disc height. Pfirrmann grading included 5 stages of disc degeneration. In this study, the non-degenerated disc composed of Pfirrmann grades 1 and 2, and the degenerated disc category included grades 3, 4 and 5.

In all patients, standing anteroposterior and lateral X-rays along with flexion extension images were obtained. Plain X-rays were used for evaluating the standing sagittal and coronal balance, and spinal instability. Standardized standing lateral lumbosacral radiographs were obtained with patients assuming a comfortable upright posture while maintaining horizontal gaze and full knee extension. All radiographic measurements were performed using a digital picture archiving and communication system by investigators experienced in spinal radiographic assessment.

The following spinopelvic and sacral morphological parameters were recorded:

PI: It is the angle between a line perpendicular to the midpoint of the S1 upper endplate and a line connecting it to the center of the femoral heads.

Pelvic tilt (PT): It is the angle between a vertical line that transects the center of the femoral heads and a line between the center of the femoral heads to the midpoint of S1 upper endplate.

SS: It is the angle between a horizontal line and a line parallel to the S1 upper endplate.

LL: It is the angle between the upper end plate of L1 vertebra and the upper end plate of S1 vertebra.

LL distribution index (LLDI): It is measured via (L4-S1 lordosis/ L1-S1 lordosis) 100.

SI: It is the angle between a vertical line and a line that is parallel to the posterior aspect of the S1 vertebra.

STA: It is the angle between a line that is parallel to the superior end plate of S1 vertebra and a line along the posterior aspect of S1 vertebra. Lower STA values indicate a more horizontally oriented sacral endplate, potentially increasing anterior shear forces at the lumbosacral junction. STA is equal to SI+90-SS (Figure 1).

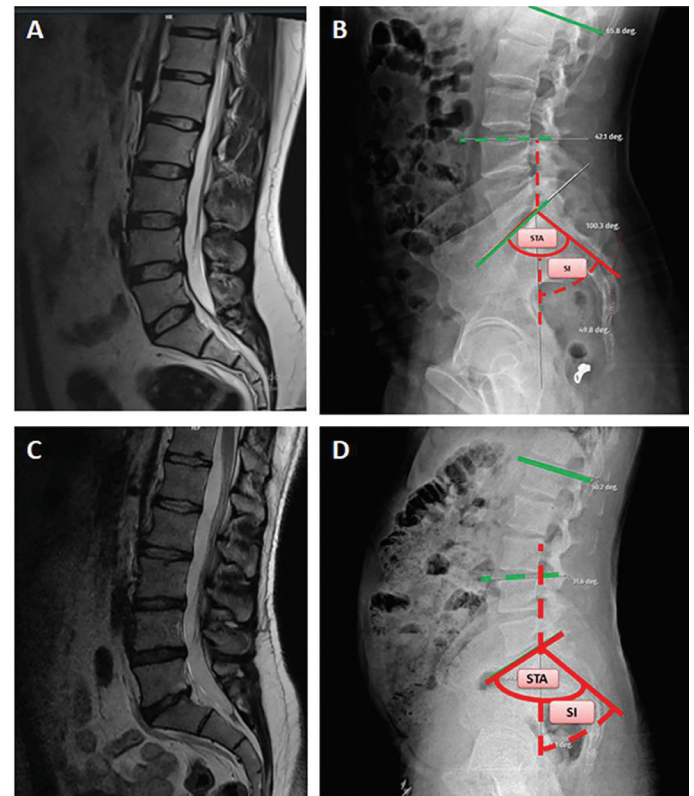


Figure 1. Representative radiological comparison of patients with and without lower lumbar disc degeneration. (A) Sagittal T2-weighted lumbar magnetic resonance imaging (MRI) of a patient with Pfirrmann grade 1 discs at both L4-L5 and L5-S1. (B) Standing lateral lumbar radiograph of the same patient demonstrating the measurements of total lumbar lordosis, distal lumbar lordosis, sacral table angle (STA), and sacral inclination (SI). (C) Sagittal T2-weighted lumbar MRI of a patient with Pfirrmann grade 3 degeneration at L4-L5 and grade 4 degeneration at L5-S1. (D) Standing lateral lumbar radiograph of the same patient demonstrating lower STA and SI values and a less favorable distribution of lumbar lordosis compared with the patient without disc degeneration. The green lines indicate the reference endplates used for lumbar lordosis measurements, whereas the red lines indicate the reference lines used for STA and SI measurements

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows (IBM Corp., Armonk, NY, USA). Continuous variables were presented as mean $\pm$ standard deviation, and categorical variables as frequencies and percentages. Normality was assessed using the Shapiro-Wilk test. Pfirrmann grades 1-2 were defined as non-degenerated and grades 3-5 as degenerated. Comparisons between degenerated and non-degenerated groups at each disc level were performed using the independent samples t-test or Mann-Whitney U test, as appropriate. Categorical variables were analyzed using the chi-square test or Fisher's exact test. Correlations between radiographic parameters and Pfirrmann grades were evaluated using Pearson or Spearman correlation analysis, as appropriate. For degeneration burden analysis, patients were classified as having no degeneration, single-level degeneration, or two-level degeneration, and groups were compared using one-way analysis of variance or Kruskal-Wallis test. A two-tailed p-value <0.05 was considered statistically significant.

RESULTS

A total of 90 patients met the study criteria and were included in the analysis. The cohort consisted of 54 women (60.0%) and 36 men (40.0%), with a mean age of 47.42 ± 9.84 years. Disc degeneration was observed only at L4-L5 in 6 (6.7%), only at L5-S1 in 9 (10%) and both L4-L5 and L5-S1 in 38 (42.2%) patients. In 37 (41.1%) patients, both disc levels were evaluated as non-degenerative (Table 1).

Comparisons of spinopelvic parameters according to L4-L5 and L5-S1 degeneration status are presented in Tables 2 and

Table 1. Distribution of lower lumbar disc degeneration patterns

Degeneration pattern	Number of patients	Percent
No degeneration	37	41.1%
L4-L5 degeneration only	6	6.7%
L5-S1 degeneration only	9	10.0%
Two-levels degeneration	38	42.2%

3, respectively. SI showed strong negative correlation with PT ($r=-0.656$, $p<0.001$) and positive correlation with SS ($r=0.297$, $p=0.005$) and LLDI ($r=0.332$, $p=0.001$). SI was also negatively correlated with Pfirrmann grades in both L4-L5 ($r=-0.487$, $p<0.001$) and L5-S1 levels ($r=-0.505$, $p<0.001$). These findings indicate that lower SI values were associated with greater degeneration severity at both lower lumbar levels. The correlation of SI with PI and LL were statistically insignificant ($p=0.134$ and $p=0.090$, respectively).

In contrast with SI, STA showed a very strong negative correlation with PI ($r=-0.844$, $p<0.001$). It was negatively correlated with PT ($r=-0.641$, $p<0.001$) and SS ($r=-0.634$, $p<0.001$). There was a positive correlation between LLDI and STA ($r=0.606$, $p<0.001$). Similar to SI, STA showed a strong correlation with L4-5 ($r=-0.771$, $p<0.001$) and L5-S1 ($r=-0.791$, $p<0.001$) Pfirrmann grade. These results suggest that lower STA values were associated with higher Pfirrmann grades at both L4-L5 and L5-S1.

At the L4-L5 level, patients with disc degeneration were significantly older than those without degeneration (49.68 ± 9.49 vs. 45.26 ± 9.79 years, $p=0.032$). The degenerated group had significantly higher PI, PT, and SS values, whereas LLDI, SI, and STA were significantly lower. LL did not differ significantly between the groups ($p=0.279$). At the L5-S1 level, patients with degeneration were also significantly older than those without degeneration (50.72 ± 9.50 vs. 43.81 ± 9.00 years, $p<0.001$). PI, PT, and SS were significantly higher in the degenerated group, while LLDI, SI, and STA were significantly lower. Similar to L4-L5, LL was not significantly different between degenerated and non-degenerated discs ($p=0.244$). In the degeneration pattern analysis, STA showed a stepwise decrease according to the extent of lower lumbar disc degeneration. Mean STA was $105.09 \pm 3.09^\circ$ in patients without degeneration, $101.05 \pm 3.18^\circ$ in isolated L4-L5 degeneration, $99.31 \pm 4.51^\circ$ in isolated L5-S1 degeneration, and $95.85 \pm 4.17^\circ$ in concomitant L4-L5/L5-S1 degeneration (overall $p<0.001$). Although the group means were progressively lower across these categories, the isolated L4-L5 ($n=6$) and isolated L5-S1 ($n=9$) subgroups were small; therefore, these subgroup estimates should be considered exploratory.

To further evaluate the relationship between sacral morphology

Table 2. Comparison of demographic and radiographic parameters according to L4-L5 disc degeneration status

Parameters	Non-degenerative	Degenerative	p-value
Age	45.26 ± 9.79	49.68 ± 9.49	0.032
PI	46.26 ± 5.51	53.67 ± 5.43	<0.001
PT	13.69 ± 3.42	17.97 ± 2.90	<0.001
SS	32.57 ± 4.88	35.70 ± 4.47	0.002
LL	50.43 ± 4.81	49.31 ± 4.98	0.279
LLDI	67.13 ± 3.18	61.82 ± 3.60	<0.001
SI	46.53 ± 4.16	42.26 ± 3.91	<0.001
STA	103.96 ± 4.08	96.56 ± 4.40	<0.001

PI: Pelvic incidence, PT: Pelvic tilt, SS: Sacral slope, LL: Lumbar lordosis, LLDI: Lumbar lordosis distribution index, SI: Sacral inclination, STA: Sacral table angle

and the extent of lower lumbar degeneration, patients were grouped according to degeneration burden as no degeneration, single-level degeneration, and two-level degeneration. Mean STA was progressively lower across these groups: $105.09 \pm 3.09^\circ$ in patients without degeneration, $100.01 \pm 4.00^\circ$ in those with single-level degeneration, and $95.85 \pm 4.17^\circ$ in those with two-level degeneration (overall $p < 0.001$). A similar but less pronounced pattern was observed for SI, with corresponding values of $46.71 \pm 4.02^\circ$, $45.13 \pm 4.20^\circ$, and $41.97 \pm 3.98^\circ$ (overall $p < 0.001$) (Table 4). These overall comparisons indicate an association with degeneration burden but do not establish a temporal or causal sequence.

DISCUSSION

The present study evaluated the relationship between sacral morphological parameters and lower lumbar intervertebral disc degeneration at the L4-L5 and L5-S1 levels. The principal finding of this study was that lower STA values were strongly associated with both the presence and severity of lower lumbar disc degeneration. This relationship was observed at both disc levels and became more evident when degeneration was evaluated according to the number of affected levels. Although SI was also significantly associated with degeneration severity, STA demonstrated a stronger and more consistent relationship with Pfirrmann grade and degeneration burden. The progressively lower group means should not, however, be interpreted as proof of a biological sequence, particularly because the isolated L4-L5 and L5-S1 subgroups were small. Numerous studies have investigated the relationship between spinopelvic parameters and lumbar disc degeneration. Ergün

et al.⁽¹⁰⁾ demonstrated that lumbar disc degeneration and disc herniation were inversely correlated with sacral kyphosis and LL angles, emphasizing the importance of sagittal alignment in the development of degenerative lumbar disease. Similarly, Barrey et al.⁽¹¹⁾ reported that patients with lumbar disc herniation frequently exhibit reduced LL and SS compared with healthy individuals, further supporting the role of sagittal spinopelvic imbalance in lumbar degeneration.

Lumbosacral disc degeneration has been shown to closely parallel alterations in lumbosacral stability. In a series of 126 patients, Ohmori⁽¹²⁾ evaluated disc degeneration and intervertebral disc height and demonstrated that progressive degenerative changes significantly influence lumbosacral stability. Likewise, Iguchi et al.⁽¹³⁾ reported that grade III disc degeneration represents a critical threshold for the development of degenerative L4-L5 spondylolisthesis, highlighting the close relationship between disc degeneration and spinal instability. Changes in spinopelvic morphology have also been associated with degenerative lumbar disorders. Mardare et al.⁽¹⁴⁾ observed decreased PI, SS, and LL, accompanied by increased PT, in patients with lumbar degenerative disc disease. Similarly, Oh and Eun⁽¹⁵⁾ demonstrated a significant association between segmental lumbar disc degeneration and both vertebral slip and the lumbosacral angle. In contrast to these findings, our study demonstrated that total LL did not differ significantly between degenerated and non-degenerated groups at either L4-L5 or L5-S1. This suggests that the presence of lower lumbar degeneration may not necessarily be reflected by a reduction in global LL. In contrast, the LLDI was significantly lower in patients with degeneration at both levels. This finding indicates that the distribution of lordosis, rather than the absolute amount of total lordosis, may be more relevant when evaluating lower lumbar disc degeneration. In other words, patients may preserve a similar total LL while demonstrating an unfavorable redistribution of lordosis across the lower lumbar segments. Yang et al.⁽¹⁶⁾ further emphasized the importance of PI in the pathogenesis of lumbar degeneration by demonstrating a significant relationship between increased PI and degenerative lumbar disease. Consistent with these observations, Wang et al.⁽⁵⁾ reported that both PI and STA contribute to the development of L5-S1 spondylolisthesis, underscoring the biomechanical importance of sacropelvic morphology.

The effect of the STA on lumbar degeneration may extend beyond a simple angular measurement. Variations in STA alter the anatomical orientation of the sacral endplate and consequently modify the distribution of mechanical forces acting across the

Table 3. Comparison of demographic and radiographic parameters according to L5-S1 disc degeneration status

Parameters	Non-degenerative	Degenerative	p-value
Age	43.81±9.00	50.72±9.50	<0.001
PI	45.44±4.67	53.94±5.37	<0.001
PT	13.62±3.25	17.75±3.20	<0.001
SS	31.82±4.32	36.19±4.51	<0.001
LL	50.51±4.68	49.31±5.07	0.244
LLDI	67.25±3.16	62.05±3.68	<0.001
SI	46.35±3.97	42.70±4.38	<0.001
STA	104.53±3.38	96.51±4.40	<0.001

PI: Pelvic incidence, PT: Pelvic tilt, SS: Sacral slope, LL: Lumbar lordosis, LLDI: Lumbar lordosis distribution index, SI: Sacral inclination, STA: Sacral table angle

Table 4. Sacral morphological parameters according to the number of degenerated disc levels

Parameter	No degeneration (n=37)	Single-level degeneration (n=15)	Two-level degeneration (n=38)	p-value
SI	46.71±4.02	45.13±4.20	41.97±3.98	<0.001
STA	105.09±3.09	100.01±4.00	95.85±4.17	<0.001

SI: Sacral inclination, STA: Sacral table angle

lumbosacral junction. A lower STA alters the orientation of the sacral endplate and may increase anterior shear forces relative to compressive forces at the lumbosacral junction. Repetitive shear loading may increase stress on the disc and adjacent supporting structures, accelerating degeneration at L5-S1 and, through altered load distribution, at L4-L5. This mechanism may explain the association of lower STA with lower LLDI and multilevel degeneration despite similar total LL. However, this biomechanical explanation remains hypothetical and was not directly evaluated in this study. Although numerous studies have reported that reduced STA is associated with spondylolysis and spondylolisthesis (5), Tallarico et al.⁽³⁾ did not identify a significant association between STA and these pathological conditions, suggesting that the biomechanical role of STA may be more complex than previously assumed. Further evidence supporting the importance of sacral morphology was provided by Strube et al.⁽¹⁷⁾, who identified STA and pelvic radius as the anatomical parameters most strongly associated with lumbar disc degeneration and spinopelvic morphology. These findings are consistent with the present study, in which STA showed the strongest association with lower lumbar disc degeneration among all evaluated radiographic parameters.

Lumbosacral morphology also appears to influence degeneration of the posterior spinal elements. Sahin et al.⁽¹⁸⁾ demonstrated that reduced SS, altered sacral kyphosis, and decreased LL were significantly associated with lumbar facet joint degeneration, indicating that sagittal alignment affects both the intervertebral discs and posterior column structures. Furthermore, the Roussouly classification emphasizes the fundamental role of pelvic morphology in determining sagittal spinal alignment by categorizing both healthy individuals and patients into distinct sagittal alignment profiles⁽¹⁹⁾.

More recently, increasing attention has focused on the contribution of STA to degenerative spinal disease. Khodair et al.⁽²⁰⁾ demonstrated that increased STA combined with reduced sacral kyphosis may accelerate the progression of lumbar degenerative changes. Conversely, decreased STA has been associated with progression of L5 spondylolisthesis, further highlighting the critical biomechanical role of sacral morphology in disorders affecting the lumbosacral junction⁽³⁾. These conflicting results suggest that the role of STA may be dependent on the etiology of the degeneration, such as disc degeneration, spondylolysis, spondylolisthesis or global sagittal morphology. Our findings expand upon these previous observations by demonstrating that STA is strongly associated with degeneration at both the L4-L5 and L5-S1 levels, suggesting that this anatomical parameter may serve as a valuable radiographic marker for identifying individuals at increased risk of lower lumbar degenerative disc disease.

Study Limitations

This study has several limitations. First, its retrospective and cross-sectional design prevents any causal inference

regarding the relationship between sacral morphology and disc degeneration. Second, although the total cohort size was sufficient for the main analyses, the isolated L4-L5 and isolated L5-S1 degeneration subgroups were relatively small; therefore, the pattern-based analysis should be interpreted cautiously. Third, the study population consisted of symptomatic patients presenting with low back pain with or without radicular symptoms, and the findings may not be generalizable to asymptomatic individuals. Finally, clinical outcome measures and longitudinal imaging follow-up were not included, which limits the ability to determine whether STA predicts future degeneration progression. Despite these limitations, this study provides a focused evaluation of sacral morphology in relation to lower lumbar disc degeneration. The findings suggest that STA may be an important morphological marker associated with degeneration at both L4-L5 and L5-S1. More importantly, the stepwise decrease in STA with increasing degeneration burden supports the idea that sacral morphology may be related not only to the severity of degeneration at individual disc levels, but also to the extent of lower lumbar disc involvement. Future prospective studies with larger cohorts and longitudinal follow-up are needed to determine whether STA has predictive value for the development or progression of lower lumbar disc degeneration.

CONCLUSION

This study demonstrates a strong association between sacral morphology and lower lumbar disc degeneration. Lower STA values were associated with higher Pfirrmann grades in both L4-L5 and L5-S1 intervertebral disc levels and with a greater number of degenerated lower lumbar levels. SI was also associated with disc degeneration, however, the association with STA was stronger when degeneration severity and the number of degenerated disc levels were considered. Degenerative changes were observed with higher PI, PT and SS, along with a worse LL distribution pattern. STA may therefore be a useful morphological parameter reflecting the biomechanical environment of the lumbosacral junction. Because the study was cross-sectional and included only symptomatic patients, these findings should not be interpreted as evidence that lower STA causes degeneration or predicts its progression. Longitudinal studies are needed to determine the temporal and predictive role of STA in lower lumbar disc degeneration.

Ethics

Ethics Committee Approval: The ethical approval for this study was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital Ethical Committee (approval no: 318, date: 23.10.2025).

Informed Consent: Informed consent was obtained from patients.

Footnotes

Authorship Contributions

Surgical and Medical Practices: L.A., B.S., A.T., F.B.Ö., A.F.R., Concept: L.A., B.S., A.T., Design: L.A., B.S., F.B.Ö., A.F.R., Data Collection or Processing: B.S., Analysis or Interpretation: B.S., Literature Search: L.A., A.T., Writing: L.A.

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