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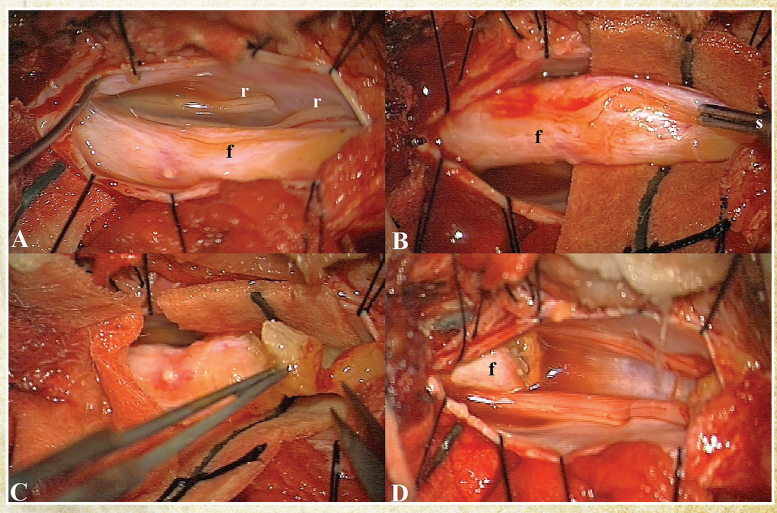

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JOURNAL OF TURKISH SPINAL SURGERY

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ORIGINAL ARTICLES

JOURNAL OF TURKISH SPINAL SURGERY

EDITORIAL

Dear Colleagues,

Spine surgery in Türkiye has undergone a remarkable evolution over the past two decades. Increasing surgical volume, expanding subspecialization, and broader access to advanced instrumentation have positioned Turkish spine surgeons as active contributors to regional and international practice. However, as the discipline matures, it faces a critical transition: moving from experience-driven practice to a more standardized, data-oriented, and outcome-focused model of care.

One of the defining characteristics of spine surgery in Türkiye is its high clinical exposure. Surgeons frequently manage complex degenerative conditions, trauma, deformity, and revision cases, often at volumes exceeding those of many comparable healthcare systems. This experience constitutes a significant strength. Yet, high case volume alone does not automatically translate into high-quality evidence. The systematic collection of prospective data, the use of standardized outcome measures, and long-term follow-up remain inconsistent across institutions. Strengthening national registries and multicenter collaborations should therefore be viewed not as an academic luxury but as a clinical necessity.

Another important challenge lies in the variability of practice patterns. Differences in surgical indications, technique selection, and perioperative management are observed not only between institutions but also within the same center. While individual judgment remains central to surgical decision-making, excessive variability can obscure best practices and hinder meaningful comparison of outcomes. Developing consensus-based national guidelines-adapted to local resources and patient characteristics-would help align care while preserving clinical autonomy.

Technological adoption presents both opportunity and responsibility. Advanced spinal implants, navigation systems, and minimally invasive techniques are increasingly available in Türkiye, particularly in tertiary centers. However, access remains uneven, and structured training pathways are not always standardized. The rapid diffusion of technology without parallel emphasis on indications, learning curves, and cost-effectiveness risks widening disparities and compromising patient safety. A deliberate, education-centered approach to innovation-supported by national societies and academic institutions-is essential.

Spine surgery training also warrants renewed attention. While residency and fellowship programs provide strong foundational skills, the expanding complexity of modern spine care demands ongoing professional development. Topics such as outcome interpretation, complication management, shared decision-making, and interdisciplinary collaboration should be integrated more formally into training curricula. Furthermore, nurturing a research-oriented mindset among young surgeons is critical for sustaining academic productivity and clinical advancement.

Patient expectations in Türkiye are also evolving. Increased access to information, heightened awareness of surgical alternatives, and growing emphasis on quality-of-life outcomes require surgeons to communicate more transparently and engage patients as active partners in care. Incorporating patient-reported outcome measures into routine practice would not only improve clinical insight but also strengthen trust and accountability.

Finally, spine surgery in Türkiye must continue to define its role within the broader healthcare system. As spinal disorders place an increasing burden on working-age and elderly populations, surgeons have a responsibility to advocate for evidence-based care pathways that balance effectiveness, safety, and sustainability. Collaboration with policymakers, rehabilitation specialists, and primary care providers will be essential to achieving this goal.

In conclusion, spine surgery in Türkiye stands at a decisive moment. By transforming extensive clinical experience into structured knowledge, embracing standardization without rigidity, and prioritizing education and data-driven practice, the Turkish spine community can shape a future defined not only by technical excellence, but by measurable, meaningful patient outcomes.

Co-Editor-in-Chief

Ömer Erşen, M.D.,

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ORIGINAL ARTICLE

1

IMPACT OF THORACOLUMBAR BRACING ON ADOLESCENT IDIOPATHIC SCOLIOSIS DEFORMITY

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ABSTRACT

Objective: Adolescent idiopathic scoliosis (AIS) is the most common type of scoliosis and often requires conservative treatment to prevent curve progression. Bracing is the primary non-surgical intervention, but its impact on multidimensional spinal parameters remains incompletely characterized.

Materials and Methods: This study included 33 patients with AIS (mean age 12.76±1.20 years, range 10-14, 90.9% female) who had initial Cobb angles of 20°-40° and Risser stages 0-3. All were treated with thoracolumbosacral orthosis and were followed for 12 months. Radiographic assessments included Cobb angle, cervical lordosis (C2-7), thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic parameters [sacral slope (SS), pelvic incidence (PI), pelvic tilt (PT)], vertebral rotation, and T1 slope.

Results: Bracing yielded substantial coronal correction: thoracic Cobb angle 24.2°→10.3° (Δ=13.9°; -57%; p=0.003), thoracolumbar Cobb angle 25.7°→11.2° (Δ=14.5°; -57%; p=0.003), and lumbar Cobb angle 26.3°→12.3° (Δ=14.0°; -53%; p=0.028). In the sagittal plane, TK decreased modestly (34.7°→31.0°, p=0.007), yet remained within the physiological range (20-45°); LL showed a small, non-significant change (44.8°→43.8°, p=0.118), and the proportion of patients with LL <40° decreased from 27.3% to 24.2%. C2-7 remained stable (11.37°→10.33°, p=0.161), whereas the T1 slope declined (21.33°→19.48°, p=0.015), indicating preserved cervicothoracic adaptation. Spinopelvic parameters were unchanged: SS 34.34°→33.64° (p=0.376), PT 12.40°→14.31° (p=0.136), PI 46.34°→47.05° (p=0.633); SVA also remained stable (9.06→11.22 mm, p=0.406). Raimondi rotation decreased (from 8.74° to 6.05°, p=0.024).

Conclusion: Brace therapy provides effective three-dimensional correction in AIS, with significant improvements in coronal, sagittal, and transverse parameters while preserving global spinal balance and pelvic morphology. These results support bracing as a safe and effective conservative treatment for skeletally immature patients.

Keywords: Adolescent idiopathic scoliosis, brace therapy, spinal alignment

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is defined as a lateral curvature of the spine greater than 10° on the Cobb angle, accompanied by vertebral rotation. Scoliosis develops in approximately 3% of children under the age of 16, although only 0.3%-0.5% present with progressive curves that require treatment. Curvatures exceeding 50° are generally considered surgical indications, as they carry a high risk of progression in adulthood[1,2]. AIS accounts for nearly 90% of idiopathic scoliosis cases and is more frequently observed in adolescent girls[3]. Conservative management is the first-line approach for curves below the surgical threshold, particularly those with Cobb angles between 20° and 40°, aiming to halt progression and reduce the need for surgery[4,5]. Among conservative strategies, bracing is the most widely applied and effective modality[6]. Modern brace systems are designed according to three-dimensional correction principles, targeting curve reduction and balance of asymmetric spinal loading.

Thoracolumbosacral orthosis (TLSO) is a broad term that includes different designs such as the symmetric Boston brace and the asymmetrical Chêneau brace. The Chêneau-type TLSO is based on three-dimensional correction principles and has been widely adopted in contemporary scoliosis management due to its ability to achieve multiplanar correction[5,7].

Previous studies have demonstrated that Chêneau-type TLSO treatment provides significant improvements in Cobb angle and influences sagittal spinal profiles. For example,

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in AIS patients treated with a Chêneau brace, in-brace radiographs revealed a significant reduction in Cobb angle, accompanied by flattening of lumbar lordosis (LL) and thoracic kyphosis (TK)[8]. Similarly, Chêneau-type bracing has been associated with a marked reduction in cervical lordosis (C2-7), a change that persisted even one-year after discontinuation of treatment[9].

Nevertheless, the success of brace therapy depends not only on the type of orthosis used but also on factors such as skeletal maturity, initial curve magnitude, degree of vertebral rotation, and patient compliance. Notably, brace failure rates are particularly high in patients with a Risser grade of 0 and Cobb angles exceeding 45°[10].

The purpose of this study is to evaluate the effects of a Chêneau-type TLSO on spinal deformity in patients with AIS, to investigate associated changes across the sagittal, coronal, and transverse planes, and to examine patient selection criteria and treatment response for optimizing outcomes.

MATERIALS AND METHODS

Study Design

This retrospective cohort study was conducted at Clinic of Orthopedics and Traumatology, University of Health Sciences Türkiye, Bursa City Hospital between January 2022 and June 2024. The study was approved by the Bursa Uludağ University Faculty of Medicine Local Institutional Ethics Committee (approval no: 2025/759-13/14, date: 16.07.2025) and carried out in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all patients and their parents.

Patient Selection

Patients diagnosed with AIS were screened for eligibility. Inclusion criteria were: age between 10 and 15 years, skeletal immaturity (Risser stage 0-3), and an initial Cobb angle between 20° and 40°. Patients with congenital, neuromuscular, or syndromic scoliosis were excluded.

Brace Protocol

All patients were prescribed a Chêneau-type TLSO in accordance with the guidelines of the Scoliosis Research Society. Brace therapy was recommended for skeletally immature patients with curves measuring 20°-40°. Patients were advised to gradually increase brace wear over the course of several days (typically 3-5) until reaching the prescribed full-time regimen of 18-23 hours per day. Compliance was monitored during regular clinical visits based on reports from patients and their family members, as no objective monitoring was available. Patients in this cohort used the brace for approximately 12 months, as documented in clinical records, during which a full-time wear regimen was recommended in routine practice. Importantly, no discontinuation criteria (e.g., skeletal maturity or curve stabilization) were applied, as the study was designed to evaluate outcomes within a one-year observation period."

Data Collection and Radiographic Assessment

Baseline variables included age, sex, curve type (thoracic, lumbar, or thoracolumbar), Cobb angle, C2-7, TK, LL, sagittal vertical axis (SVA), pelvic tilt (PT), pelvic incidence (PI), sacral slope (SS), T1 tilt, vertebral rotation, and Risser stage. All radiographic measurements were performed digitally using Surgimap® software (Nemaris Inc., New York, USA) (Figure 1A-B, Figure 2A-B, Figure 3A-B). T1 slope (T1S) was measured on standing lateral radiographs as the angle between the superior endplate of T1 and a horizontal reference line. When the T1 superior endplate was partially obscured by the shoulder shadow, the visible anterior and posterior cortices were used to reconstruct the endplate line. In cases where T1 was completely unobservable, the inferior endplate of C7 was used

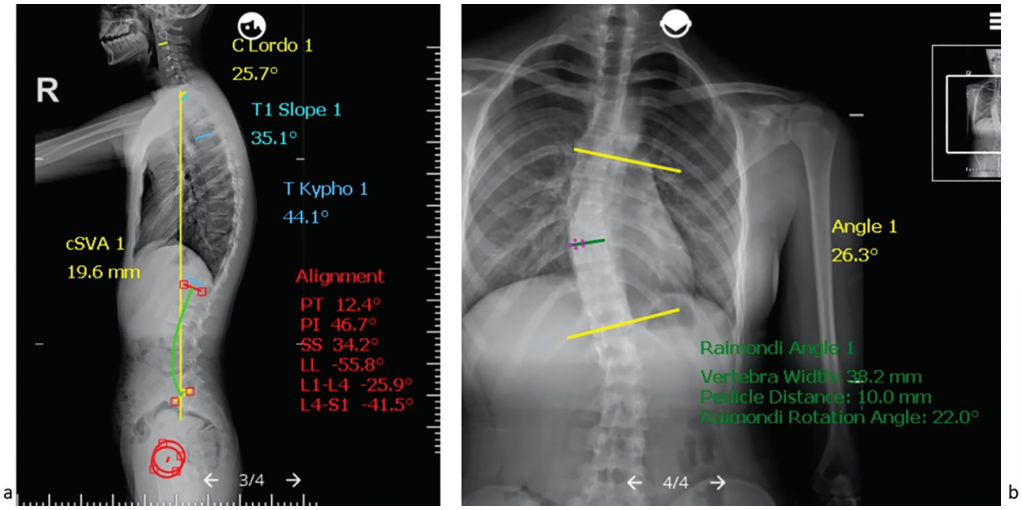

Figure 1. **(a)** Lateral radiograph of an adolescent idiopathic scoliosis patient showing sagittal alignment parameters, including C2-7, T1 slope, thoracic kyphosis, LL, SVA, and spinopelvic measurements (PT, PI, and SS). **(b)** Posteroanterior radiograph of the same patient demonstrating coronal Cobb angle measurement and vertebral rotation (Raimondi) angle assessment. C2-7: Cervical lordosis, LL: Lumbar lordosis, SVA: Sagittal vertical axis, PT: Pelvic tilt, PI: Pelvic incidence, SS: Sacral slope

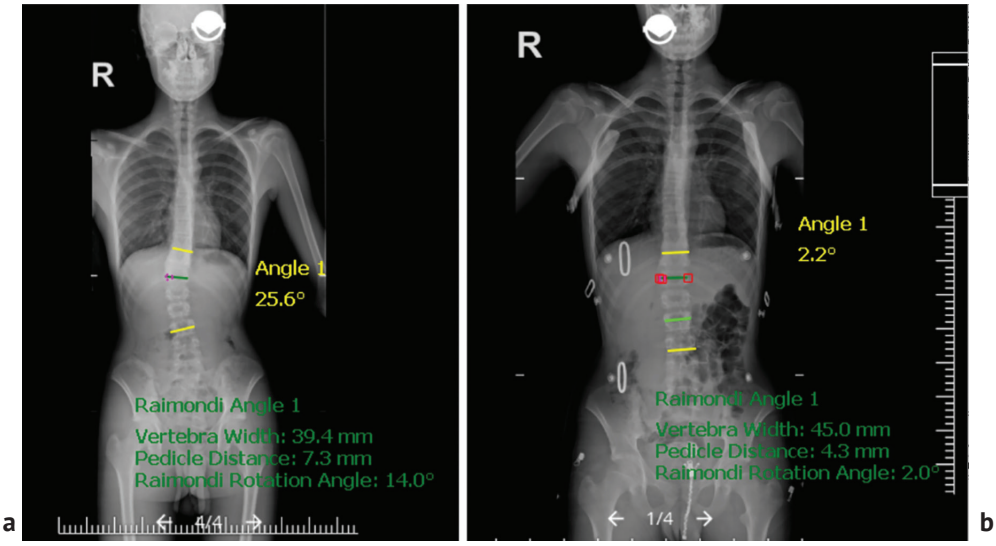

Figure 2. Representative AP radiographs of an AIS patient before and after TLSO treatment. **(a)** Pre-brace radiograph showing a thoracolumbar curve with a Cobb angle of 25.6° and Raimondi rotation angle of 14.0°. **(b)** Post-brace radiograph obtained after 12 months of TLSO treatment demonstrating marked coronal correction, with the Cobb angle reduced to 2.2° and Raimondi rotation angle decreased to 2.0°. AP: Anteroposterior, AIS: Adolescent idiopathic scoliosis, TLSO: Thoracolumbosacral orthosis

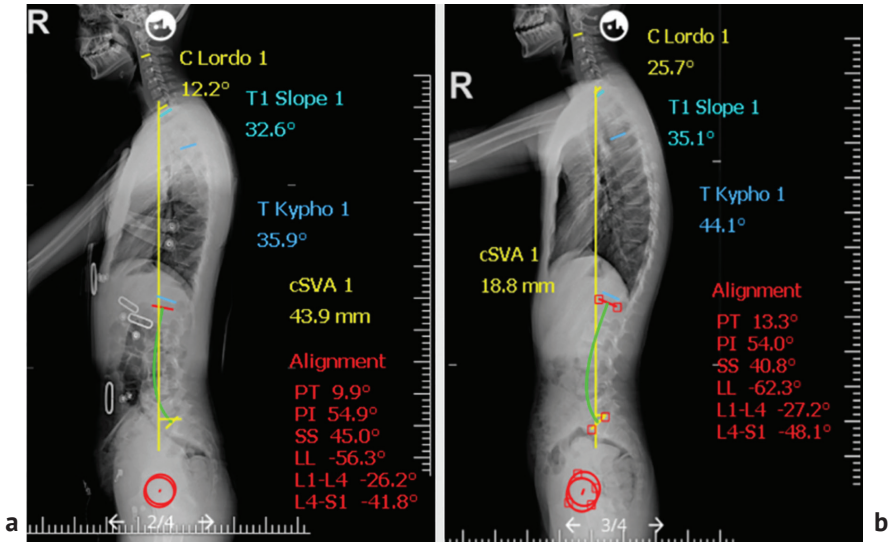

Figure 3. Representative standing lateral radiographs of an AIS patient before and after TLSO treatment. (a) Pre-brace: C2-7 =12.2°, T1 slope =32.6°, thoracic kyphosis (T Kypho) =35.9°, LL =56.3°, SS =45.0°, PT =9.9°, and PI =54.9°. Global sagittal alignment shows a cSVA of 43.9 mm. (b) Post-brace: Cervical lordosis increases to 25.7°, T1 slope =35.1°, thoracic kyphosis =44.1°, LL =55.8°, SS =40.8°, PT =12.4°, and PI =46.7°. The cSVA improves to 19.6 mm, demonstrating preserved global sagittal balance following TLSO treatment. AIS: Adolescent idiopathic scoliosis, TLSO: Thoracolumbosacral orthosis, C2-7: Cervical lordosis, LL: Lumbar lordosis, SS: Sacral slope, PT: Pelvic tilt, PI: Pelvic incidence, cSVA: Sagittal vertical axis

as a validated surrogate, as several studies have demonstrated a strong correlation between C7 slope and T1S[11,12]. Patients were followed clinically and radiographically at 6-month intervals. In-brace correction rates were calculated from radiographs obtained at 12 months after brace initiation.

Outcome Measures

The primary endpoint was defined as the absence of curve progression ≥5° or failure to reach the surgical threshold of Cobb angle ≥45°. In addition, sagittal alignment was evaluated relative to established normative ranges, defined as 20-45° for TK and 40-60° for LL in adolescents[13,14].

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA). The normality of distribution for continuous variables was assessed with the Shapiro-Wilk test. For normally distributed variables, the paired-samples t-test was applied, whereas the Wilcoxon signed-rank test was used for non-normally distributed

variables. A p-value of <0.05 was considered statistically significant in all analyses.

Prior to the study, an a priori power analysis was conducted using G*Power version 3.1.9.7. Based on mean and standard deviation values reported in the existing literature, a sample size of 33 patients was calculated to achieve 90% statistical power with a significance level of α=0.05.

Following completion of the study, post-hoc analyses were performed to calculate Cohen's d effect sizes for the differences between pre- and post-treatment measurements. Large effect sizes were observed across multiple variables, indicating that the findings were not only statistically significant but also clinically meaningful.

Radiographic parameters (Cobb angle, TK, LL, PT, SS) were independently measured by two senior orthopedic surgeons to evaluate inter- and intra-observer reliability. Intraclass correlation coefficients exceeded 0.90 for all parameters, demonstrating excellent measurement consistency.

RESULTS

A total of 33 pediatric patients with a mean age of 12.76±1.20 years (range: 10-14 years) were included in the study. According to curve classification, 12 patients (36.4%) had thoracic scoliosis, 15 (45.5%) had thoracolumbar scoliosis, and 6 (18.2%) had lumbar scoliosis. Based on Risser staging for skeletal maturity, 9 patients (27.3%) were stage 0, 3 (9.1%) were stage 1, 14 (42.4%) were stage 2, and 7 (21.2%) were stage 3 (Table 1). Curve distribution (thoracic, thoracolumbar, and lumbar) reflected the characteristics of patients presenting during the study period; no specific selection criteria were applied based on curve location.

After bracing, mean TK decreased from 33.8° to 29.6° and mean LL from 45.9° to 40.9°, with both cohort means remaining within normative bands (TK 20-45°, LL 40-60°). Categorically, TK stayed within range in all patients (0/33 <20°; 0%), while LL <40° (hypolordosis) was present in 8/33 (24.2%) patients post-brace, a slight improvement from 9/33 (27.3%) pre-brace. No patient exceeded the upper limits for TK or LL (Table 2). Coronal plane analyses demonstrated marked improvements in all major-curve locations: thoracic 24.16°→10.31° (Δ=13.85°, 57.3%), thoracolumbar 25.67°→11.15° (Δ=14.52°, 56.6%), and lumbar 26.28°→12.25° (Δ=14.03°, 53.4%), each with large effect sizes and statistically significant reductions (Table 2).

Radiographic comparisons demonstrated significant coronal correction across all curve types after TLSO treatment. Mean thoracic Cobb decreased from 24.16°±4.04 to 10.31°±7.42 (p=0.003, d=0.86), thoracolumbar Cobb from 25.67°±6.35 to 11.15°±9.06 (p=0.003, d=0.87), and lumbar Cobb from 26.28°±3.28 to 12.25°±5.68 (p=0.028, d=0.90). These findings confirm robust three-dimensional deformity correction in the coronal plane. In the sagittal cervical-thoracic profile, C2-7 remained stable, changing from 11.37°±3.16 to 10.33°±2.16 (p=0.161). TK decreased from 34.66°±4.56 to 30.96°±5.24 (p=0.007, d=0.47), yet all values remained within the physiological range (20-45°). According to normative-band categorization, 0/33 (0%) patients were outside the TK range either before or after treatment, indicating that the observed reduction reflects preservation of a physiological thoracic sagittal profile rather than hypokyphosis. LL showed a small, non-significant decrease from 44.75°±7.14 to 43.78°±7.41 (p=0.118). Normative-band analysis showed 9/33 (27.3%) patients were below 40° at baseline versus 8/33 (24.2%) after bracing, while no

Table 1. Demographic and clinical characteristics of the study population

Variable	n (%) or mean ± SD (range)
Number of patients	33
Age (years)	12.76±1.20 (10-14)
Sex	Female: 30 (90.9%) Male: 3 (9.1%)
Curve type	
• Thoracic	12 (36.4%)
• Thoracolumbar	15 (45.5%)
• Lumbar	6 (18.2%)
Risser stage	
• Stage 0	9 (27.3%)
• Stage 1	3 (9.1%)
• Stage 2	14 (42.4%)
• Stage 3	7 (21.2%)

Values are expressed as mean ± SD with range in parentheses, or as number of patients (percentage). SD: Standard deviation

Table 2. Distribution of sagittal profile relative to normative ranges before and after bracing

Parameter	Normative range (°)	Before brace: patients outside range, n (%)	After brace: patients outside range, n (%)
TK	20-45	Below: 0 (0%) Normal: 33 (100%) High: 0 (0%)	Below: 0 (0%) Normal: 33 (100%) High: 0 (0%)
LL	40-60	Below: 9 (27.3%) Normal: 24 (72.7%) High: 0 (0%)	Below: 8 (24.2%) Normal: 25 (75.8%) High: 0 (0%)

Distribution of patients according to normative reference ranges for TK and LL. Values are given as the number (percentage) of patients falling below, within, or above the normal range before and after brace application. TK: Thoracic kyphosis, LL: Lumbar lordosis

patient exceeded the upper limit (≥60°) at either time point. Thus, the overall distribution of LL remained largely physiological, with a slight reduction in the proportion below the normative-band. Spinopelvic parameters exhibited stability. SS decreased modestly from 34.34°±5.61 to 33.64°±6.02 (p=0.376), and PT showed a mild, non-significant increase from 12.40°±5.43 to 14.31°±5.20 (p=0.136), while PI remained unchanged (46.34°±7.04 to 47.05°±7.11; p=0.633). This pattern-small, statistically non-significant reciprocal trends in SS and PT with stable PI-indicates preservation of spinopelvic harmony and supports the interpretation that correction occurred primarily at the spinal level without pelvic imbalance. Global sagittal alignment was maintained. The SVA did not change significantly (9.06±9.77 mm to 11.22±10.88 mm; p=0.406), confirming preserved global balance. Axial plane deformity improved: Raimondi rotation decreased from 8.74°±7.73 to 6.05°±4.09 (p=0.024, d=0.39), demonstrating effective derotational correction in addition to coronal and sagittal improvements. Finally, T1S decreased significantly from 21.33°±6.09 to 19.48°±5.21 (p=0.015, d=0.42), whereas C2-7 remained within normal limits without a significant reduction. Taken together with stable SVA and non-significant pelvic adjustments, this dissociation suggests a physiologic compensatory mechanism that preserved horizontal gaze and overall sagittal equilibrium rather than maladaptive compensation (Table 3).

DISCUSSION

This study demonstrated that TLSO bracing provided effective three-dimensional correction in AIS while preserving physiological sagittal morphology. TK decreased modestly but remained within normal limits, and LL showed no clinically significant loss, with no focal reduction in the lower lumbar or lumbosacral region. Pelvic parameters were stable: SS exhibited only a minor, non-significant decrease, balanced by a slight compensatory rise in PT, while PI remained unchanged, indicating that pelvic morphology was unaffected. Global sagittal balance (SVA) was preserved, and T1S reduction suggested favorable cervicothoracic alignment without detrimental effects on C2-7. Importantly, no thoracolumbar kyphosis developed, and alignment between T10-L2 remained stable, indicating that brace-induced modifications did not trigger secondary compensatory curves. The sagittal inflection point was maintained, and no shift in sagittal morphology or lumbar apex was observed. Although Roussouly profiling could not be performed due to the reliance on standing neutral lateral radiographs, the constancy of SS and SVA supports preservation of sagittal type. Overall, these results indicate that TLSO bracing successfully corrected coronal and axial deformity without inducing pathological sagittal flattening or disrupting spinopelvic harmony.

Table 3. Comparison of radiographic spinopelvic parameters before and after brace application

	Before (mean ± SD) (IQR)	After (mean ± SD) (IQR)	p-value	Effect size
Thoracic Cobb	24.16±4.04 (17.00-29.00)	10.31±7.42 (1.80-26.00)	0.003	0.86
Thoracolumbar Cobb	25.67±6.35 (15.40-36.40)	11.15±9.06 (0.90-24.80)	0.003	0.87
Lumbar Cobb	26.28±3.28 (23.70-29.25)	12.25±5.68 (8.00-16.73)	0.028	0.90
C2-7	11.37±3.16 (7.20-25.70)	10.33±2.16 (6.20-14.60)	0.161	0.24
TK	34.66±4.56 (25.90-44.10)	30.96±5.24 (22.00-41.40)	0.007	0.47
LL	44.75±7.14 (25.50-56.00)	43.78±7.41 (24.60-56.30)	0.118	0.27
SVA	9.06±9.77 (-11.00-23.80)	11.22±10.88 (-7.50-43.90)	0.406	0.14
SS	34.34±5.61 (18.70-49.10)	33.64±6.02 (18.10-47.00)	0.376	0.15
	Mean Δ (Post-pre)±SD -0.72±8.19	**95% CI (Lower-upper)** -3.62-2.19		
PT	12.40±5.43 (3.50-25.90)	14.31±5.20 (0.60-23.60)	0.136	0.26
	Mean Δ (Post-pre)±SD -1.91±6.93	**95% CI (Lower-upper)** -4.37-0.54		
PI	46.34±7.04 (32.60-63.10)	47.05±7.11 (32.60-64.50)	0.633	0.08
	Mean Δ (Post-pre)±SD +0.70±6.61	**95% CI (Lower-upper)** -1.64-3.05		
RAI	8.74±7.73 (-7.50-23.30)	6.05±4.09 (-0.50-15.30)	0.024	0.39
T1 slope	21.33±6.09 (11.10-35.10)	19.48±5.21 (9.80-32.60)	0.015	0.42

Values are presented as the mean±standard deviation (interquartile range). Comparisons between pre- and post-brace parameters were made using the Wilcoxon signed-rank test. Δ values indicate the mean change between pre- and post-brace measurements, p<0.05 was considered statistically significant. SD: Standard deviation, IQR: Interquartile range, C2-7: Cervical lordosis, TK: Thoracic kyphosis, LL: Lumbar lordosis, SVA: Sagittal vertical axis, SS: Sacral slope, PT: Pelvic tilt, PI: Pelvic incidence, RAI: Raimondi rotation

In agreement with these observations, bracing is widely used in the management of AIS to halt curve progression and achieve meaningful coronal correction. Its effectiveness is closely tied to patient compliance. Large-scale evidence supports this relationship: in the multicenter randomized controlled trial by Weinstein et al.[4], wearing the brace for more than 13 hours per day prevented progression beyond 50° in 72% of patients. Similarly, Negrini et al.[14] found success rates of 97-98% in curves <45° with ≥18 hours/day wear time, preventing progression in 85-87% of cases. Our results parallel these observations, emphasizing that appropriately indicated and consistently used bracing provides substantial coronal improvement and slows curve progression. Beyond coronal control, sagittal interactions-particularly between TK and C2-7-also warrant consideration. A moderate-quality study examining immediate in-brace effects of the Chêneau brace reported no significant alteration in cervical sagittal parameters[8]. Consistently, although TK decreased in our cohort, cervical lordosis remained within normal limits. T1S decreased significantly, yet CL showed only a minor, non-significant reduction, suggesting that patients maintained horizontal gaze through physiologic adaptation rather than maladaptive compensation. Stability of global SVA and the absence of pelvic changes further support this interpretation.

Only a few studies have specifically evaluated the effect of bracing on T1S. A retrospective analysis of AIS patients treated with the Chêneau brace reported small, non-significant in-brace changes in T1S and no improvement in C2-7 cervical lordosis[16]. Combined with our findings, these data suggest that braces exert limited influence on upper spinal segments and that T1S functions as a stable marker of global sagittal alignment. Multiple studies have shown that brace treatment in AIS tends to flatten sagittal curvatures, particularly TK and LL. Systematic reviews and prospective clinical studies consistently report this effect: Ghorbani et al.[15] highlighted a generalized trend toward TK and LL reduction during brace use while Pepke et al.[8] demonstrated significant immediate in-brace decreases with the Chêneau brace. Similarly, Almansour et al.[16] documented measurable reductions in sagittal curvatures, especially TK, throughout treatment. Magnetic resonance imaging (MRI)-based analysis by de Mauroy et al.[17] further confirmed that brace design can influence sagittal alignment, showing marked TK reduction with the Lyon ARTbrace. In our cohort, TK and LL also decreased significantly; however, both remained within physiological limits. This relative preservation of sagittal morphology may reflect the milder baseline deformity (<40°) and early initiation of treatment, as more severe curves typically exhibit greater loss of TK and LL. Thus, the maintenance of TK and LL within normal ranges despite bracing likely represents a milder degree of sagittal flattening associated with lower initial curve magnitude. Given these observations, brace design is an important determinant of sagittal outcomes. Traditional TLSOs, particularly Boston-type posterior shell designs, are known to reduce TK and LL, contributing to sagittal flattening. In contrast, modern three-dimensional brace concepts such as the Rigo-Chêneau, Gensingen, and Lyon ARTbrace incorporate anterior thoracic expansion and optimized lumbar pad and trimline configurations to better preserve physiological sagittal contours while achieving coronal correction. Clinical series and review studies consistently report less kyphosis loss and improved spinopelvic harmony with these contemporary designs compared with conventional TLSOs[16,18-21]. In our cohort, reductions in TK and LL were modest and remained within normal ranges, consistent with sagittal preservation rather than maladaptive flattening.

While brace treatment in AIS provides significant improvements in Cobb angle and spinal curvatures, pelvic parameters generally remain stable. Li et al.[21] reported no significant changes in SS, PT, or PI in Chêneau brace users. Similarly, in a clinical study of 25 patients, Saeedi et al.[22] observed no significant changes in PI, PT, or SS; only thoracolumbar kyphosis, LL, and Cobb angle demonstrated improvements. These findings indicate that bracing exerts its primary corrective effect at the spinal level rather than the pelvis, which functions as a relatively static structure. Our results were consistent with this pattern: SS demonstrated a slight, non-significant decrease accompanied by a mild compensatory rise in PT, while PI remained unchanged. This minor reciprocal relationship reflects adaptive postural equilibrium rather than maladaptive compensation. Although these changes were clinically insignificant, they underscore the importance of periodic imaging to ensure continued preservation of sagittal and spinopelvic harmony during treatment. Given this relative pelvic stability, it becomes essential to evaluate whether global sagittal alignment is similarly preserved. Prior studies show that bracing has limited impact on the SVA. Li et al.[21] found no significant differences between pre-bracing and in-bracing SVA values. and Almansour et al.[16] similarly demonstrated that despite reductions in TK and LL during Chêneau brace treatment, overall sagittal balance, including SVA, remained stable. A prospective study of Providence night-time bracing also reported no adverse effects on sagittal alignment, supporting the concept that bracing maintains postural stability[23]. Our results similarly demonstrated preserved SVA, confirming that bracing maintains postural equilibrium and functional alignment. Building upon the preservation of pelvic and global sagittal balance, our findings additionally demonstrate significant improvement in the axial dimension: vertebral rotation measured with the Raimondi method decreased markedly. This aligns with existing literature showing axial derotation through modern brace designs, including MRI-confirmed improvements reported by Schmitz et al.[24], and Willers et al.[25] reported significant long-term rotational improvements with the Boston brace. The derotational mechanism described in Kumari and Surbhi's[26] review further supports the three-dimensional corrective capacity of modern brace designs. Collectively, these observations indicate that bracing provides effective multiplanar correction-coronal, sagittal, and axial-while maintaining sagittal harmony.

A major strength of this study is its comprehensive evaluation of bracing across all three anatomical planes-coronal, sagittal, and transverse. This multidimensional assessment offers a more complete understanding of bracing effects than analyses limited to Cobb angle reduction. The inclusion of spinopelvic parameters and upper spinal alignment measures, such as the T1S, enhances the clinical relevance of our findings by demonstrating that bracing can correct spinal deformity while largely preserving pelvic morphology. Clinically, these results highlight the importance of early brace initiation in skeletally immature patients and emphasize the need to monitor sagittal and rotational parameters in addition to coronal outcomes. The observation that pelvic parameters remained stable while spinal deformities improved reinforces that correction occurs primarily at the spinal level without compromising pelvic balance, providing valuable information for treatment planning and patient counseling.

Study Limitations

This study has several limitations. First, its retrospective design restricts causal inference, and the single-center setting with a modest sample size limits generalizability. Brace-wearing time was based on patient and family reports rather than objective sensors, which may have led to overestimation of compliance. Additionally, subgroup analysis according to Risser stage was not possible due to limited statistical power; however, our findings remain consistent with studies identifying Risser 0 as a predictor of brace failure[4,27]. Skeletal maturity assessment relied solely on the Risser sign, as more detailed measures such as Sanders classification, distal radioulnar grading, and menarcheal status were not systematically documented. Curve flexibility,an important predictor of bracing success,could not be evaluated due to the absence of bending or traction radiographs in the retrospective dataset. Sagittal evaluation was also limited because segmental lordosis (L4-S1) and thoracolumbar kyphosis (T10-L2) were not separately measured, and total LL (L1-S1) was used as a surrogate. Roussouly classification could not be applied due to the lack of in-brace lateral radiographs and detailed segmental measurements. Despite these limitations, the physiological ranges of thoracic and lumbar curvatures and the preserved global sagittal alignment make secondary thoracolumbar kyphosis unlikely. The inability to obtain precise minimum and maximum brace-wearing durations resulted in standardization to a 12-month interval, and the absence of post-brace follow-up prevented evaluation of long-term alignment, curve progression, or functional outcomes. Finally, clinical and patient-centered measures such as pain, quality of life, or psychosocial impact were not assessed, as the study focused exclusively on radiographic parameters.

CONCLUSION

Brace therapy in AIS provides effective three-dimensional correction, with significant improvements in Cobb angle, TK, LL, and rotational deformity. While sagittal and pelvic parameters largely remained stable, global spinal balance was preserved. These findings support bracing as a safe and effective conservative option in skeletally immature patients, emphasizing the importance of long-term follow-up and brace designs that maintain sagittal alignment.

Ethics

Ethics Committee Approval: The study was approved by the Bursa Uludağ University Faculty of Medicine Local Institutional Ethics Committee (approval no: 2025/759-13/14, date: 16.07.2025) and carried out in accordance with the principles of the Declaration of Helsinki.

Informed Consent: Written informed consent was obtained from all patients and their parents.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.D., B.A., B.Ak., Concept: Ö.C.S., R.K., H.Ç.B., Design: M.D., B.A., Ö.C.S., R.K., H.Ç.B., Data Collection or Processing: M.D., B.A., R.K., B.Ak., Analysis or Interpretation: Ö.C.S., R.K., H.Ç.B., Literature Search: M.D., B.A., H.Ç.B., Writing: M.D., B.A., H.Ç.B.

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SPINAL OUTCOMES AND GAP SCORE ANALYSIS FOLLOWING SEQUENTIAL TOTAL HIP ARTHROPLASTY IN HIP-SPINE SYNDROME

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ABSTRACT

Objective: The study aimed to evaluate changes in early clinical outcomes and radiological parameters before and after two surgeries in patients with hip-spine syndrome (HSS) who underwent staged bilateral total hip arthroplasty (THA).

Materials and Methods: Sixty three patients (mean age, 56.6 years) who underwent staged bilateral THA and had spinal symptoms were included. Hip disability and osteoarthritis outcome score (HOOS), Oswestry disability index (ODI), and Roland-Morris disability questionnaire (RMDQ), together with radiological parameters (leg length discrepancy and pelvic obliquity), were assessed preoperatively, at three months after the first THA, and at three months after the second THA. Changes after surgeries were compared, and correlations between radiological parameters and scores were analyzed. Global alignment and proportion (GAP) scores were evaluated in a subgroup of thirteen patients.

Results: HOOS scores improved after both surgeries (32.7±5.8, 60.9±5.8, and 91.7±2.3). Median RMDQ scores were 17-5-4, and median ODI scores were 55-15-10. After the second surgery, RMDQ and ODI scores worsened in 16 (25.4%) and 14 (22.2%) patients, respectively. Improvements in both scores were significantly greater after the first surgery than after the second. No correlations were found between radiological parameters and improvements in RMDQ and ODI scores. GAP scores did not change after surgeries.

Conclusion: In HSS patients undergoing staged bilateral THA with hip-first approach, lumbar symptoms improved after first surgery but not the second surgery in the same extent at short-term. Lumbar changes were unrelated to changes in coronal pelvic parameters, and global sagittal balance remained unchanged.

Keywords: Hip-first, global alignment and proportion score, patient-reported outcome measures, bilateral total hip arthroplasty

INTRODUCTION

Hip-spine syndrome (HSS), first described by Offierski and MacNab[1] in 1983, refers to the coexistence of degenerative lumbar pathology and hip degeneration. When degenerative hip disease and spinal disorders (spinal stenosis, facet arthropathy, lumbar disc degeneration, spondylolisthesis, or degenerative scoliosis) occur together, their interaction often amplifies both hip- and spine-related symptoms[2]. In many patients, this overlap also creates diagnostic uncertainty, making it challenging to determine whether the primary source of symptoms is the lumbar spine or the hip[2,3].

There is currently no clear consensus regarding which pathology should be addressed first in patients with HSS. Some studies recommend prioritizing treatment of the hip joint[4,5], whereas others advocate treating the spine first[6]. In our clinical practice, when imaging demonstrates both degenerative hip disease and spinal pathology in patients presenting with hip pain and HSS is suspected, we routinely perform total hip arthroplasty (THA) as the initial intervention. Subsequent spinal treatment is considered only if spinal symptoms persist following THA.

Degenerative hip osteoarthritis is seen bilaterally in 34% of patients with lumbar degenerative disease[7]. In this patient group, clinical scores were reported to be worse both at baseline and after treatment[7]. Reviewing the current literature, we observed that there are very few studies evaluating the spinal status (radiographic or clinical) of patients with HSS and bilateral degenerative hip disease who underwent two-stage bilateral THA[8-10].

Our clinical observations indicate that in patients with HSS and bilateral degenerative hip disease, lumbar symptoms improve substantially after the first THA, whereas the contralateral THA provides no additional reduction in lumbar complaints. The primary aim of this study is therefore to evaluate short-term changes in clinical and radiological outcomes in patients with HSS who undergo staged bilateral THA, comparing results after

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the first and second procedures. A secondary aim is to assess sagittal balance-specifically global alignment and proportion (GAP) score-after each stage in the subgroup of patients for whom surgery was considered due to persistent lumbar symptoms. We hypothesize that spinal complaints will improve significantly following the first THA, but will show no further clinical improvement after contralateral THA.

MATERIALS AND METHODS

This single-center, observational clinical study, patient data were retrospectively evaluated after obtaining ethical committee approval from University of Health Sciences Türkiye, Ankara Etlik City Hospital's Ethics Committee (approval no: AEŞH-BADEK-2024-175, date: 28.02.2024). Written and verbal consent was obtained from all participants, and our study was conducted in accordance with the Declaration of Helsinki.

Data from patients who underwent THA in the Clinic of Orthopedics and Traumatology at University of Health Sciences Türkiye, Ankara Etlik City Hospital between September 2022 and October 2024 were reviewed. Inclusion criteria consisted of patients who had undergone bilateral THA and demonstrated radiological evidence of spinal degeneration (spinal stenosis, facet joint degeneration, lumbar disc degeneration, spondylolisthesis, or degenerative scoliosis) in the hospital imaging archive, along with clinical spinal or lumbar symptoms (radicular pain, low back pain, or neurogenic claudication). Exclusion criteria included THA performed for indications other than hip osteoarthritis (e.g., femoral neck fracture, femoral head avascular necrosis or trauma), bilateral THA performed less than 3 months apart, postoperative wound complications, periprosthetic fracture, postoperative hip dislocation, unwillingness to participate, or insufficient data. A total of 63 patients met the study criteria and were included in the final analysis. The study flowchart is presented in Figure 1.

Surgery and Follow-up Protocol

All patients were given antibiotics 1 hour before surgery (1 gram of cefazolin sodium for <80 kg, 2 grams for >80 kg). Patients were operated on the lateral decubitus position under spinal or general anesthesia, as determined by the anesthesiologists, using a standard posterolateral approach. Component placement was performed using the combined anteversion principle. The acetabular component was placed using the press-fit technique. Acetabular screw placement was performed according to the surgeon's preference. After performing an appropriate neck cut and medullary reaming, the femoral stem was placed using the press-fit technique. The operation was completed after intraoperative assessment of leg length, safe joint range of motion, and stability. Patients were allowed to bear weight as tolerated on the first postoperative day. Anticoagulation (enoxaparin) and compression socks were administered for deep vein thrombosis prophylaxis for one month. Patients were called for follow-up on the 15th day, 6th week, and 3rd month after surgery. After the 3-month follow-up, patients were scheduled for contralateral THA, and contralateral THAs were performed using the same protocol.

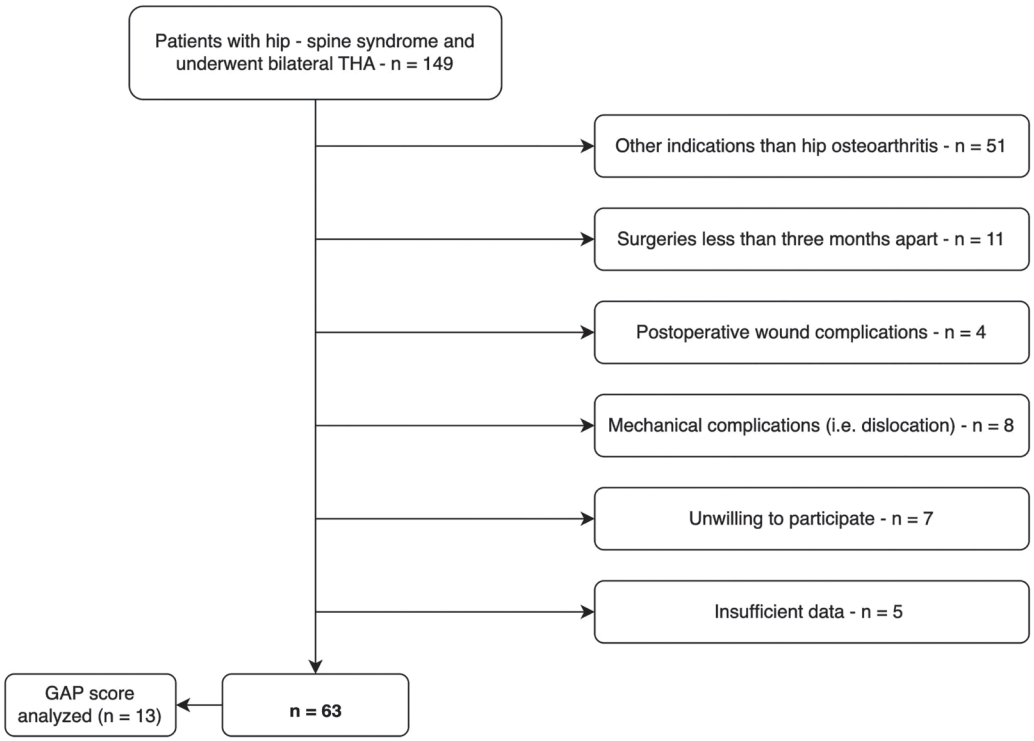

Figure 1. Study flowchart. THA: Total hip arthroplasty, GAP: Global alignment and proportion

Radiological and Clinical Evaluation

The demographic data (age, sex, body mass index) of all patients included in the study were recorded.

For clinical outcome assessment, the Turkish versions of the hip disability and osteoarthritis outcome score (HOOS), Roland-Morris disability questionnaire (RMDQ) and Oswestry disability index (ODI) were administered preoperatively, three months after the first THA, and three months after the second THA. HOOS is a 40-item questionnaire designed to evaluate pain, function, and quality of life in patients undergoing hip arthroplasty, covering pain, symptoms, activities of daily living, sports and recreation, and quality of life domains[11,12]. RMDQ is a 24-item questionnaire that measures limitations in daily activities secondary to low back pain[13,14]. ODI, consisting of ten subscales, is the most widely used and is considered the gold standard for assessing functional limitations related to back pain and lumbar spine degeneration[15,16].

Radiographic measurements were performed by two independent observers who were blinded to all clinical information. Measurements were obtained using the hospital's picture archiving and communication system (Innbiotec DICOM Viewer, Innbiotec Software, Dubai, UAE) on preoperative radiographs, as well as images acquired three months after the first THA and three months after the second THA. Leg length discrepancy (LLD) and pelvic obliquity were evaluated on standing anteroposterior pelvic radiographs. Additionally, GAP score was assessed in the subgroup of patients with persistent lumbar complaints who were scheduled for spinal surgery. LLD was measured as the vertical distance between two lines drawn parallel to the inter-teardrop line, each passing through the apex of a lesser trochanter (Figure 2)[17]. Pelvic obliquity was calculated by measuring the angle between the line connecting the highest points of the iliac crests and the horizontal plane (Figure 2)[18]. The GAP score, a system used to estimate the risk of mechanical complications following spinal deformity surgery, was calculated using patient age, pelvic incidence, sacral slope, L1-S1 lordosis, L4-S1 lordosis, and global tilt (Figure 3)[19].

Changes in HOOS and its subscale scores, as well as RMDQ and ODI scores, were compared between the preoperative period and after the first surgery, and between the first and second surgeries. Additionally, the relationship between these score changes and changes in LLD and pelvic obliquity was evaluated. In the subgroup in which GAP scores were measured, changes in GAP scores after each surgery were also analyzed.

Statistical Analysis

Statistical analyses were performed using Jamovi 2.0 (Jamovi Project, Sydney, Australia). Kolmogorov-Smirnov test was used to assess whether the data followed a normal distribution. Descriptive and outcome variables were presented as mean ± standard deviation or median (Q1-Q3), as appropriate, and categorical variables as frequencies and percentages. Differences between numerical variables were examined using the paired t-test or the Wilcoxon signed-rank test. Correlations between numerical variables were assessed using Spearman's rank correlation coefficient. Interrater reliability of the radiological measurements were evaluated with intraclass correlation coefficient (ICC), and ICC of the measurements were found to be 0.914. Mean values of two observations were used for analyses. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 63 patients (mean age 56.6±11.4 years, 49.2% male, body mass index =29.4±4.1) were included in the study. In 40 patients (63.5%), the right hip was operated on first.

Mean total HOOS scores improved from 32.7±5.8 to 60.9±5.8 after the first hip surgery (p<0.001) and to 91.7±2.3 after the second hip surgery (p<0.001). Significant improvements were also observed across all HOOS subscales following each procedure (p<0.001) (Table 1).

Median RMDQ scores were 17 (15-18.5) at baseline, 5 (4-11) after the first surgery, and 4 (3-10) after the second surgery, with both intervals showing statistically significant improvement (p<0.001 and p=0.004, respectively). Median ODI scores were 55 (47.5-65) at baseline, 15 (10-40) after the first surgery, and

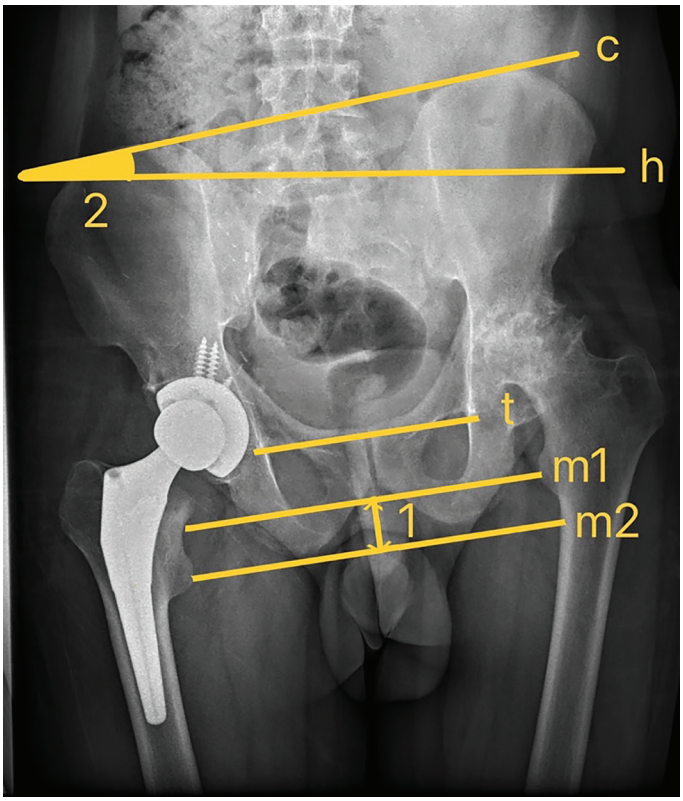

Figure 2. Measurement of coronal pelvic parameters on standing anteroposterior pelvis X-ray. Leg length discrepancy (1) was measured as the vertical distance between two lines drawn parallel to the inter-teardrop line (t), each passing through the apex of a lesser trochanter (m1 and m2). Pelvic obliquity (2) was calculated by measuring the angle between the line connecting the highest points of the iliac crests (c) and the horizontal plane (h)

10 (10-37.5) after the second surgery. Although there was a significant improvement after the first procedure (p<0.001), no significant additional improvement was observed after the second operation (p=0.161) (Figure 4, Table 1).

After the first surgery, RMDQ scores worsened in one patient (1.6%) and ODI scores worsened in four patients (6.3%). Following the second surgery, RMDQ scores worsened in 16 patients (25.4%) and ODI scores worsened in 14 patients (22.2%). Overall, the improvements in both RMDQ and ODI scores were significantly greater after the first surgery compared with the second (both p<0.001).

Spearman correlations between radiological changes (LLD and pelvic obliquity) and changes in disability scores (RMDQ and ODI) at both intervals (baseline to first surgery and first to second surgery) were small (|rho|<0.2) and not statistically significant (all p>0.05) (Table 2). Also, age did not correlate with changes in the HOOS, RMDQ and ODI scores (p>0.05 for all score changes).

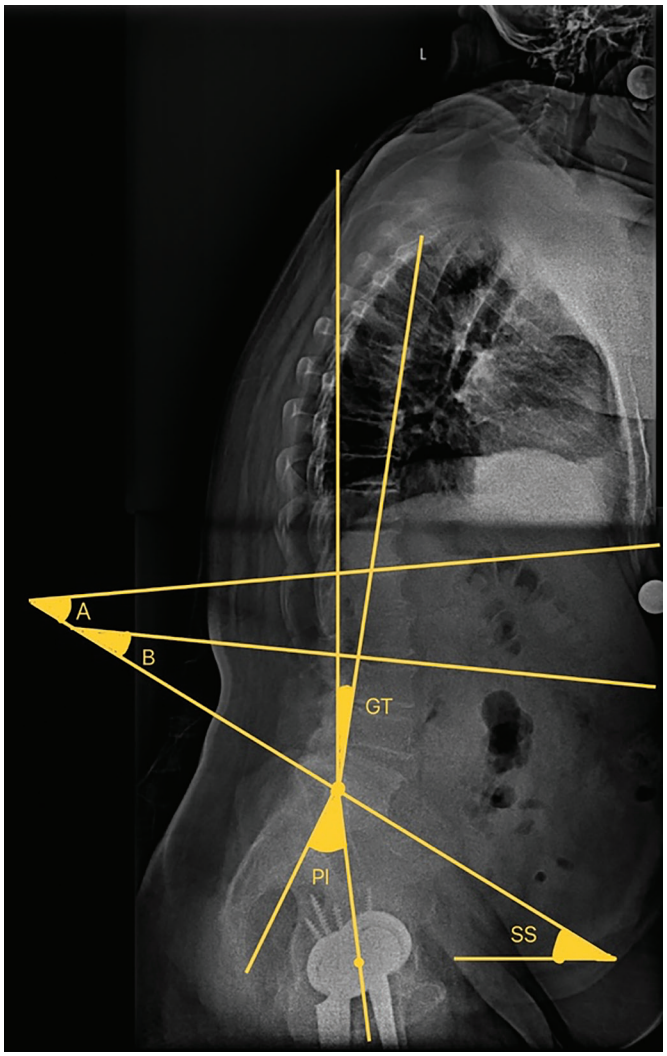

Figure 3. PI, SS, L1-S1 lordosis (A), L4-S1 lordosis (B), and GT were measured on sagittal spinal X-rays to assess global alignment and proportion score. PI: Pelvic incidence, SS: Sacral slope, GT: Global tilt

In the subgroup in which GAP scores were analyzed (n=13, mean age 66.4±7.5 years), GAP scores [median 3 (0-5)] did not change in any patient after either the first or second surgery. Also, no statistically significant differences in terms of measured sagittal parameters were observed (all p>0.05) (Table 1).

DISCUSSION

Our study evaluated early changes in lumbar symptoms following staged bilateral THA in patients with coexisting lumbar spinal findings. Significant improvement in lumbar complaints was observed after the first surgery, whereas no further improvement was noted after the second surgery. Moreover, a subset of patients experienced worsening lumbar scores following the second procedure. Improvements in lumbar scores were not associated with coronal radiographic parameters. In the subgroup assessed, sagittal balance remained unchanged after both hip surgeries.

The relationship between the spine and the pelvis has been a subject of investigation for a long time. Dubousset emphasized that the pelvis is a continuation of the spine and highlighted the concept of "pelvic vertebra"[20]. Jackson and Hales[21] identified strong correlations between pelvic parameters and spinal alignment. Following these descriptions, hip and spine surgeons have focused on the view that disorders occurring in the hip joint affect the lumbar alignment and degeneration, or that degeneration occurring in the spinal region affects the hip joint[22]. With aging and the associated degenerative process, patients' lumbar lordosis decreases, the sacral slope increases as a compensatory mechanism, and pelvic retroversion may develop. This situation may lead to the risk of posterior impingement and anterior dislocation after hip arthroplasty. For this reason, the development of implant designs such as dual-mobility hip replacement and the importance of acetabular cup placement in patients with lumbar degeneration are being focused on[22].

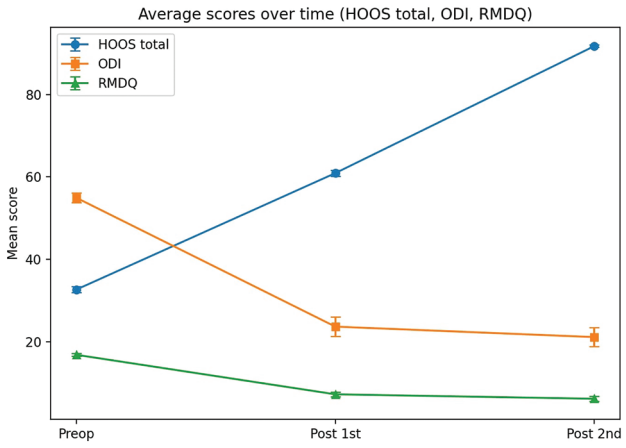

Figure 4. Changes in HOOS, RMDQ and ODI after first and second surgeries. HOOS: Hip disability and osteoarthritis outcome score, RMDQ: Roland-Morris disability questionnaire, ODI: Oswestry disability index

Table 1. Clinical scores and radiological results

	Baseline	After first surgery	Difference after first surgery	p-value	After second surgery	Difference after second surgery	p-value
HOOS	32.7±5.8	60.9±5.8	28.3±3.4	**<0.001 (1)**	91.7±3	30.8±4	**<0.001 (1)**
HOOS-sympt	39.3±7.5	66.8±8.3	27.5±6.6	**<0.001 (1)**	93.7±3	26.9±7.5	**<0.001 (1)**
HOOS-pain	35.9±7	58.8±8.2	22.9±1.4	**<0.001 (1)**	90.5±4	31.7±7.2	**<0.001 (1)**
HOOS-ADL	31.7±7.5	64.1±7	32.5±6.2	**<0.001 (1)**	93.2±1.8	29±7.3	**<0.001 (1)**
HOOS-sp/rec	34.4±8.2	56.4±11.8	22±8.6	**<0.001 (1)**	87.9±4	31.6±10.6	**<0.001 (1)**
HOOS-QoL	18.7±4.4	49.4±7.5	30.7±6	**<0.001 (1)**	90.2±5.4	40.8±11.6	**<0.001 (1)**
RMDQ	17 (15-18.5)	5 (4-11)	10 (8-12)	**<0.001 (2)**	4 (3-10)	1 (-0.5-3)	**0.004 (2)**
ODI	55 (47.5-65)	15 (10-40)	35 (25-42.5)	**<0.001 (2)**	10 (10-37.5)	0 (0-5)	0.161 **(2)**
Leg length discrepancy (mm)	8±8.5*	12.3±13.5	15.2±12.9	0.246 (1)	4.9±5.1*	12.9±12.6	0.399 (1)
Pelvic obliquity	2.2±2.1*	3.2±2.9	3±2.6	0.456 (1)	2±1.9*	2.7±2.9	0.170 (1)
Subgroup analysis (n=13)							
GAP score	3 (0-5)	-	-	-	3 (0-5)	0 (0-0)	-
Pelvic incidence	55.2 (45.8-66.3)	-	-	-	57.4 (44.2-67.4)	1.4 (-1.1-2.2)	0.340 (2)
Sacral slope	43.2 (39.3-46.1)	-	-	-	43.4 (39.7-44.6)	1 (-1.3-1.8)	0.463 (2)
L1-S1 lordosis	52.9 (41.4-61.3)	-	-	-	50.1 (40.6-59.7)	-2 (-2.2-0.8)	0.133 (2)
L4-S1 lordosis	33.4 (24.9-39.5)	-	-	-	33.4 (21.5-38.2)	-2 (-2.4-1)	0.147 (2)
Global tilt	13.5 (12.4-19.2)	-	-	-	14.1 (11.4-15.6)	-1-1 (-3.3--0.2)	0.094 (2)

*: Absolute values were used for mean ± standard deviation calculations, (1) Paired t-test, (2) Wilcoxon signed-rank test, HOOS: Hip disability and osteoarthritis outcome score, sympt: Symptoms, pain: Hip-related pain, ADL: Activities of daily living, sp/rec: Sports and recreation, QoL: Hip-related quality of life, RMDQ: Roland-Morris disability questionnaire, ODI: Oswestry disability index, GAP: Global alignment and proportion

Table 2. Spearman's correlation coefficients (rho) between changes in radiological parameters and changes in disability scores

	RMDQ score difference	p-value	ODI score difference	p-value
Leg length discrepancy after first surgery	-0.040	0.754	0.107	0.404
Pelvic obliquity after first surgery	0.191	0.132	0.118	0.356
Leg length discrepancy after second surgery	-0.154	0.226	0.013	0.916
Pelvic obliquity after second surgery	-0.080	0.532	-0.031	0.809

RMDQ: Roland-Morris disability questionnaire, ODI: Oswestry disability index

There is ongoing debate about which should be treated first in patients with HSS-hip or spine. It is argued that lumbar fusion prior to THA increases the risk of hip dislocation as it affects lumbar lordosis. It is claimed that gait and posture may improve after THA, which may reduce back pain due to changes in the load distribution on the spine. Andah et al.[23] reported that hip dislocation was not observed in patients with HSS syndrome who underwent THA first, while hip dislocation was observed in 11.9% of patients who underwent spinal surgery followed by THA. They also state that spinal surgery should be performed first, as radiculopathy and spinal stenosis findings may progress further if spinal surgery is performed following THA. Yang et al.[6] reported higher rates of dislocation, infection, revision surgery, and opioid usage in patients who underwent THA first. Although there is no clear consensus in the current literature, our own clinical experience suggests that performing THA first reduces lumbar complaints.

In patients with HSS syndrome who underwent bilateral THA, we observed a significant improvement in the patients' spinal-related clinical scores after the first THA, while we observed no significant change in the clinical scores after THA on the contralateral side. There are very few studies in the current literature on the stepwise treatment of bilateral hip pathologies in patients with HSS. Eguchi et al.[8] observed a reduction in back pain when THA was performed in patients with unilateral OA, but reported no change in back pain in patients who underwent THA due to bilateral OA. In contrast, Issani et al.[24] stated that bilateral THA in patients with HSS reduced the need for lumbar surgery, but unilateral THA reduced the need for lumbar surgery to a lesser extent.

They argued that this was because unilateral THA did not sufficiently correct spinopelvic alignment[24].

John et al.[25] reported that RMDQ scores decreased significantly within one year in their study examining dysfunctional low back pain after THA. Weng et al.[26] reported a significant improvement in postoperative RMDQ scores in patients with HSS syndrome who underwent unilateral THA. Vigdorchik et al.[27] reported that patients' symptomatic low back pain decreased after THA, and that the mean ODI score, which was 38 before surgery, was 17 after surgery. Can et al.[10] found a significant decrease in ODI scores after surgery in patients who underwent THA due to low back pain and Crowe IV developmental hip dysplasia. In our study, a significant decrease in RMDQ and ODI scores was observed after the first THA, while no improvement was observed in ODI scores in particular after the second THA.

A considerable amount of patients (nearly 25% of the study population) had worsened lumbar scores at short-term after the second THA. It was previously reported that the improvements of lumbar scores in unilateral hip osteoarthritis is more pronounced than in bilateral hip osteoarthritis after THA, and the authors of that study were attributed this finding to the correction of coronal alignment (specifically scoliosis)[8]. We investigated this by analyzing the correlation between several coronal alignment parameters and score changes, however we were unable to reach a significant correlation. Other factors that might have an influence on this finding include the possibility that hip-related pain may mask concomitant spinal symptoms[27]. Following hip surgery, the resolution of dominant hip pain may unmask pre-existing lumbar pathology, leading patients to perceive persistent or even worsened spinal symptoms despite technically successful arthroplasty. Also, due to the short-term follow-up (three months), dynamic recovery, such as restoration of gait, might be incomplete for resolution of lumbar symptoms.

Sagittal spinal balance has become an important subject for spinal surgeons in recent years[28]. While coronal alignment was previously emphasized after spinal surgery, sagittal spinal balance has become increasingly important due to reasons such as the increase in the number of surgeries, the occurrence of back and spine pain in patients after surgery, and the development of implant failure after surgery. For this reason, although many parameters are used, the use of the GAP score, a scoring system that aims to predict the risk of mechanical complications (post-junctional kyphosis, implant failure, etc.) after spinal surgery by evaluating the sagittal alignment of adult degenerative spines on an individual basis[19], is becoming widespread. For this purpose, we wanted to evaluate whether there was a change in the GAP score in patients with HSS syndrome who continued to have low back complaints after THA, and we observed that the GAP score was not affected by THA. We believe that our study is the first to evaluate this issue in the current literature.

Study Limitations

Among the limitations of our study, in addition to its retrospective nature, the time interval between the two surgeries and the follow-up period being as short as three months can be noted. Although we anticipated that three months would be sufficient time for patients to be aware of changes in their daily lives and that the significant improvement was observed in all scores within three months, studies demonstrate that changes in lumbar scores are more prominent in at least one year[4,29], therefore the results of this study should be considered as short-term. The same applies to spinopelvic parameters[30]. Studies with long-term follow-up are needed to interpret the adaptations in spinopelvic alignment and GAP scores.

According to the purpose of the study, spinal degenerative conditions were considered as a single phenomenon, but it should be noted that different spinal conditions might cause distinct symptomatology. Including the main cause of spinal symptoms would be beneficial to evaluate the effect of specific spinal condition (i.e., disc degeneration) on the spinal scores. However, most of the patients with HSS have overlapping spinal pathologies[31], and it would be challenging to isolate a single etiological factor and attribute clinical outcomes to a specific spinal pathology with sufficient reliability. Therefore, spinal degenerative conditions were evaluated collectively to reflect real-world clinical practice and the multifactorial nature of HSS.

Subgroup analysis of the GAP score was performed in a cohort with an extremely small sample size. Although these findings may provide preliminary insight into potential GAP score changes following THA, they should be interpreted with caution, and no definitive conclusions can be drawn. Further studies with larger sample sizes are warranted to validate these findings and to better elucidate the relationship between THA and spinopelvic alignment as assessed by the GAP score.

The patients were not operated on by a single surgeon, and the brands, models, and sizes of the hip prostheses were not uniform. This heterogeneity limits the ability to fully control for surgery-related factors. Although this issue was partially addressed by excluding patients with surgical complications, variations in surgeon experience, implant selection, and technical details of the procedures may still have influenced both functional and radiological outcomes.

CONCLUSION

In patients with HSS undergoing staged bilateral THA using a hip-first approach, a marked improvement in lumbar spinal symptoms was observed after the first procedure in short-term, however, this improvement did not persist to the same extent following the second procedure, with a subset of patients demonstrating worsening lumbar scores postoperatively. No significant association was identified between changes in

lumbar scores and coronal pelvic radiographic parameters. Furthermore, in the analyzed subgroup, GAP scores remained unchanged after both procedures, and no significant differences could be detected in sagittal alignment parameters.

Ethics

Ethics Committee Approval: This single-center, observational clinical study, patient data were retrospectively evaluated after obtaining ethical committee approval from University of Health Sciences Türkiye, Ankara Etlik City Hospital's Ethics Committee (approval no: AEŞH-BADEK-2024-175, date: 28.02.2024).
Informed Consent: Written and verbal consent was obtained from all participants.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: F.B., E.B.D., Concept: F.B., Design: F.B., Data Collection or Processing: E.B.D., Analysis or Interpretation: F.B., Literature Search: E.B.D., Writing: F.B., E.B.D.
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CLINICAL AND RADIOLOGICAL OUTCOMES OF MICROSURGICAL DETETHERING IN ADULT TETHERED CORD SYNDROME

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ABSTRACT

Objective: Tethered cord syndrome (TCS) is traditionally considered a pediatric disorder, yet an increasing number of adults are now diagnosed with symptomatic tethering. Adult presentations often differ from childhood cases, and the extent to which microsurgical detethering benefits this population remains a subject of clinical interest. This study aims to evaluate the clinical and radiological outcomes of microsurgical detethering in adults with TCS.

Materials and Methods: This retrospective study included patients aged ⩾18 years who underwent detethering between 2015 and 2024. Preoperative variables included symptoms, neurological findings, cutaneous stigmata, magnetic resonance imaging (MRI) features, urodynamic results, and tibial nerve somatosensory evoked potentials latency. All patients underwent microsurgical filum sectioning or release of pathological adhesions with routine intraoperative neuromonitoring. Outcomes were assessed through postoperative clinical follow-up and MRI studies.

Results: Twenty-one patients (mean age 26.2 years) were included. Back pain (81%), urinary dysfunction (67%), and radicular pain (57%) were the most common symptoms. A low-lying conus was present in 95% of subjects, and a thick filum in 76%. Split cord malformation occurred in 38% of patients and syringomyelia in 24% of patients. At a mean follow-up of 21.3 months, leg pain resolved in all affected patients, urinary incontinence improved in 78% of patients, and syringomyelia decreased in 60% of patients. Only one cerebrospinal fluid leak occurred, and no retethering was observed.

Conclusion: Microsurgical detethering resulted in meaningful symptom relief and radiological improvement in most adult TCS patients, with low complication rates. These findings support surgical intervention as an effective treatment option for symptomatic adults.

Keywords: Tethered cord syndrome, filum terminale, congenital, spine

INTRODUCTION

Tethered cord syndrome (TCS), which typically presents in childhood and is traditionally considered a pediatric condition, is now being increasingly recognized in adults[1]. Although the earliest descriptions of TCS were associated with abnormalities of the filum terminale, subsequent studies have demonstrated that lipomas, myelomeningocele, split cord malformations (SCM), and postoperative adhesions may also serve as etiological factors[2]. While congenital tension mechanisms constitute the primary cause of the disorder, cumulative mechanical stressors in adults such as prolonged sitting, strenuous activities, spine-loading movements, and pregnancy may precipitate the onset of TCS symptoms[3]. The most common reasons for adults to seek medical evaluation include low back pain, radicular complaints, sensory disturbances, and bladder dysfunction, all of which arise from neural injury due to sustained traction of the conus and nerve roots[4].

Diagnosis relies on clinical evaluation supported by magnetic resonance imaging (MRI) findings such as a low-lying conus, a thick or fatty filum, or other spinal anomalies. Importantly, the severity of radiological features does not always correlate with the degree of clinical impairment[5]. Accumulating clinical experience indicates that surgical intervention can prevent neurological decline and significantly improve, or even fully resolve, long-standing symptoms in challenging TCS cases[6]. However, questions remain regarding optimal timing of surgery and the predictability of postoperative improvement, particularly in adults with secondary tethering related to prior spinal malformations or surgical procedures[7]. Despite these uncertainties, recent studies consistently indicate that the most effective approach for halting progressive neurological

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deterioration and achieving favorable clinical outcomes in adults with TCS is surgical sectioning of the filum[8].

This study aims to assess the effectiveness of the surgical treatment we performed by analyzing the clinical and radiological data of our adult TCS patients.

MATERIALS AND METHODS

This retrospective study included adult patients who underwent surgical treatment for TCS at our institution between January 2015 and December 2024. Patients aged 18 years or older with clinical symptoms and radiological findings consistent with TCS were eligible for inclusion. Individuals with both primary TCS and secondary tethering etiologies such as myelomeningocele, SCM or lipomyelomeningocele were included. Pediatric patients, individuals who did not undergo surgery, and those with a postoperative follow-up period of less than three months were excluded from the study.

Preoperative data collected included demographic characteristics, presenting symptoms, presence of cutaneous stigmata, neurological examination findings, bladder or bowel dysfunction, MRI findings, urodynamic results, and somatosensory evoked potentials (SSEP). All patients underwent microsurgical detethering, typically via a single-level laminectomy with identification and sectioning of a tight or fatty filum terminale or release of pathological adhesions when present. Intraoperative neuromonitoring was routinely used in all cases (Figure 1A-1D). Postoperative data included complications, duration of follow-up, and clinical and radiological outcomes.

Clinical improvement was assessed based on resolution or reduction of pain, sensory deficits, motor symptoms, and bladder or bowel dysfunction. Radiological improvement was defined as postoperative evidence of a released filum or reduction of associated syringomyelia when applicable. No formal statistical analysis was performed due to the descriptive nature of the study. The study was approved by the University of Health Sciences Türkiye, Gülhane Training and Research Hospital Non-Interventional Research Ethics Committee (approval no: 2025/9, date: 16.01.2025).

Statistical Analysis

Preoperative and 1 month postoperative overall pain visual analog scale (VAS) scores were compared using a paired-samples t-test after confirming approximate normality of within-patient differences. Effect size was calculated using Cohen's dz.

RESULTS

The average age of the 21 patients included in the study was 26.2 years, with 15 (71%) male and 6 (29%) female. Back pain was the most frequent presenting symptom (81%), followed by urinary incontinence (67%) and radicular pain (57%). One patient presented solely with urinary retention. Hypertrichosis was the most common cutaneous abnormality (33%), while dermal sinus tracts and myelomeningocele scars were each observed

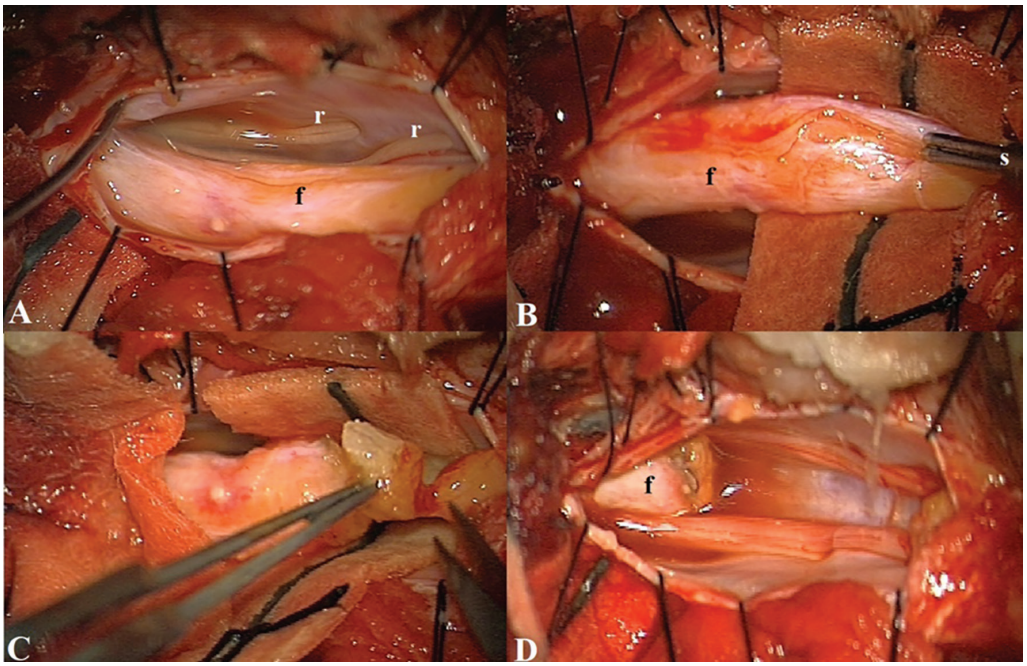

Figure 1. **A)** Intraoperative view of the lumbar region after dural opening, demonstrating a thickened and fatty filum terminale (f) and two lumbar nerve roots (r). **B)** After visual identification of the filum terminale (f), it is isolated from the nerve roots and stimulated with a bipolar neurostimulator probe (s) to confirm the absence of neural tissue and the safety of sectioning. **C)** Following confirmation that no nerve roots are present within the filum, coagulation is performed and the filum terminale is transected using microscissors. **D)** The filum terminale (f) after sectioning, demonstrating adequate release of tension

in 19% of cases. Hypoesthesia represented the most frequent neurological deficit on motor and sensory examination (24%). A conus medullaris terminating below the L2 level was defined as a low-lying conus, and this finding was identified on MRI in 95% of patients (Figure 2A-B). A thickened filum terminale (>2 mm) constituted the second most common radiological feature (76%). SCM, a well-recognized anomaly associated with TCS, was present in 38% of the cohort (Figure 2C-D). In all patients with SCM, the septum responsible for dividing the cord was removed during the same procedure in which the filum terminale was sectioned, and the surgical goals were fully achieved. Syringomyelia was also detected among the radiological abnormalities, appearing in 24% of the patients.

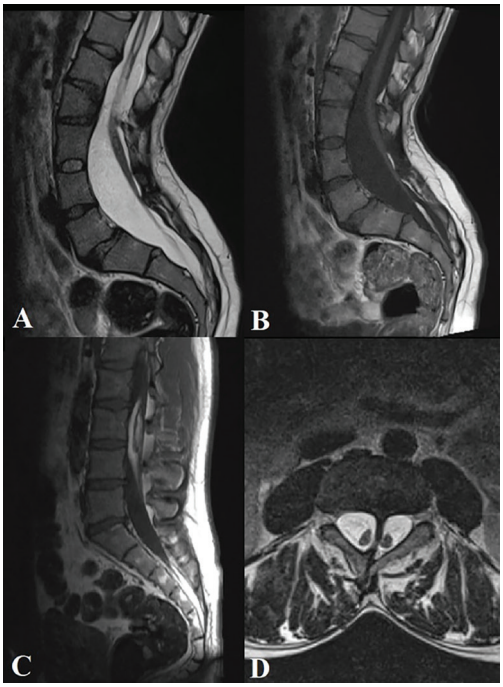

Figure 2. A) Sagittal T2-weighted lumbar MRI demonstrating a low-lying conus, a tight filum terminale, and a syrinx at the T12 level. **B)** Sagittal T1-weighted images of the same patient showing a fatty filum terminale. **C)** A filar lipoma at the L3-L4 level contributing to cord tension. **D)** Axial T2-weighted lumbar MRI revealing a bony septum dividing the spinal canal into two hemicords, consistent with split cord malformation. MRI: Magnetic resonance imaging

Neurophysiological tests, although not diagnostic in isolation, supported clinical assessment and provided objective parameters for perioperative evaluation. Delayed tibial nerve SSEP latency was found in 38% of cases, and an equal proportion demonstrated impaired urodynamic studies.

The mean postoperative follow-up was 21.3 months (range, 3-62 months). Clinical reassessments performed on the first postoperative day, at one month, and throughout follow-up demonstrated that leg pain reported preoperatively by all symptomatic patients (12 patients) had resolved by the first postoperative month at the latest. The mean preoperative VAS score was 4.33±2.58, which decreased significantly to 1.24±1.37 at 1 month postoperatively. Paired-samples t-test demonstrated a statistically significant reduction in pain scores following surgery (mean difference: 3.10±2.49; t (20)=5.70, p<0.001). The magnitude of this improvement corresponded to a large effect size (Cohen's dz =1.24).

Urinary incontinence improved in 78% of affected individuals by the sixth month, and fecal incontinence either resolved or diminished to a socially non-limiting level in two of the three patients within the same period. By final follow-up, 59% of patients reported resolution of back pain. Among those with syringomyelia, postoperative MRI demonstrated a reduction in syrinx size in 60% of cases (Table 1).

Table 1. Summary of the clinical and radiological characteristics of the patients who underwent surgery for tethered cord syndrome

Presenting symptoms	**n**	**%**
Back pain	17	81
Radicular pain	12	57
Paresthesia	6	28
Urinary incontinence	14	67
Urinary retention	1	5
Fecal incontinence	3	14
Sexual dysfunction	1	5
Cutaneous findings		
Hypertrichosis	7	33
Dermal sinus tract	4	19
Myelomeningocele scar	4	19
Neurological examination		
Hypoesthesia	5	24
Motor deficit	1	5
Unilateral lower extremity atrophy	1	5

Table 1. Continued

Presenting symptoms	n	%
MRI findings		
Low-lying conus	20	95
Thick filum	16	76
Fatty filum	6	28
Split cord malformation	8	38
Syringomyelia	5	24
Dermal sinus tract	4	19
Lipomyelomeningocele	4	19
Myelomeningocele	4	19
Scoliosis	3	14
Hydrocephalus	1	5
Abnormal urodymanic findings	8	38
Delayed tibial nerve SSEP	8	38
Clinical and radiological improvements		
Back pain	10	59
Radicular pain	12	100
Paresthesia	2	33
Urinary incontinence	11	78
Fecal incontinence	2	66
Shrinkage of the syrinx	3	60

MRI: Magnetic resonance imaging, SSEP: Somatosensory evoked potentials

Early postoperative complications were minimal. Cerebrospinal fluid (CSF) leakage at the incision site occurred in only one patient and was successfully managed with additional sutures and dressing changes. No instances of retethering were identified during the entire follow-up period.

DISCUSSION

Adult TCS encompasses a wide spectrum of clinical manifestations, and its presentation often differs from that seen in children. Pain, particularly low back or radicular pain, consistently emerges as the most frequent complaint in adults, a trend reflected both in our cohort and in numerous published series[7,9-11]. The prominence of pain in adults likely reflects the cumulative effects of prolonged mechanical traction on the conus and lumbosacral nerve roots, which aligns with the suggestion that chronic tethering may impair spinal cord blood flow and mitochondrial function, ultimately contributing to progressive neurological dysfunction[12]. Although unusual presentations such as isolated unilateral calf atrophy have been described[13], these rare manifestations are exceptions rather than the rule and were not encountered in our series.

Urinary dysfunction is another major feature of adult TCS and is often a significant driver for seeking medical care. In our cohort, bladder symptoms were the second most common presenting complaint, consistent with earlier studies documenting high rates of urinary involvement in adults[1,14,15]. Reports vary widely regarding the reversibility of bladder dysfunction following detethering, but many authors have observed partial or even substantial improvement in a notable subset of patients[7,11]. Our findings parallel these observations, showing recovery or meaningful improvement in most symptomatic individuals by the sixth postoperative month. While sensory or sphincter deficits tend to be less responsive and often require longer follow-up to demonstrate change, the degree of improvement we observed indicates that even long-standing neurological dysfunction may retain some capacity for reversibility.

Radiological findings in our patients largely mirror those documented in the literature. Nearly all patients exhibited a low-lying conus and a thickened filum terminale, features that frequently correlate with structural tethering. Co-existing anomalies, particularly SCM, also appeared at notable rates in our cohort. This observation is consistent with other adult series reporting SCM among the most common co-malformations in TCS[6,16]. The recognition of such anomalies is clinically meaningful, as their presence may influence the surgical strategy. The literature includes examples where tethering has been exacerbated or triggered by prior spinal interventions, with arachnoid adhesions forming many years after the initial procedure[17]. These delayed presentations emphasize the importance of detailed preoperative assessment, especially in adults with complex operative histories.

Surgical detethering remains the cornerstone of treatment for adult TCS, and our outcomes add to the growing evidence

supporting its efficacy. Across several published studies, pain has been the most consistently improved symptom after surgery, with many patients reporting early and durable relief[2,8,9]. Our findings align closely with these reports, as all patients with preoperative leg pain experienced resolution by the first postoperative month. Improvements in urinary dysfunction, while less uniform across studies, occurred in the majority of symptomatic individuals in our cohort. Reports from the literature suggest that bladder symptoms may recover to varying degrees but are less likely to show the dramatic early improvement seen in pain, a trend that matches the gradual but meaningful gains observed in our patients[1,7,14].

Radiological improvement following detethering was also observed, most notably in patients with syringomyelia, where over half showed a reduction in syrinx size. This is consistent with other published work documenting significant decreases in syringomyelia after effective release of the tethered cord[18]. The improvement likely reflects restoration of CSF flow dynamics and reduction of traction forces on the spinal cord, which may promote gradual collapse of the syrinx cavity.

Neurophysiological testing served as a complementary diagnostic tool. Abnormal tibial SSEP latencies were observed in many of our patients, paralleling the high rates of electrophysiological abnormalities reported by authors in the literature[19]. Although these studies are not diagnostic on their own, they provide valuable objective data supporting clinical suspicion of tethering. Intraoperative neuromonitoring, used routinely in our surgeries, had a favorable impact on postoperative motor stability according to previous analyses[20]. Our experience was similar, as no patient developed new permanent motor deficits, and the overall complication rate remained low.

The absence of retethering in our series may reflect a combination of careful surgical technique and relatively shorter follow-up compared with studies reporting recurrence rates as high as 16%[20]. Even so, the lack of symptomatic or radiographic evidence of retethering during our follow-up period is encouraging. Many authors advocate for timely surgical intervention, recommending detethering within a few years of symptom onset to prevent irreversible neurological decline[21]. Our findings reinforce this concept, as earlier symptom duration appeared to correlate with better outcomes, particularly in pain resolution.

The overall pattern of improvement in our cohort, strong relief of pain, meaningful recovery in urinary symptoms, reduction of syringomyelia, and minimal complications, fits well within the established body of evidence supporting microsurgical detethering as the primary treatment approach for symptomatic adult TCS. This benefit extends to individuals with long-standing symptoms and structural anomalies such as SCM or lipomyelomeningocele, as shown in multiple published cohorts[6,8,16].

Study Limitations

Nevertheless, several limitations must be acknowledged. Our study was retrospective and included a relatively small number of patients, which restricts the ability to identify predictors of surgical outcome or make strong statistical inferences. Variability in symptom duration, radiological features, and preoperative neurological status may also confound outcome interpretation. Despite these constraints, the overall consistency between our findings and those reported in the literature underscores the validity of our observations.

CONCLUSION

In this study, most adult patients with symptomatic TCS experienced meaningful improvement after microsurgical detethering. Pain tended to resolve early, while bladder symptoms and radiological abnormalities also improved in a considerable portion of the cohort. Patients with long-standing complaints or co-existing conditions such as SCM benefited as well, suggesting that symptom duration or anatomical complexity does not necessarily limit the potential for recovery. The procedure was safe in our experience, with only one minor complication and no cases of retethering during follow-up. Although the retrospective design and small sample size restrict the strength of our conclusions, the overall pattern of improvement aligns with growing evidence favoring surgical treatment in adults with TCS. Larger studies with systematic outcome measures may help clarify which patients are most likely to benefit and how postoperative recovery unfolds over time.

Ethics

Ethics Committee Approval: The study was approved by the University of Health Sciences Türkiye, Gülhane Training and Research Hospital Non-Interventional Research Ethics Committee (approval no: 2025/9, date: 16.01.2025).
Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.C.E., Concept: M.C.E., S.K., Design: M.C.E., Data Collection or Processing: M.C.E., S.K., Analysis or Interpretation: M.C.E., S.K., Literature Search: M.C.E., Writing: M.C.E., S.K.
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LEVEL OF AWARENESS OF SCOLIOSIS AMONG STUDENTS AT SÜLEYMAN DEMİREL UNIVERSITY FACULTY OF MEDICINE

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ABSTRACT

Objective: To determine the level of scoliosis awareness among medical students and to examine demographic factors associated with awareness, including age, gender, and academic year.

Materials and Methods: This cross-sectional, survey-based study was conducted among undergraduate medical students enrolled in Süleyman Demirel University Faculty of Medicine between March 1 and April 30, 2025. A structured questionnaire developed through literature review and expert opinion was administered online. The questionnaire collected demographic data and consisted of 11 items assessing awareness of scoliosis. Of the 1.555 students invited, 906 valid questionnaires were included in the final analysis. Descriptive statistics were calculated, and differences in awareness levels according to demographic variables were analyzed using the chi-square test.

Results: The majority of participants were female (56.1%) and were aged between 18 and 22 years. Most respondents were first- and fourth-year students (28.5% and 25.6%, respectively). Overall, 93.2% of participants had heard of scoliosis; 70.5% reported moderate awareness, and 11.1% reported good awareness. Awareness levels differed significantly according to age group (p=0.012) and academic year (p<0.001), with higher proportions of good awareness observed among third- and sixth-year students. No significant difference in awareness levels was observed by gender (p=0.417). Although belief in the availability of treatment options was high (74.3%), awareness of scoliosis symptoms was limited to 59.1%. Participation in scoliosis awareness campaigns was very low (2.1%), whereas most participants (90.7%) supported organizing awareness activities in schools and public spaces.

Conclusion: Medical students demonstrated basic awareness of scoliosis; however, notable gaps remain, particularly in recognizing symptoms and participating in awareness campaigns. Although awareness increases with academic progression, integrating scoliosis awareness into structured curricula, social responsibility initiatives, and community-based education programs may enhance student engagement and contribute to improved public health outcomes.

Keywords: Scoliosis, awareness, medical students, medical education, public health

INTRODUCTION

Scoliosis is a three-dimensional skeletal deformity characterized by a lateral curvature of the spine greater than 10 degrees from the midline, typically presenting in an "S" or "C" shape. This deformity is not limited to lateral deviation of the vertebrae but is also marked by vertebral rotation around their own axis. Scoliosis is a complex spinal disorder that can lead to both structural and functional impairments[1].

The diagnosis of scoliosis begins initially with a clinical evaluation. The patient's posture, asymmetries between shoulder and hip levels, and curvature of the waistline are carefully observed. The most used clinical assessment method is the Adam's forward bend test, during which the patient is asked to bend forward, and rib prominence or asymmetry in the thoracic or lumbar regions is examined[2]. To confirm the diagnosis, standing posteroanterior and lateral radiographs are required. The spinal curvature is measured on these radiographs using the Cobb angle, and a diagnosis of scoliosis is established when the angle is 10 degrees or greater[3].

Scoliosis is classified into various categories based on factors such as age of onset, etiology, location, and severity of the curvature. The most common form in the general population is adolescent idiopathic scoliosis (AIS)[4]. The overall prevalence of this form emerges during adolescence has been reported in the literature to range between 0.47% and 5.2%[5]. Females have a higher risk of developing scoliosis compared to males, with a

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female-to-male ratio ranging from 1.5:1 to 3.1. Besides, higher Cobb angles are considerably more frequent in females than in males[4].

Early diagnosis decelerates the progression of scoliosis and reduces the need for surgical intervention. The level of knowledge among healthcare professionals regarding scoliosis plays a crucial role in the early detection of affected individuals and their timely referral to medical facilities. Thus, it is especially important that medical students possess adequate knowledge about the definition, clinical findings, epidemiology, and treatment approaches of scoliosis; this is crucial for proper patient referral and enhancing the effectiveness of the treatment process[6].

The treatment of scoliosis should be individualized with respect to the patient's age, degree of curvature, and accompanying symptoms. In mild cases, regular clinical follow-up and exercise programs may be sufficient, whereas physical therapy and specific exercises aimed at improving spinal stability are recommended for moderate cases. In advanced deformities, surgical intervention is an effective treatment option, particularly to preserve spinal balance and pulmonary functions. Due to the multifaceted nature of scoliosis, the treatment process should be managed through a multidisciplinary approach[4].

The aim of this study was to determine the level of scoliosis awareness among medical students and to examine factors associated with awareness levels, including age, gender, and academic year.

MATERIALS AND METHODS

This survey-based cross-sectional study was approved by the Süleyman Demirel University Scientific Research Publication Ethics Committee (approval no: 90/2, date: 29.01.2025), and all necessary permissions for conducting the research were obtained. All stages of the study were carried out in accordance with the principles of the Helsinki Declaration.

Participants and Procedure

This cross-sectional descriptive study was conducted among 1st, 2nd, 3rd, 4th, 5th, and 6th year undergraduate students enrolled at Süleyman Demirel University Faculty of Medicine. Data were collected between March 1 and April 30, 2025. The total registered student population at the faculty consists of 1555 individuals. Students who voluntarily completed the online questionnaire and met the inclusion criteria participated in the study.

In the introduction section of the questionnaire, participants were informed about the purpose, scope, and confidentiality principles of the study. The informed consent form was provided online, and only students aged 18 and above who were able to read and understand Turkish and who checked the box stating, "I voluntarily agree to participate in the study" were included. Participants who submitted incomplete questionnaires or did not provide consent were excluded from the study.

The questionnaire was developed by the researchers based on a review of relevant literature. Content validity was evaluated through expert opinion from two orthopedic surgeons and one medical education specialist. A pilot test was conducted with 20 medical students to ensure clarity and comprehensibility. The online questionnaire developed by the researchers consisted of two sections. The first section included questions about participants' demographic information, such as age, gender, and academic year. The second section comprised a knowledge assessment form with 11 questions aimed at measuring scoliosis awareness. Questions 5-14 were structured with response options appropriate to the content of each item (e.g., yes/no/undecided or multiple-choice formats), while the final question was open-ended (Table 1).

A total of 1555 students responded to the questionnaire. After excluding incomplete forms, 906 valid questionnaires (58%) were included in the final analysis. At Süleyman Demirel University Faculty of Medicine, scoliosis education is primarily delivered during the 5th-year orthopedics and traumatology clerkship.

The questionnaire was digitized using the Google Forms platform (Google LLC, California, USA) and distributed to participants via WhatsApp groups managed by the class representatives of Süleyman Demirel University Faculty of Medicine. Participants

Table 1. Questions listed in the scoliosis awareness level assessment form

Question no	Content of question
1	What is your gender?
2	What age group do you belong to?
3	Which academic year are you in?
4	Which region of Türkiye do you live in?
5	Have you heard of scoliosis before?
6	Has a close acquaintance ever been diagnosed with scoliosis?
7	(If the answer to the previous question is "Yes") How was scoliosis noticed?
8	What is your level of knowledge about scoliosis?
9	Which gender do you think is more affected by scoliosis?
10	Do you believe that scoliosis patients have treatment options?
11	Are you aware of the symptoms of scoliosis?
12	Have you participated in any campaign or event related to scoliosis awareness?
13	Do you think there is sufficient awareness about scoliosis in your region?
14	Do you support organizing exhibitions in schools, universities, and public spaces to increase scoliosis awareness?
15	What do you recommend raising scoliosis awareness?

Table 2. Demographic characteristics of participants and their perspectives on scoliosis awareness (n=906)

Characteristics	Categories	n (%)
Gender	Male	401 (43.9)
	Female	505 (56.1)
Age range (years)	18-20	306 (33.8)
	20-22	348 (38.4)
	22-24	217 (24.0)
	≥24	35 (3.9)
Academic year	1st year	258 (28.5)
	2nd year	130 (14.3)
	3rd year	182 (20.1)
	4th year	232 (25.6)
	5th year	80 (8.8)
	6th year	24 (2.6)
Region of residence in Türkiye	Mediterranean	647 (73.1)
	Eastern Anatolia	16 (1.8)
	Aegean	77 (8.7)
	Central Anatolia	121 (13.7)
	Black Sea	14 (1.6)
	Marmara	10 (1.1)
	Not specified/ missing	21 (2.3)
Heard of scoliosis before	No	62 (6.8)
	Yes	844 (93.2)
Close acquaintance diagnosed with scoliosis	No	548 (60.5)
	Yes	358 (39.5)
Self-reported scoliosis awareness level	I don't know	166 (18.3)
	Moderate	639 (70.5)
	Good	101 (11.1)
Gender perceived to be more affected by scoliosis	Male	206 (22.7)
	Female	443 (48.9)
	Both	257 (28.4)
Belief that scoliosis has treatment options	No	40 (4.4)
	Yes	673 (74.3)
	Undecided	193 (21.3)
Awareness of scoliosis symptoms	No	371 (40.9)
	Yes	535 (59.1)
Participation in scoliosis awareness campaigns	No participation	880 (97.1)
	Participated	19 (2.1)
	Participated, no perceived benefit	7 (0.8)
Perceived sufficiency of scoliosis awareness in region	No	596 (65.8)
	Yes	56 (6.2)
	Undecided	254 (28.0)
Support for organizing scoliosis awareness events	No	84 (9.3)
	Yes	822 (90.7)

who completed the questionnaire submitted their responses online, and the data were digitally recorded by the researchers. Data related to age, gender, academic year, and knowledge of scoliosis from participants who met the eligibility criteria were used in the analysis.

Description: This form, designed to assess participants' knowledge, experience, and awareness regarding scoliosis, consists of multiple-choice and open-ended questions. Some questions (5-14) are answered with options such as "yes, no, and undecided" while question 15 is open-ended, allowing participants to express their opinions.

Statistical Analysis

Statistical analysis of the study were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were presented as frequencies (percentages). The chi-square test was used to determine relationships among variables obtained from the knowledge form. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Most of the participants were female (56.1%), and the majority were between 18 and 22 years of age. Most participants were first-year (28.5%) and fourth-year (25.6%) medical students. The majority of respondents resided in the Mediterranean Region (73.1%). Approximately 93.2% of the participants reported that they had heard the term scoliosis before, and 39.5% stated that a close acquaintance had been diagnosed with scoliosis. Most participants described their level of scoliosis awareness as moderate (70.5%), and 48.9% believed that scoliosis affects females more frequently. Belief in the availability of treatment options was high, with 74.3% considering scoliosis to be treatable. However, only 59.1% reported being aware of the symptoms of scoliosis. The vast majority of participants (97.1%) had not participated in any scoliosis awareness campaigns, and 65.8% believed that scoliosis awareness in their region was insufficient. Nevertheless, 90.7% supported the organization of awareness events in schools and public spaces (Table 2). Responses to the open-ended question most frequently emphasized the need for public education campaigns, school-based screening programs, and increased use of social media to raise scoliosis awareness.

Differences in self-reported scoliosis awareness levels were examined according to demographic variables. A statistically significant difference was observed in awareness levels across age groups (p=0.012). The proportion of participants aged ≥24 years who reported a "good" level of awareness (22.9%) was higher than that observed in other age groups. Awareness levels also differed significantly according to academic year (p<0.001). Notably, third- and sixth-year students demonstrated higher proportions of "good" awareness levels (17.6% and 33.3%, respectively). In contrast, the proportions of participants

reporting "I don't know" were higher among first- and second-year students (23.6% and 23.8%, respectively). No statistically significant difference in awareness levels was observed according to gender (p=0.417), with similar distributions between male and female participants (Table 3).

The study findings indicate that the knowledge of students and attitudes regarding scoliosis vary by their academic year. Differences were observed in the variables related to beliefs about which gender scoliosis affects more and knowledge of its symptoms (p<0.001). The higher level of symptom knowledge among upper-year students suggests that health-related awareness increases with educational level. No statistically significant differences were found between grade levels for the other variables (Table 4).

Table 3. Differences in self-reported scoliosis awareness levels according to demographic variables

Variable	Category	I don't know n (%)	Moderate n (%)	Good n (%)	p-value
Gender	Male	83 (21.0)	264 (66.8)	48 (12.2)	0.417
	Female	81 (16.0)	373 (73.9)	51 (10.1)	
Age range (years)	18-20	66 (21.6)	211 (69.0)	29 (9.5)	0.012*
	20-22	61 (17.5)	250 (71.8)	37 (10.6)	
	22-24	34 (15.7)	156 (71.9)	27 (12.4)	
	≥24	5 (14.3)	22 (62.9)	8 (22.9)	
Academic year	1st year	61 (23.6)	177 (68.6)	20 (7.8)	<0.001*
	2nd year	31 (23.8)	92 (70.8)	7 (5.4)	
	3rd year	22 (12.1)	128 (70.3)	32 (17.6)	
	4th year	37 (15.9)	176 (75.9)	19 (8.2)	
	5th year	12 (15.0)	53 (66.3)	15 (18.8)	
	6th year	3 (12.5)	13 (54.2)	8 (33.3)	

*: Statistically significant at p<0.05 (chi-square test)

Table 4. Distribution of scoliosis awareness and perceptual variables according to academic year

Variable	Response	1st year	2nd year	3rd year	4th year	5th year	6th year	p-value
Have you heard of scoliosis before?	No	24 (9.3)	7 (5.4)	15 (8.2)	11 (4.7)	3 (3.8)	2 (8.3)	0.075
	Yes	234 (90.7)	123 (94.6)	167 (91.8)	221 (95.3)	77 (96.3)	22 (91.7)	
Has a close acquaintance been diagnosed with scoliosis?	No	159 (61.6)	85 (65.4)	102 (56.0)	150 (64.7)	41 (51.3)	11 (45.8)	0.190
	Yes	99 (38.4)	45 (34.6)	80 (44.0)	82 (35.3)	39 (48.8)	13 (54.2)	
Which gender do you think is more affected by scoliosis?	Male	42 (16.3)	42 (32.3)	46 (25.3)	55 (23.7)	16 (20.0)	5 (20.8)	<0.001*
	Female	108 (41.9)	42 (32.3)	95 (52.2)	133 (57.3)	52 (65.0)	13 (54.2)	
	Both	108 (41.9)	46 (35.4)	41 (22.5)	44 (19.0)	12 (15.0)	6 (25.0)	
Do you believe that scoliosis patients have treatment options?	No	9 (3.5)	5 (3.8)	8 (4.4)	14 (6.0)	3 (3.8)	1 (4.2)	0.073
	Yes	189 (73.3)	95 (73.1)	133 (73.1)	170 (73.3)	69 (86.3)	17 (70.8)	
	Undecided	60 (23.3)	30 (23.1)	41 (22.5)	48 (20.7)	8 (10.0)	6 (25.0)	
Are you aware of the symptoms of scoliosis?	No	122 (47.3)	64 (49.2)	83 (45.6)	84 (36.2)	12 (15.0)	6 (25.0)	<0.001*
	Yes	136 (52.7)	66 (50.8)	99 (54.4)	148 (63.8)	68 (85.0)	18 (75.0)	

*: Statistically significant at p<0.05 (chi-square test)

Comparisons based on gender revealed notable differences in certain scoliosis awareness indicators. The rate of having a close acquaintance diagnosed with scoliosis was significantly higher among female participants compared to males (p=0.010). Additionally, the perception that scoliosis affects females more frequently was considerably more prevalent among female participants (p<0.001). No significant gender-based differences were found in the other variables. These findings indicate that female individuals have different experiences and perceptions regarding scoliosis compared to males (Table 5).

DISCUSSION

In this study, the knowledge levels, awareness, and attitudes of students from the Süleyman Demirel University Faculty of Medicine regarding scoliosis were evaluated. The findings indicate that a large proportion of students were familiar with the term scoliosis and believed that it is treatable. In addition, differences in awareness levels were observed across academic years and age groups, while participation in scoliosis awareness activities was found to be very limited.

A total of 93.2% of participants reported having heard the term scoliosis before. This rate is higher than the awareness levels reported in previous studies. For example, a study conducted among health sciences students in Indonesia found that 72.4% of participants were knowledgeable about scoliosis[7]. The higher familiarity observed in the present study may be explained by medical students' greater exposure to fundamental health-related concepts.

Regarding self-reported awareness levels, 70.5% of participants described their awareness as "moderate" while 11.1% reported a "good" level of awareness. Awareness levels differed significantly according to academic year, with higher proportions of "good" awareness observed among third- and sixth-year students (p<0.001). This finding is consistent with the transition to clinical training in the third year and increased exposure to both theoretical and practical knowledge during the final year of medical education. Similarly, a study by Cuschieri and Grech[8] involving 101 medical students reported that although 62.38% had heard of AIS, substantial gaps remained in knowledge related to risk factors, screening, and treatment thresholds. While students in clinical years demonstrated higher awareness levels, gaps in etiological understanding and conservative treatment approaches persisted. Doucet et al.[6] likewise emphasized that awareness and knowledge levels tend to increase throughout health sciences education.

The proportion of female students reporting close acquaintances diagnosed with scoliosis was significantly higher than that of male students (p=0.010). In addition, the perception that scoliosis affects females more frequently was more common among female participants (p<0.001). These findings are consistent with the literature indicating that AIS occurs more frequently in females and that curve progression risk is higher in this group[4,5]. However, no statistically significant difference was observed between genders in terms of awareness of scoliosis symptoms.

Overall, 59.1% of participants reported being aware of the symptoms of scoliosis. Despite widespread access to information, this finding suggests that symptom awareness remains insufficient. The significant increase in symptom awareness across academic years (p<0.001) highlights the importance of clinical exposure in recognizing scoliosis-related physical findings. Early identification of these signs has been shown to improve treatment outcomes[9]. Kuru Çolak et al.[10] evaluated 611 students from 60 universities, including 155 medical students, and reported that a substantial proportion of fourth-year students graduated without basic knowledge of scoliosis. In contrast, symptom awareness among fourth-year students was relatively higher in the present study. Most existing studies have focused on physiotherapy students and practitioners. For instance, Akgül et al.[11] reported that only 19.5% of physiotherapy students and 30.7% of physiotherapists correctly

Table 5. Comparison of scoliosis awareness, knowledge level, and perceptions according to gender

Variable	Response	Male n (%)	Female n (%)	p-value
Have you heard of scoliosis before?	No	31 (7.8)	29 (5.7)	0.209
	Yes	364 (92.2)	476 (94.3)	
Has a close acquaintance been diagnosed with scoliosis?	No	257 (65.1)	286 (56.6)	0.010*
	Yes	138 (34.9)	219 (43.4)	
Which gender do you think is more affected by scoliosis?	Male	130 (32.9)	75 (14.9)	<0.001*
	Female	153 (38.7)	288 (57.0)	
	Both	112 (28.4)	142 (28.1)	
Do you believe that scoliosis patients have treatment options?	No	18 (4.6)	21 (4.2)	0.588
	Yes	288 (72.9)	381 (75.4)	
	Undecided	89 (22.5)	103 (20.4)	
Are you aware of the symptoms of scoliosis?	No	175 (44.3)	192 (38.0)	0.057
	Yes	220 (55.7)	313 (62.0)	

*: Statistically significant at p<0.05 (chi-square test)

identified diagnostic criteria for scoliosis, while du Toit et al.[12] reported a rate of 56%among physiotherapists involved in orthopedic rehabilitation. Although medical students may have stronger theoretical backgrounds, these findings indicate persistent gaps in practical knowledge related to diagnosis and treatment algorithms.

Participation in scoliosis awareness campaigns was notably low, with only 2.1% of participants reporting previous attendance, while 97.1% had never participated in such events. This low participation suggests that scoliosis remains insufficiently visible as a public health issue. Public awareness initiatives conducted during scoliosis awareness month (June) have been shown to play a critical role in early diagnosis[13,14]. In comparison, a cross-sectional study conducted in Saudi Arabia reported a 12% participation rate in awareness campaigns[15]. In the present study, 90.7% of participants supported the organization of awareness activities in schools and public spaces, underscoring the need to expand such initiatives.

Study Limitations

Several limitations of this study should be acknowledged. Although the medical curriculum is predominantly theoretical, scoliosis education is primarily delivered during the fifth-year orthopedics and traumatology clerkship. The relatively low participation rate of fifth- and sixth-year students, who receive formal clinical training in scoliosis, represents an important limitation when interpreting educational outcomes. In addition, the absence of complete demographic data regarding the total population exposed to the survey limits the generalizability of the findings to all medical students in Türkiye.

CONCLUSION

This study evaluated the knowledge and awareness levels of students at Süleyman Demirel University Faculty of Medicine regarding scoliosis. Although awareness increased significantly with academic year and age, no significant difference was observed according to gender. Enhancing medical students' awareness of scoliosis, a condition that can be effectively managed with early diagnosis, is essential for both individual and public health. Delayed recognition may result in missed early intervention opportunities, leading to advanced-stage AIS and increased long-term healthcare burden. Therefore, in addition to clinical education, integrating scoliosis awareness into social responsibility initiatives and community-based education programs may enhance student engagement, promote active participation in public health efforts, and contribute to both societal benefit and the development of students' personal awareness.

Ethics

Ethics Committee Approval: This survey-based cross-sectional study was approved by the Süleyman Demirel University Scientific Research Publication Ethics Committee (approval no: 90/2, date: 29.01.2025).

Informed Consent: The informed consent form was provided online.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Ü.Ü.S., R.D., Concept: A.T., Ü.Ü.S., R.D., Design: Ü.Ü.S., R.D., Data Collection or Processing: A.T., D.N.T., E.S.G., A.G., İ.S., Analysis or Interpretation: İ.S., Ü.Ü.S., Literature Search: A.T., D.N.T., E.S.G., A.G., Writing: A.T., D.N.T., E.S.G., A.G., İ.S.

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TRI-PLATFORM TRENDS IN ENDOSCOPIC SPINE SURGERY: A DECADE OF DIGITAL SEARCH BEHAVIOR AND ACADEMIC OUTPUT (2015-2025)

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ABSTRACT

Objective: Endoscopic spine surgery (ESS) has emerged as a widely adopted minimally invasive technique for the treatment of spinal disorders. Over the past decade, both clinical utilization and scholarly attention toward ESS have increased. This study aimed to examine temporal trends in public and academic engagement with ESS across multiple digital platforms.

Materials and Methods: Data from Google trends and YouTube searches for the terms "endoscopic spine surgery" and "endoscopic discectomy" were were collected as monthly relative search volume (RSV) series covering 1 October 2015-1 October 2025. Monthly RSVs were then aggregated to yearly values (annual arithmetic mean and annual sum) for year-level analyses. Bibliometric data were retrieved from the Scopus database for the same period. Temporal patterns were assessed using linear regression, and correlations between online search activity and publication output were examined using statistical analysis.

Results: The annual number of ESS-related publications demonstrated a significant upward trend over time (adjusted R^2=0.966). Public interest, as reflected by Google and YouTube search activity, showed parallel increases during the study period. A very strong positive correlation was observed between annual YouTube RSV and Scopus publication counts (Pearson's r=0.956). This relationship remained statistically significant after correction for multiple comparisons (unadjusted $p=4.29\times10^{-6}$, Benjamini-Hochberg adjusted $p=1.72\times10^{-5}$), supporting the robustness of the association.

Conclusion: This tri-platform analysis demonstrates a sustained and parallel increase in both public and academic engagement with ESS over the past decade. Rather than implying causality, the observed associations highlight concurrent temporal trends and underscore the growing role of digital platforms in shaping the awareness and dissemination of surgical knowledge. These findings should be interpreted as descriptive and hypothesis-generating, emphasizing the importance of accurate, evidence-based online content to support clinical education and informed engagement.

Keywords: Endoscopic spine surgery, endoscopic discectomy, minimally invasive spine surgery, Google trends, YouTube, bibliometric analysis, digital health trends

INTRODUCTION

Endoscopic spine surgery (ESS) has emerged over the past two decades as a transformative approach in spine care. Initially developed for lumbar discectomy (LD) procedures, it has evolved into a versatile surgical method applicable to lumbar stenosis, cervical and thoracic pathologies, spinal infections, and even interbody fusion surgeries[1]. Advances in high-definition endoscopic optics, improved instrumentation, and irrigation technologies have enabled surgeons to access and treat spinal pathologies through small percutaneous incisions, minimizing collateral tissue damage and enhancing surgical visualization[2].

The clinical benefits of ESS are increasingly well documented. Patients typically report less postoperative pain, lower complication rates, and quicker return to work or daily activities[2]. However, barriers such as steep learning curves, the need for advanced training, and high equipment costs remain significant challenges for widespread adoption among spine surgeons[3].

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With the growth of patient-centered healthcare and digital literacy, analyzing public interest in medical procedures has become increasingly important. Today, patients actively participate in decision-making and remain informed about current developments and new treatments. Tools such as Google trends, YouTube search analytics, and publication databases like PubMed offer valuable insights into how public and academic attention evolves. In orthopedic and spine surgery literature, several studies have utilized these tools to assess interest in topics such as arthroplasty, stem cell injections, and foot and ankle procedures[4-9]. These trends reflect both patient curiosity and the demand for less invasive, faster-recovery surgical options. Despite its growing popularity, no comprehensive study has assessed ESS using a multimodal approach that integrates Google trends, YouTube behavior, and Scopus academic output. The objective of this study is to quantitatively evaluate the growing interest in ESS from both public and scientific perspectives via global Google search trends (GT), YouTube search trends (YT) and the frequency of peer-reviewed publications via Scopus trends. We hypothesized that public interest in ESS, as reflected by online search activity, has increased in parallel with academic output over the past decade. Specifically, we anticipated a positive temporal association between trends in digital search behavior and the volume of peer-reviewed publications, reflecting the simultaneous growth of public engagement and scientific research in this field.

MATERIALS AND METHODS

A multiplatform analysis was conducted to evaluate public and academic interest in endoscopic spinal procedures. Data were obtained from Google trends, YouTube trends (via Google trends YouTube filter), and the Scopus database, focusing on the search terms "endoscopic discectomy (ED)" and "ESS". The search terms "ESS" and "ED" were chosen to strike a balance between terminological accuracy and common usage. While more specific terms like "full-endoscopic" or "unilateral biportal endoscopy" exist in search engines, these expressions are not consistently used across different databases and time periods. Therefore, we opted to use the two more comprehensive terms from ESS. The study period (October 2015-October 2025) was selected to represent a complete and recent decade for longitudinal trend analysis, serving as a methodological convention rather than reflecting a specific milestone year in the evolution of ESS.

Google Trends

Google trends is a free, open-access tool that tracks the frequency of specific search terms entered into the Google search engine over time and across geographic regions. For any given term, GT presents data as relative search volume (RSV), normalized on a scale from 0-100. A value of 100 indicates peak popularity during the selected period and region, whereas other data points are scaled proportionally. A value of 0 denotes that the term had a search frequency of less than 1% of the peak RSV during that time. When multiple terms are compared, RSV values are relative to the most popular term in the group. In this study, Google trends data were extracted via the "web search" option, worldwide, spanning October 2015-October 2025. Monthly RSV data were downloaded in comma-separated values format and subjected to linear regression analysis[10,11].

YT Analysis

Unlike general web searches, YouTube offers access to direct demonstrations of surgical procedures, expert presentations, and patient explanations, making it a critical platform for assessing the interest of both the public and healthcare professionals. Public interest in video-based search behavior was evaluated using the YouTube search filter within Google trends. The same keywords were queried under the "YouTube search" setting, restricted to worldwide data for October 2015-October 2025. Monthly RSVs were retrieved and analyzed via linear regression to assess temporal changes

Scopus Bibliometric Analysis

A comprehensive bibliometric search was conducted via the Scopus database on October 2025. The following query was applied: [TITLE-ABS-KEY("ED") OR TITLE-ABS-KEY("ESS")] AND PUBYEAR >2014 AND PUBYEAR <2026 AND [LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO(DOCTYPE,"re")] AND [LIMIT-TO(PUBSTAGE,"final")] AND (LIMIT-TO (SRCTYPE,"j")] AND [LIMIT-TO (LANGUAGE,"English")]. Only articles and review papers published in English and indexed as final publications in peer-reviewed journals between 2015 and 2025 were included. A total of 1307 records were retrieved and exported for further bibliometric trend analysis. To ensure methodological consistency and data reliability, only peer-reviewed original articles and review articles indexed as final publications in Scopus were included. Conference proceedings, editorials, letters, and other non-peer-reviewed document types were excluded, as these formats often differ in review rigor and may introduce heterogeneity that could confound bibliometric trend analyses.

Statistical Analysis

Annual publication data from Scopus were combined with four time series representing public interest: YouTube trends for ESS, Google trends for ESS, YouTube trends for ED, and Google trends for ED. Raw monthly "month/value" tables were converted to date format and sorted chronologically. Missing observations were retained. The data were loaded into the RStudio platform (Ver. 2025.05.1+513) using the readxl package. The tidyr, tibble, dplyr, tidyverse, lubridate, broom, and ggpmisc packages were used for table preprocessing and statistical analysis. For each monthly series, two annual summaries were calculated: the arithmetic mean (value_mean) and the total sum (value_sum). These yearly aggregates were then merged with the Scopus data via the "year" variable, yielding a comprehensive table (year+pubs+*_mean/*_sum), as presented in Table 1.

Table 1. Annual summary of public interest and academic output related to ESS (2015-2025). The table presents yearly data from GT and YT for the search terms ESS and ED together with the corresponding number of peer-reviewed publications indexed in Scopus. For each search term, annual mean and total RSV values are reported, enabling direct comparison between public search interest and scientific publication trends over time

Year	Pubs_sum	YT-ESS_mean	GT-ESS_mean	YT-ED_mean	GT-ED_mean	YT-ESS_sum	GT-ESS_sum	YT-ED_sum	GT-ED_sum
2015	18	0	16	0	39.1666666666667	0	96	0	235
2016	35	0	25.0833333333333	0	29.0833333333333	0	301	0	349
2017	48	3.41666666666667	17.25	14.3333333333333	32.5833333333333	41	207	172	391
2018	56	17.75	19.3333333333333	45.6666666666667	34.3333333333333	213	232	548	412
2019	81	16.3333333333333	23.8333333333333	49.1666666666667	38.0833333333333	196	286	590	457
2020	132	26.5	26.6666666666667	34.75	32.75	318	320	417	393
2021	123	40.8333333333333	39.75	28.9166666666667	31.5833333333333	490	477	347	379
2022	132	36.9166666666667	44.6666666666667	28.6666666666667	35.3333333333333	443	536	344	424
2023	161	58.4166666666667	51.25	41.5	50.6666666666667	701	615	498	608
2024	188	80.8333333333333	61	52	55.0833333333333	970	732	624	661
2025	192	84.5714285714286	76.5714285714286	63.4285714285714	70.7142857142857	592	536	444	495

ESS: Endoscopic spine surgery, GT: Google search trends, YT: YouTube search trends, ED: Endoscopic discectomy, RSV: Relative search volume, Pubs: Publication counts

For each annual *_mean series we fitted;
(a) an ordinary least squares (OLS) model pubs~search_mean,
(b) a log-log model log (pubs+1)~log (search_mean+1) to assess elasticity and stabilize variance, and
(c) a robust regression using Huber M-estimation (MASS::rlm) to assess sensitivity to influential observations. Regression standard errors, coefficients, and p/adusted-p values are reported.

A linear regression model (pubs~year) was employed to assess the temporal trend in Scopus publication counts. Both the observed and fitted values were visualized, with the regression equation and corresponding adjusted R^2 displayed on the graph. For all regression models, the statistical significance of the slope was assessed using a t-test. The same approach was applied to the monthly trend models.

Model Fit and Error Metrics

To assess how well simple linear trends fit the monthly platform series, we calculated three complementary fit/error metrics for each monthly series:

- Mean absolute percentage error (MAPE),
- Mean absolute deviation (MAD), and
- Mean squared deviation (MSD).

These metrics were computed between observed monthly values and trend-predicted values as follows:

$$\mathbf{MAPE} = \frac{1}{n}\sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{y_i} \right| \times 100$$

$$\mathbf{MAD} = \frac{1}{n}\sum_{i=1}^{n} | y_i - \hat{y}_i |$$

$$\mathbf{MSD} = \frac{1}{n}\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

MAPE expresses relative percentage error. MAD reports the average absolute error in the original measurement units. MSD emphasizes larger deviations by squaring residuals. We note that MAPE is undefined when $y_i=0$ $y_i=0$. In such cases (rare in our monthly series), the denominator was set to 1 for the affected months, and the presence of zeros is explicitly reported. These metrics are used here as descriptive summaries to compare the quality of trend fits across series. They are not used as dichotomous "accept/reject" criteria because acceptable thresholds depend on context.

Pearson and Spearman correlation coefficients were computed between annual publication counts (pubs) and each platform's annual mean. As multiple pairwise tests were performed, p-values were adjusted using the Benjamini-Hochberg method. Adjusted p-values are reported as p_adj. To explore temporal relationships, we computed Pearson correlations between search_t and pubs_{t+L} for lags of L=0,1,2,3 years. These lag correlations are exploratory and reported with BH-adjusted p-values where applicable. For each annual *_mean series, we fitted;

(a) an OLS model pubs~search_mean,
(b) a log-log model log (pubs+1)~log (search_mean+1) to assess elasticity and stabilize variance, and
(c) a robust regression using Huber M-estimation (MASS::rlm) to assess sensitivity to influential observations. Regression standard errors, coefficients, and p-values (adjusted for multiple comparisons) are reported.

RESULTS

The monthly YT-ESS series (YouTube index for ESS) exhibited a positive long-term trend, with periodic peaks and sharp increases. A linear trend line confirmed a statistically significant increase over time (Figure 1).
The GT-ESS series (Google trends index for ESS) also showed an upward trend, with intermittent surges in interest, which is consistent with growing public curiosity (Figure 2).
Linear fits for YT-ED and GT-ED (YouTube and Google trends indices for ED) also indicated a generally increasing trend. However, these series displayed greater volatility, with zero-level plateaus and intermittent spikes. Consequently, these series yielded higher error metrics (MAPE, MAD, and MSD), suggesting more variability in public interest (Figures 3 and 4).
A significant upward trend was observed in the annual number of publications in Scopus, as indicated by the linear regression model (pubs~year), yielding the equation y=-36896.73+18.318×year with adjusted R^2=0.966, demonstrating that the linear model explains a substantial portion of the year-to-year variation in publication counts (Figure 5).
There is a strong, statistically significant association between YT-ESS and annual Scopus publication counts (Pearson's r≈0.956, p≪0.001). GT-ESS mean is also strongly and positively associated with annual publication counts (Pearson's r≈0.909, p<0.001). The YT-ED and GT-ED series also show positive correlations (YT-ED r≈0.762, p≈0.006; GT-ED mean r≈0.713, p≈0.014). The OLS regression pubs~YT-ESS_mean yielded an intercept ≈41.64 and a slope ≈1.94, indicating that, on average, a one-unit increase in the YouTube index is associated with approximately 1.94 additional publications per year (σ^2≈363.5, Akaike information criterion ≈99.86). A log-log transformation (logpubs~log_YT-ESS) was also significant, with a log-coefficient ≈0.446, indicating positive elasticity on a percentage-change basis. Results from a robust regression (Huber M-estimator) produced coefficients consistent with OLS (robust slope ≈1.94), suggesting that outliers do not unduly drive the estimates. Monthly time-series plots show a long-term upward trend alongside isolated sharp peaks reflecting episodic effects. Durbin-Watson tests indicate residual autocorrelation in some models. Cook's distance analysis identifies a single influential observation in the GT-ESS series; such influential points can materially affect estimated coefficients and should be considered when interpreting results (Figure 6).
A strong positive association was observed between YouTube search interest for ESS (YT-ESS) and annual Scopus publication counts (r≈0.96, p<0.001). Google trends for ESS (GT-ESS) also showed a strong positive correlation with publication volume (r≈0.91, p<0.001). Search trends for ED demonstrated moderate positive associations. Linear regression analysis indicated that increases in YouTube search interest were associated with higher annual publication output. YT-ESS correlates very strongly with annual Scopus publication counts (Pearson's r=0.956, p<0.001; Spearman's rho similar). The OLS model pubs~YT-ESS_mean returned an estimated slope of ≈1.94 (highly significant), and this effect is stable to a Huber M-estimator (robust regression) and to a log-log transformation; sensitivity checks (Cook's distance) flagged a single influential observation in the Google trends series but did not materially change the GT-ESS result.

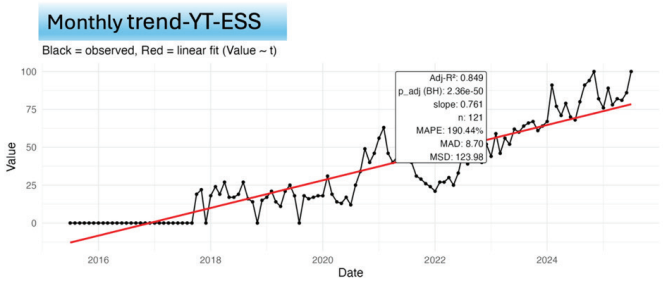

Figure 1. Monthly trend in YT-ESS: the black line represents observed monthly RSV between October 2015 and October 2025. The red line represents the fitted linear regression model, which shows a significant upward trend over time (slope =0.761, adjusted R^2=0.849, p<0.001). YT: YouTube search trends, ESS: Endoscopic spine surgery, RSV: Relative search volume, MAPE: Mean absolute percentage error, MAD: Mean absolute deviation, MSD: Mean squared deviation

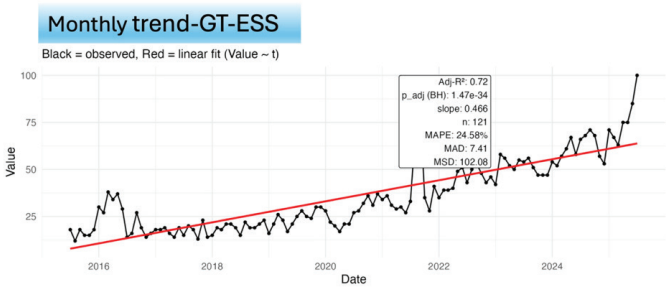

Figure 2. Monthly trend in GT-ESS: observed RSV data (black) and linear regression trend line (red) demonstrate a steady increase in public interest through general Google searches. Temporal fluctuations are visible, but the overall trend is positive and statistically significant. The red line in this figure illustrates the overall long-term trend (slope =0.466, adjusted R^2=0.720, p_adj (BH) =1.47×10^{-34}). GT: Google search trends, ESS: Endoscopic spine surgery, RSV: Relative search volume, MAPE: Mean absolute percentage error, MAD: Mean absolute deviation, MSD: Mean squared deviation, BH: Benjamini-Hochberg

DISCUSSION

In this study, we conducted a comprehensive evaluation of public and academic interest in ESS using a tri-platform approach encompassing Google trends, YouTube trends, and bibliometric data from Scopus. To the best of our knowledge, this represents the first investigation to concurrently assess ESS-related search behaviors across general web and video platforms and to correlate these patterns with publication trends in the scientific literature.

Google trends data demonstrated a clear upward trajectory in online search activity for "ESS" and "ED" throughout the past decade. Similarly, analysis of YT revealed a significant increase in public engagement with video-based content related to these procedures, as confirmed by linear regression models indicating statistically significant growth in RSV over time. This suggests not only increased curiosity about ESS in the general population but also a shift toward audiovisual platforms as preferred sources of medical information.

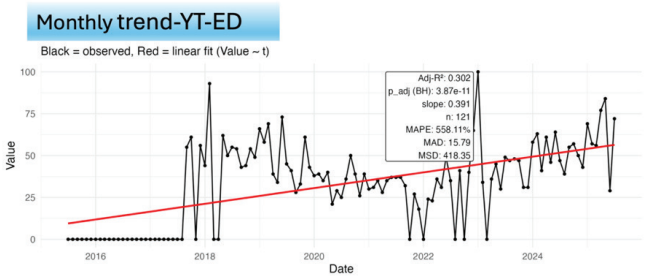

Figure 3. Monthly trend in YT-ED: search activity for this term displays a general increase over time, despite some variability and periods of low or zero RSV. The linear trend line (red) confirms an upward trajectory (slope =0.391, adjusted R^2=0.302, p_adj (BH) =3.87×10^{-11}). YT: YouTube search trends, ED: Endoscopic discectomy, RSV: Relative search volume, MAPE: Mean absolute percentage error, MAD: Mean absolute deviation, MSD: Mean squared deviation, BH: Benjamini-Hochberg

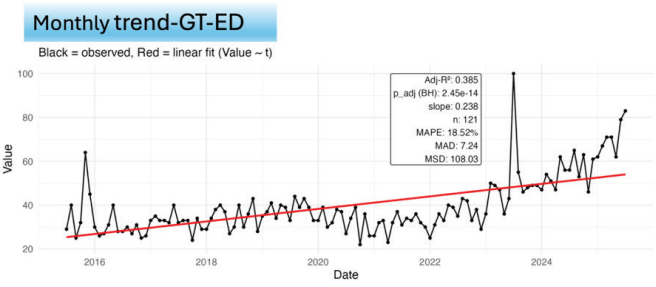

Figure 4. Monthly trend in GT-ED: a similar pattern of gradual growth is seen in general web searches for "endoscopic discectomy". The plot shows fluctuating but rising interest, supported by the linear regression model (slope =0.238, adjusted R^2=0.385, p_adj (BH) =2.45×10^{-14}). GT: Google search trends, ED: Endoscopic discectomy, MAPE: Mean absolute percentage error, MAD: Mean absolute deviation, MSD: Mean squared deviation, BH: Benjamini-Hochberg

These findings suggest not only heightened curiosity regarding ESS among the general population but also a discernible shift toward audiovisual platforms as preferred sources of medical information. Another salient observation derived from our analysis is the parallel rise in academic interest, evidenced by the increasing number of peer-reviewed publications in this domain.

Most bibliometric analyses share common data sources: Thomson Reuters' Web of Science (WoS) and Elsevier's Scopus. Wu et al.[12] reported a steady increase in the number

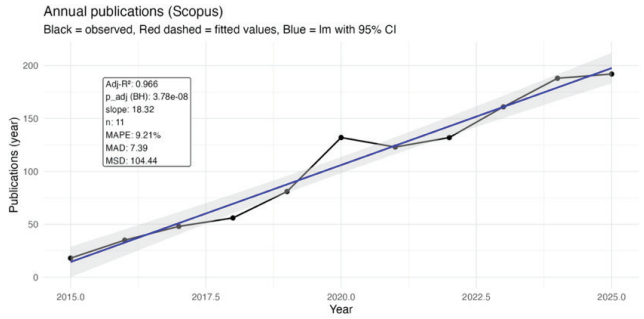

Figure 5. Annual number of publications in Scopus data: the bar chart displays the yearly count of articles retrieved from the Scopus database between 2015 and 2025 using the defined search terms. The red line shows the fitted linear regression line (y=-36896.73+18.318×year), with an adjusted R^2=0.966, indicating a strong increase in academic interest. The red line in this figure illustrates the overall long-term trend (slope =18.32, adjusted R^2=0.966, p_adj (BH) =3.78×10^{-8}). CI: Confidence interval, MAPE: Mean absolute percentage error, MAD: Mean absolute deviation, MSD: Mean squared deviation, BH: Benjamini-Hochberg

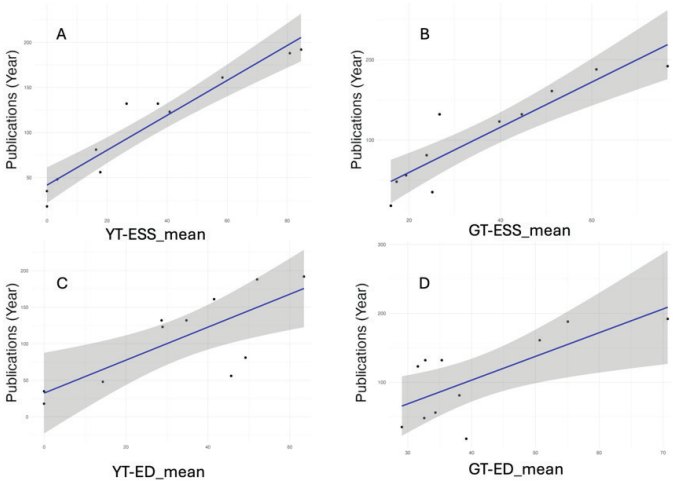

Figure 6. Correlations between Scopus publications and social media trends. A-publication-YT-ESS correlations-slope ≈1.937, adjusted R^2≈0.9045, Adj p-value≈4.29e-06; B-publication-GT-ESS correlations-slope ≈2.815, adjusted R^2≈0.8079, Adj p-value≈0.000104; C-publication-YT-ED-slope ≈2.2555, adjusted R^2≈0.5340, Adj p-value≈0.006413; D-publication-GT-ED-slope ≈3.444, adjusted R^2≈0.4541, Adj p-value≈0.013737. GT: Google search trends, YT: YouTube search trends, ED: Endoscopic discectomy, ESS: Endoscopic spine surgery, BH: Benjamini-Hochberg

of publications on ED over 20 years on the basis of the WoS database. They stated that they used the WoS database in their studies and stated that the WoS database is the most widely used tool for bibliometric analysis. Bibliometric variables are used in many fields for a variety of purposes, particularly in research evaluation. Previous comparative studies have shown that Scopus and WoS have a high degree of overlap in key scientific disciplines[13,14]. We used Scopus as the database in our study.

Since Kambin's[15] pioneering efforts to adapt arthroscopy for lumbar disc herniation, ED has undergone substantial advancements over recent decades. With progressive technological innovation and the accumulation of surgical expertise, the initial indications for ESS-once confined to LD-have expanded considerably. At present, ESS is increasingly utilized in the management of complex spinal pathologies, including lumbar spinal stenosis and cervical degenerative disorders, signifying a paradigm shift in the surgical treatment of spinal diseases[16,17]. Accordingly, to capture a broader spectrum of relevant procedures and reflect evolving terminology, our search strategy incorporated both "ED" and the more inclusive term "ESS".

The emergence of a novel or trending surgical technique does not inherently denote superiority or inferiority relative to established standards of care. Historical precedents illustrate divergent trajectories: total meniscectomy, once conventional, yielded to a paradigm favoring meniscal preservation as evidence accumulated on its deleterious long-term joint effects[18]; similarly, the shift from rigid anatomical fixation toward relative stability with intramedullary nailing reflected a deeper understanding of fracture biology[19]. By contrast, some innovations endure when they deliver durable clinical value; for example, the transition from open to arthroscopic rotator cuff repair reduced postoperative morbidity while maintaining comparable functional outcomes[20]. Taken together, these examples suggest that popular adoption alone does not determine the fate of a technique; rather, sustained clinical benefits, reproducibility, and integration into training ecosystems shape whether a procedure declines or becomes embedded in practice. The potential trajectory of ESS appears more aligned with the latter pathway: sustained public and academic interest-driven by perceived advantages such as shorter recovery, minimal invasiveness, and preservation of anatomical structures-indicates that ESS may continue to consolidate its role where its benefits are demonstrable and outcomes are rigorously validated[16,21,22]. In practical terms, this trajectory carries clear implications for the community: surgeons should pursue structured, competency-based training pathways and outcome tracking to ensure safe diffusion of technique; educators should adopt standardized curricula that include simulation-based modules to accelerate skill acquisition, and surgeons should participate in structured training; and content creators-including clinicians and institutions-should prioritize accurate, peer-reviewed, and patient-appropriate materials to meet rising public information needs and mitigate misinformation.

Our findings highlight a growing reliance on audiovisual platforms for surgical education and patient information, reflecting a broader digital shift in healthcare communication. YouTube analytics confirm this trend; however, prior studies indicate that most ESS-related videos lack scientific rigor and peer review[23,24]. This raises concerns about the dissemination of incomplete or misleading content to both patients and surgeons. As video-based platforms become integral to medical education, academic institutions and clinicians must assume responsibility for producing accurate, evidence-based, and pedagogically sound material. Improving the quality of online resources is essential to counter misinformation and support informed decision-making.

The stronger correlation between YouTube activity and academic publication output, compared to Google trends, likely reflects the inherently visual and procedural nature of ESS. Video platforms provide an effective medium for conveying complex surgical techniques, thereby influencing both professional education and patient engagement. These dynamics underscore the growing role of audiovisual media in shaping knowledge dissemination within technically demanding surgical fields. While these associations do not imply causality, they suggest parallel trends driven by technological innovation and global interest in minimally invasive spine surgery.

Although strong correlations were observed between online search activity and publication volume, these associations should not be interpreted as evidence of a causal relationship. The present findings reflect temporal co-occurrence rather than directional influence, and do not establish whether increased public interest drives academic output or vice versa. Instead, both trends are likely influenced by shared external factors such as technological advances, dissemination of surgical innovations, and growing global interest in minimally invasive spine surgery. Therefore, the results should be interpreted as descriptive indicators of parallel evolution rather than causal associations.

Study Limitations

This study has several limitations. This study is limited by its exclusive use of English-language keywords, potentially introducing language bias. Additionally, certain ESS subcategories were excluded to maintain methodological consistency. Also this study is descriptive and exploratory: observed concurrent trends across platforms do not establish causal relationships between online interest and scientific publications. Other limitation of this study is the relatively small number of annual observations (n=11), which reflects the temporal scope of available data rather than sampling insufficiency. This limited sample size may reduce statistical power and widen confidence intervals in regression analyses, thereby restricting the strength of causal inferences. Consequently, the observed associations should be interpreted as descriptive indicators of parallel trends rather than definitive evidence of causal relationships.

Platform indices may be influenced by non-clinical factors (media coverage, viral content, platform algorithm changes), and such influences cannot be disentangled from the present data. For these reasons, results should be interpreted as hypothesis-generating and informative about parallel temporal patterns rather than definitive evidence of causal linkage.

CONCLUSION

This tri-platform analysis reveals a substantial rise in public and academic interest in ESS over the past decade, reflecting its growing presence in both patient awareness and scientific discourse. The alignment between increased Google and YouTube search volumes and the rising number of peer-reviewed publications underscores ESS as a rapidly evolving field with significant translational momentum. Future efforts should focus on optimizing the quality and accessibility of online content while supporting evidence-based adoption of ESS in clinical practice.

Ethics

Ethics Committee Approval: This study did not involve human participants, animal experiments, or patient data. All analyses were conducted using publicly accessible datasets (Google trends, YouTube analytics, and Scopus).

Informed Consent: Ethical approval and informed consent were not required, in accordance with institutional and international research guidelines.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: O.G.M., Concept: O.G.M., C.Y., H.C., G.G., K.A., Design: O.G.M., C.Y., H.C., G.G., Data Collection or Processing: O.G.M., Analysis or Interpretation: E.E.Y., Literature Search: O.G.M., E.E.Y., Writing: O.G.M., C.Y., H.C., G.G., K.A., E.E.Y., K.A.

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MODIFIED PARAMEDIAN APPROACH FOR FAR LATERAL LUMBAR DISC HERNIATION: RETROSPECTIVE ANALYSIS OF A STABILITY-PRESERVING, FACET/PARS-SPARING SERIES

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ABSTRACT

Objective: Far lateral lumbar disc herniation (FLLH) is a rare entity (about 7-12% of lumbar disc herniations) but causes severe radicular pain. Traditional midline approaches to FLLH frequently require facet resection, which increases the risk of postoperative segmental instability. A paraspinal (Wiltse) approach offers an alternative corridor that may preserve posterior elements.This study aimed to evaluate a modified paramedian approach for FLLH that avoids resection of any facet or pars.

Materials and Methods: Fourteen patients with single-level FLLH at L2-L5 (L5-S1 excluded) were retrospectively reviewed. All patients underwent microsurgical fragmentectomy via the paramedian intermuscular (Wiltse) approach without bone removal. Leg and back pain were assessed using the visual analog scale (VAS) preoperatively and on postoperative day 10. Preoperative motor deficit, early motor recovery, neuropathic complaints, and perioperative complications were recorded.

Results: Severe radicular leg pain was the chief complaint in all patients and resolved by postoperative day 10. The mean leg pain VAS score decreased from 9.0 to 0.7 (92% reduction; p<0.001). The mean back pain VAS score decreased from 3.0 to 1.5, representing a 52% reduction (p=0.002). Six patients (42.9%) had preoperative motor weakness; by day 10, three (50%) regained full strength and three (50%) regained nearly full strength. Four patients (28.6%) developed transient postoperative dermatomal paresthesia, which resolved with conservative management. No major complications occurred, and there were no early clinical signs of instability.

Conclusion: The modified paramedian approach provided safe and effective decompression for FLLH without any facet or pars removal. Early outcomes showed marked pain relief and neurological recovery, supporting this stability-preserving "zero bone resection" technique as a viable option.

Keywords: Far lateral, lumbar disc herniation, paramedian approach, facet/pars sparing

INTRODUCTION

Far lateral lumbar disc herniation (FLLH) is a very painful clinical condition in which the exiting nerve root and dorsal root ganglion (DRG) are compressed lateral to the foraminal boundaries. It was first described by Abdullah et al.[1]. Although its incidence is low (approximately 7-12% of all lumbar disc herniations), it is seen most frequently at L4-L5 and less often at L3-L4. Clinically, FLLH presents with severe radicular pain and therefore usually requires prompt treatment[2]. Cases that show no improvement after a few weeks of conservative management are directed to surgery.

Historically, attempting to reach a far lateral fragment via a midline approach often required resection of the facet joint, a step that carries a well-known risk of instability[3-5]. For this reason, the paramedian (paraspinal/Wiltse) approach emerged as an alternative aimed at preserving the posterior elements[6]. However, even in many descriptions of the paramedian approach in the literature, it is noted that drilling and partial resection of the lateral facet or pars are performed to improve the surgical view[5,7,8].

At the L5-S1 level, a special situation exists: obtaining sufficient space for herniation removal via Kambin's triangle is only possible with some resection of the facet joint and iliac wing. Therefore, L5-S1 FLLH cases were excluded from this study. At more cranial levels, using a paramedian approach, it is possible to achieve safe and effective decompression without any bony resection of the superior facet or pars. This original study presents the early clinical outcomes of such a strategy, which was standardized by a single surgeon.

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MATERIALS AND METHODS

This study was a retrospective, single-arm, single-center series, with all surgeries performed in a standardized manner by the same surgeon. Besides, the study was approved by the Non-interventional Clinical Research Ethics Committee of İzmir Bakırçay University (approval no: 2549, date: 03.12.2025). Written informed consent was obtained from all patients included in this study.

Inclusion Criteria

Patients aged 18 years or older with a single-level FLLH at any lumbar level except the L5-S1 disc (who were operated for that indication) were included. The most important surgical inclusion criterion was complete concordance between the patient's clinical findings and radiological imaging. Therefore, only cases in which lumbar magnetic resonance imaging (MRI) clearly demonstrated a far lateral fragment and that underwent surgical treatment were included.

Exclusion Criteria

Age under 18 years; FLLH at L5-S1; pathology with a predominant intraspinal/paramedian component; and previous surgery at the same level were exclusion criteria.

Surgical Technique

All patients were operated on under general anesthesia in the prone, neutral position. The pelvis and chest were supported as a precaution in case a contralateral oblique trajectory might be needed. A skin incision ~3-4 cm lateral to the midline, parallel to the midline, was made. The paraspinal (Wiltse) approach was used through the thoracolumbar fascia by splitting the muscle. Blunt dissection was carried out with two index fingers through the intermuscular plane to palpate the upper and lower transverse processes. At this depth, two Gelpi retractors were placed in cranio-caudal and medio-lateral orientation.

Using a long electrocautery tip, muscle remnants over the transverse processes and facet joint were cauterized and removed with a pituitary rongeur. A thin layer of muscle remains over the intertransverse membrane; this was stripped away with a dissector to expose the membrane, and the muscle was removed piecemeal with a rongeur. The intertransverse membrane is a parchment-thin, semi-transparent, lax connective structure. Next, the facet joint was fully exposed, and the pars was palpated with a dissector; its surface was cleaned with cautery to achieve anatomic orientation (at this point, the surgeon recalls the classic "Scotty dog" image seen in an oblique lumbar radiograph).

By gently applying medial and lateral pressure with a dissector on the lax, semi-transparent intertransverse membrane, it is possible to delineate the longitudinal boundaries of the thick, edematous nerve root. If the FLLH is very large and has displaced the root upward, the fragment becomes visible in its cavity only after disc material is excised.

To avoid injuring the root, the intertransverse membrane should be incised near the facet joint and the lower transverse process (the region corresponding to the axilla of the nerve root) and removed in small pieces using a Kerrison rongeur. The appearance of fatty tissue is the most important sign that one is close to the nerve root. If the nerve root is directly in view, the situation is simpler: the root is retracted laterally and upward, allowing the FLLH to be identified in the root's axilla.

Two nuances are important. First, if the structure's thickness is not substantial, then it is probably not the root; it may be another tissue or a thinner sensory nerve, because in this area the nerve root appears thick due to the ganglion and compression-induced edema. Second, if the herniation is not very large, it is often better to look for it more medially than expected. If the nerve root cannot be distinguished and a tissue believed to be annulus (pearly-white) is in front of the surgeon, it is wise to proceed cautiously-the structure in front may not be disc but the root itself. In such a situation, it is appropriate to attempt to shift this tissue from medial to lateral and upward with a dissector. If it absolutely does not slide or dissect, it is more likely to be disc (the nerve root is not visible because it has been pushed far upward).

At this stage, a tiny incision is made in the disc in the direction of the nerve root's course to check for disc material; once confirmed, the disc herniation is evacuated in all directions from under the annulus. After sufficient decompression, the nerve root comes into view under the microscope. Since this region is lateral to the Obersteiner-Redlich zone, a cerebrospinal fluid leak will not occur in the event of an injury here. After confirming that the nerve root is decompressed, a facet joint block can be performed at the surgeon's discretion. Hemostasis must be meticulous, and a drain should be placed if necessary; otherwise, the risk of seroma is higher in this area.

Statistical Analysis

Leg pain (femoralgia or sciatalgia) and mechanical low back pain were evaluated by the visual analog scale (VAS) preoperatively and on postoperative day 10. The presence of any preoperative motor deficit and motor improvement at day 10, postoperative neuropathic complaints (numbness, burning or tingling in the respective dermatome), and major/minor complications were recorded.

Continuous data were summarized as mean ± standard deviation, and categorical data as number and percentage (%). For comparison of pre- versus postoperative VAS values, a paired t-test or Wilcoxon signed-rank test was used according to data distribution. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 14 patients were included in the series (mean age 60.6±10.7 years; 50% female, 50% male). The herniation levels were L4-L5 in 8 patients (57.1%), L3-L4 in 5 patients (35.7%),

and L2-L3 in 1 patient (7.1%). In all cases, the disc fragment was located completely far lateral on imaging; in none of the cases was there a foraminal or paramedian component dominant or sufficient to explain the clinical picture.

Preoperatively, the most significant complaint was severe leg pain in the affected dermatome. By postoperative day 10, this pain was entirely controlled. The mean VAS score dropped from 9.00±0.66 preoperatively to 0.65±0.59 on day 10-an absolute decrease of 92.8%, which was statistically significant ($p<0.001$, paired t-test). Similarly, the mechanical low back pain VAS score decreased from 3.02±1.00 to 1.45±1.04, a 52.0% improvement that was statistically significant ($p=0.002$).

Neurologically, 6 of the 14 patients (42.9%) had motor weakness preoperatively. In this subgroup, 3 patients (50%) showed full recovery and 3 (50%) nearly full recovery by day 10; no patient experienced worsening of motor function.

In the early postoperative period, 4 patients (28.6%) exhibited neuropathic complaints such as numbness or burning/tingling in a dermatomal distribution. All of these symptoms regressed over a short period with conservative treatment.

All surgeries were performed via a paramedian (paraspinal/Wiltse) approach, and no bony resection of the lateral facet or pars interarticularis was performed in any case. In all operations, single-level fragmentectomy was performed under the microscope; after hemostasis, patients were mobilized within 24-48 hours and discharged. No case developed any major complication such as dural tear, nerve injury, infection, hematoma, or deep vein thrombosis. In early postoperative follow-up, there were no clinical findings indicative of segmental instability.

The level of herniation, patient age/sex, preoperative and postoperative day 10 leg pain VAS and mechanical low back pain VAS scores, presence of motor deficit and degree of early neurological improvement, and presence of postoperative neuropathic pain for each case are presented in Table 1. The mean changes in leg pain and mechanical low back pain VAS on postoperative day 10 compared with preoperative values are shown graphically in Figure 1.

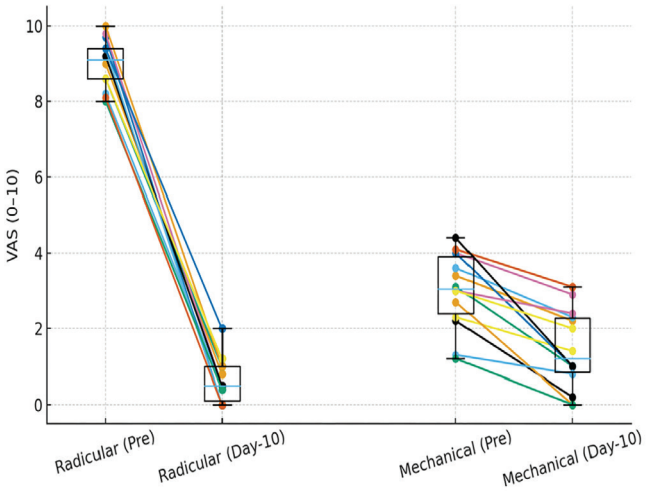

Figure 1. Comparison of preoperative and postoperative day 10 leg pain (femoralgia or sciatalgia) and mechanical low back pain VAS scores in patients with far lateral lumbar disc herniation. VAS: Visual analog scale

Table 1. Demographic data, level distribution, preoperative and postoperative day 10 VAS scores, motor deficit status, and early neurological improvement status of patients with far lateral lumbar disc herniation

				Pain scores VAS				Neurological status		
Case	Age (y)	Sex	Level	Radicular (pre)	Radicular (day-10)	Axial (pre)	Axial (day-10)	Motor deficit (pre)	Motor recovery (day-10)	Neuropathic pain (day-10)
1	44	M	L3-4	9.0	0.8	4.0	2.9	-	+	
2	63	F	L4-5	8.2	0.5	2.2	0.2	+	Complete	-
3	49	F	L3-4	8.6	1.0	3.4	2.2	-	-	
4	57	F	L3-4	9.4	0.0	3.6	2.3	-	-	
5	68	M	L4-5	9.7	0.0	3.1	1.0	+	Complete	-
6	48	M	L4-5	8.6	1.2	2.3	1.4	+	Near-complete	+
7	79	F	L4-5	9.8	0.5	4.0	1.0	-	-	
8	56	M	L3-4	9.2	0.5	4.1	3.1	-	+	
9	65	M	L4-5	10.0	1.0	3.0	2.4	+	Near-complete	-
10	71	F	L4-5	9.4	0.0	4.4	1.0	-	-	
11	75	F	L4-5	8.0	0.4	2.7	0.0	-	+	
12	50	M	L3-4	8.6	1.2	1.3	0.8	+	Near-complete	-
13	58	F	L2-3	9.4	2.0	1.2	0.0	-	-	
14	65	M	L4-5	8.1	0.0	3.0	2.0	+	Complete	-

VAS: Visual analog scale

DISCUSSION

The main message of this study is that for FLLH, even when using a paramedian corridor, it is not routinely necessary to perform "a little shaving" of the lateral facet or pars as is commonly taught; a safe and effective decompression is possible with no bone resection at all.

Historically, because a midline approach to far lateral fragments often required a total facetectomy, it has been associated with increased risk of segmental instability[3-5]. Our findings demonstrate that the ideal of "preserving the posterior elements" need not be limited to seeking alternatives to midline approaches; it can also be implemented with a paramedian approach by strictly adhering to a zero bone resection principle. The early results obtained here are consistent with efficacy and safety data reported for endoscopic and tubular technique variants[9-12].

Facet "overhang" refers to the bony protrusion formed by the lumbar superior articular process lateral to the foramen. Severe overhang has been associated with atrophy of the deep portion of the multifidus muscle[13]. In the far lateral surgical approach applied in this study, the key factor is the presence of an anatomical space that allows the surgeon to work in the nerve root's axilla without any bone resection.

Studies on endoscopic interventions are informative in this context. In a three-dimensional MRI-based analysis, the maximum cannula diameter that could pass through the neural Kambin's triangle increased from ~5.7±1.4 mm at L1-L2 to ~9.7±3.8 mm at L5-S1. In contrast, in the bony Kambin's triangle at L5-S1 the maximum diameter was limited to ~6.1±1.0 mm, and an 8 mm cannula could fit into that triangle in only 2% of 427 measurements[14]. Cadaveric morphometry shows that the distance from the tip of the superior articular process to the main nerve root is ~19 mm at L2-L3 and ~22 mm at L4-L5, suggesting that a safe working space can be obtained via a paramedian intertransverse window without bone resection[15]. A threshold of ~112.1 mm^2 for the superior articular process area has been reported to correlate strongly with foraminal narrowing; however, this parameter defines foraminal stenosis and does not directly support routine facet/pars resection in FLLH[16].

Computer modeling and *in vitro* experiments have shown that partial facetectomy significantly increases segmental mobility and intradiscal pressure; removal of even a small portion of the facet joint markedly increases segmental loading, especially in lateral flexion and axial rotation[17,18]. In this context, the "minor facet/pars shaving" commonly practiced for far lateral disc herniations appears to be a traditional but often unnecessary habit. In our series, no patient had facet or pars resection, and the early clinical outcomes are consistent with the effectiveness of this strategy. In particular, the notable decrease in mechanical low back pain VAS supports the notion that preserving facet/pars integrity has a positive impact on back pain.

Clinically, far lateral cases often present with more severe preoperative pain, yet the improvement after surgery can be similar to that observed in paracentral disc herniations[19]. Potential risk indicators for poor outcome (advanced age, long symptom duration, etc.) have been reported[20], but in our series the dramatic drop in leg pain VAS (from 9.0 to 0.65) and full or near-full early neurological recovery in patients with motor deficit underline the importance of relieving direct DRG compression. The statistically significant, marked pain reduction in the early period further emphasizes the adequacy of the decompression achieved. In this context, even partial resection of the facet overhang or pars appears unnecessary in most cases.

Longer-term results of the paramedian approach have shown good to excellent outcomes in ~80-90% of patients[21-23]. Recent series indicate that this method has a low reoperation rate and does not significantly increase instability[24,25]. Systematic reviews suggest that the overall complication profile of far lateral disc surgery is acceptable[26], and large patient series confirm that reoperation rates after single-level discectomy remain relatively low[27]. Given that no bone resection was performed in our cohort, it is reasonable to expect the rate of good outcomes to approach the upper end of this range.

For challenging anatomies, combined or modified surgical corridors have been described for far lateral discs[28]. However, even at the lumbosacral junction, far lateral nerve root compressions can be resolved safely with targeted, limited decompression[29]. Five-year outcomes of full-endoscopic transforaminal techniques support their equivalence to classic microdiscectomy in terms of efficacy[30]. Nevertheless, the focus of this article is not the choice of corridor itself, but the way it is applied-specifically, whether bone resection is truly necessary.

Classical intertransverse series have emphasized that extraforaminal disc herniation is a distinct entity that can be identified preoperatively with a high index of suspicion and the aid of MRI, and that this recognition enables a planned operative strategy in which destruction of the apophysial (facet) joint can be avoided[31]. In the same report, surgical decompression via the intertransverse approach achieved complete resolution of presenting leg pain in 85% of patients, supporting the concept that a targeted extraforaminal route can yield robust symptom relief while preserving key posterior stabilizing structures[31].

In line with this rationale, Wang et al.[32] emphasized that the key pathoanatomical feature of the condition is compression of the nerve root outside the foramen, and stated that intertransverse discectomy is a rational approach because the spinal canal is not opened and spinal stability is preserved. In their case-based experience, postoperative outcomes were reported to be satisfactory, with rapid resolution of weakness as well as low back and leg pain, reinforcing that direct extraforaminal decompression can be effective without the need for routine bony enlargement of the facet/pars complex[32].

Study Limitations

The main limitations of this study are its retrospective, single-arm design, relatively small sample size, and short follow-up duration. On the other hand, the fact that all surgeries were performed by a single surgeon-ensuring standardization and consistent implementation of the technique with close attention to surgical anatomy-is a strength. To evaluate recurrence, instability, and medium- to long-term functional outcomes, larger-sample prospective comparative studies are needed.

CONCLUSION

The modified paramedian (paraspinal/Wiltse) approach to FLLH allows effective decompression without any facet or pars resection. In this single-surgeon series, early outcomes demonstrated dramatic radicular pain relief, improvement in mechanical low back pain, and favorable early neurological recovery, with no major complications or early signs of instability. These findings support a stability-preserving, "zero bone resection" philosophy for FLLH at L2-L5 levels, and further comparative studies are warranted.

Ethics

Ethics Committee Approval: The study was approved by the Non-interventional Clinical Research Ethics Committee of İzmir Bakırçay University (approval no: 2549, date: 03.12.2025).
Informed Consent: Written informed consent was obtained from all patients included in this study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: Ü.K., Concept: Ü.K., Design: Ü.K., Data Collection or Processing: D.O.K., E.Ç., Analysis or Interpretation: D.O.K., E.Ç., Literature Search: E.Ç., Writing: Ü.K.
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ORIGINAL ARTICLE
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CLINICAL AND RADIOLOGICAL OUTCOMES OF LONG SPINAL FUSION TERMINATING AT L5 VERSUS S1 IN ADULT SPINAL DEFORMITY

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ABSTRACT

Objective: In this retrospective analysis, we evaluated differences in clinical and radiological outcomes between elderly patients with degenerative spinal deformity whose extended posterior spinal fusion terminated at L5 and those whose fusion extended to S1/S2.

Materials and Methods: We retrospectively reviewed the medical records of 113 patients aged 60 years and older who underwent long posterior spinal fusion for degenerative spinal disease and had a minimum follow-up of two years. According to the caudal extent of fusion, patients were categorized into two groups: those in whom fusion terminated at L5 (lumbar group, n=39) and those in whom fusion extended to S1 or S2 (sacral group, n=74). Pain levels and functional status were evaluated using the visual analog scale and the Oswestry disability index (ODI), respectively.

Results: Patients in both groups showed notable improvements in back pain, leg pain, and ODI scores following surgery. Both groups showed a significant increase in lumbar lordosis, with higher postoperative values in the lumbar group (p=0.005). Thoracic kyphosis did not change significantly in either group; however, the direction and magnitude of change differed between groups (p=0.041). Overall complication and reoperation rates were similar between groups. Distal adjacent segment disease was observed in four patients (10.26%) in the lumbar group, whereas none were detected in the sacral group (p=0.013).

Conclusion: Long posterior spinal fusion terminating at either L5 or the sacrum provides comparable postoperative pain relief and radiographic outcomes. Sacral distal fusion is associated with greater functional improvement, while lumbar distal fusion carries a higher risk of distal adjacent segment disease. Distal fusion level selection should therefore be individualized based on patient-specific clinical and radiological characteristics.

Keywords: Adult spinal deformity, long spinal fusion, distal fusion level, L5 versus S1, spinopelvic parameters, adjacent segment disease, functional outcomes

INTRODUCTION

Adult spinal deformity (ASD) refers to a broad and complex group of conditions that predominantly involve the lumbar and thoracolumbar regions, causing abnormal curvatures in both the coronal and sagittal planes. These may present as scoliosis (coronal plane deviation), kyphosis or lordosis (sagittal plane abnormalities), or kyphoscoliosis when both planes are affected. With the aging global population, ASD has become a significant disease burden[1]. In the general population, ASD prevalence varies widely between 2% and 32%, and it is estimated to reach 68% among the elderly[2,3]. The most common causes of ASD are iatrogenic flat back and degenerative scoliosis[3]. Degenerative changes disrupt normal spinal curvature, leading to sagittal alignment abnormalities[4].

Back pain, neurological symptoms caused by nerve compression, and reduced quality of life are frequent findings among patients diagnosed with ASD[3]. The management of ASD typically begins with a thorough physical examination focusing on gait and posture, combined with radiographic assessment, with planning largely based on risk stratification indices[5]. While non-operative management is generally the first-line approach, surgical intervention may be required and is shown to indicate greater radiographic and clinical results compared with conservative treatment[3,5].

The main objectives of surgical intervention for adult lumbar deformity are to prevent progression, alleviate back and

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leg pain, preserve lumbar lordosis (LL), restore coronal and sagittal balance and achieve a solid fusion[6]. Careful selection of instrumentation levels and osteotomy sites can reduce the risk of proximal junctional kyphosis (PJK) and surgical failure[4]. Potential risks include mechanical complications, neurovascular injury and pseudarthrosis[1]. Among these decisions, selection of the distal fusion level represents a critical and still controversial aspect of long-segment spinal fusion surgery. The choice of distal fusion level in long fusions involving the lower lumbar spine (L5 versus S1/2) is still a topic of debate[6,7]. The L5 fusion level is often reserved for patients with a relatively healthy L5-S1 disc who have preserved LL[6]. If significant deformities or degenerative pathologies are detected at L5-S1, the fusion is often extended to the sacrum[7]. One advantage of L5 fusion is that this approach can preserve the lumbosacral motion segment. This can reduce stress on the lumbosacral junction, shorten operative time, and it is also possible that preserving function and applying less surgical manipulation can decrease complication frequency and the need for reoperation. However, this approach also forgoes fixation at L5-S1, which may allow for subsequent degeneration, pain, and sagittal imbalance-which could necessitate revision surgery[6-8]. Conversely, extending the fusion to S1 provides greater stability in the mechanical sense, but may increase the risk of implant failure, pseudarthrosis and other surgical complications[7]. A better understanding of radiographic spinopelvic parameters and their relationship to deformity and postoperative outcomes might be crucial to the fusion level decision and may improve surgical outcomes and patient satisfaction[4].

Although several studies have compared distal fusion levels in ASD, reported results regarding functional outcomes, radiographic correction and complication profiles remain inconsistent, particularly in elderly patients with degenerative pathology.

Therefore, the aim of current study was to compare the radiological and clinical outcomes of long posterior spinal fusion terminating at L5 versus S1 in patients older than 60 years with degenerative spinal deformity. We hypothesized that sacral distal fusion would provide greater functional improvement, whereas lumbar distal fusion would be associated with a higher risk of distal adjacent segment disease.

MATERIALS AND METHODS

The study retrospectively examined patients older than 60 with degenerative lumbar pathology who underwent posterolateral fusion surgery utilizing pedicle screw instrumentation spanning more than six levels and terminating at lumbar (L5) or sacral (S1/S2) levels. All surgeries had occurred between January 2010 and February 2015. Prior to data collection, the study protocol was approved by the Medline Hospital Local Ethics Committee (approval no: 06, date: 10.07.2025). The research was performed following the ethical principles set forth in the Declaration of Helsinki.

Plain radiography and magnetic resonance imaging were used to verify the diagnosis of degenerative lumbar disease. Inclusion was limited to patients experiencing back pain accompanied by radiculopathy. We excluded individuals who had previously undergone decompression or fusion procedures at L5 or S1-S2. In total, 113 patients meeting these criteria and having a minimum of two years' follow-up were analyzed. Based on the distal extent of fusion, patients were categorized into either a lumbar group (n=39) or a sacral group (n=74).

Each procedure was performed by one of two senior spine surgeons, employing a posterior thoracolumbar approach combined with pedicle screw instrumentation and laminectomy. In a small subset of cases, selective interbody fusion using a cage and graft was performed. To ensure fair comparison between groups, patients who received L5-S1-S2 interbody fusion with grafting were excluded from the study. The decision regarding the distal fusion level was based on preoperative radiographic findings, disc degeneration at the L5-S1-S2 level and surgeon preference in accordance with contemporary guidelines. Although lumbar distal fusion was more frequently performed before 2013 and sacral distal fusion after this period, surgical techniques, instrumentation systems and postoperative rehabilitation protocols remained consistent throughout the study period.

Patient age, sex, follow-up duration, number of fused segments, Oswestry disability index (ODI), visual analog scale (VAS) scores, complications and data from radiographic measurements were recorded. Bone mineral density (BMD) was measured from the femur neck and recorded for each subject. Both anteroposterior and lateral full-length standing X-rays were obtained at two time points: before the operation and shortly after surgery, at one month after surgery and at each routine follow-up thereafter. For the purposes of the present analysis, baseline preoperative and final postoperative radiographs were evaluated. These radiographs were analyzed to obtain radiographic parameters, including sagittal vertical axis (SVA), T1 pelvic angle (TPA), three pelvic parameters [pelvic tilt (PT), pelvic incidence (PI) and sacral slope (SS)] and two spinal parameters [LL and T5-T12 thoracic kyphosis (TK)]. Representative postoperative radiographs demonstrating constructs terminating at L5 and extending to the sacrum are provided in Figure 1A-B.

Functional outcomes were assessed using the ODI and pain intensity was measured with the VAS both preoperatively and postoperatively.

Documented complications encompassed hardware-related issues (implant failure, screw malposition), cerebrospinal fluid (CSF) fistula, fracture, infection, hematoma, as well as junction-related problems including PJK, proximal junctional failure (PJF), and distal adjacent segment disease.

VAS

We assessed pain intensity with a 10-cm VAS. On this scale, 0 indicated no pain while 10 signified unbearable pain, and

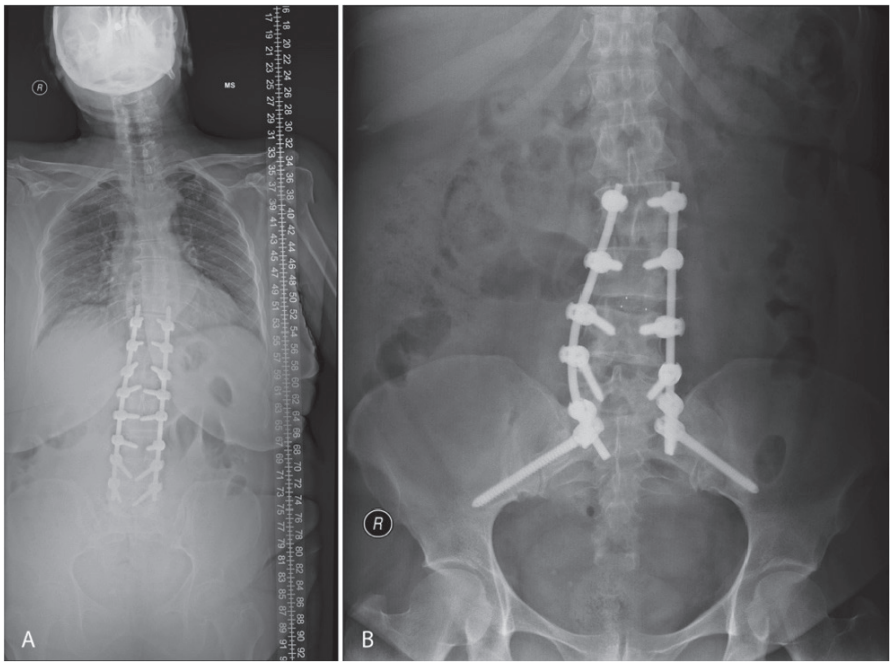

Figure 1. Representative postoperative standing anteroposterior radiographs illustrating distal fusion constructs. **(A)** Long posterior spinal fusion terminating at L5, preserving the L5-S1 motion segment. **(B)** Long posterior spinal fusion extending to S1/S2 with sacropelvic fixation (iliac screws)

patients selected the point that best reflected their current pain level. Greater scores corresponded to higher pain intensity.

ODI

Functional outcomes were evaluated using the ODI, a 10-item questionnaire covering pain intensity, personal care, lifting and carrying, walking, sitting, standing, sleeping, social activities, traveling, and changes in pain severity. Each item is rated on a 6-point scale (0 to 5), with higher scores reflecting greater disability. The total ODI score is expressed as a percentage using the formula: (sum of item scores/50)×100, yielding an overall disability level[9].

Statistical Analysis

All statistical analyses were carried out using IBM SPSS version 27 (IBM Corp., Armonk, NY, USA). A p-value below 0.05 was deemed statistically significant. Normality was evaluated using the Shapiro-Wilk test along with histogram and Q-Q plot examination. For descriptive statistics, normally distributed continuous data were presented as mean ± standard deviation, whereas non-normally distributed data were summarized using median and interquartile range (25^{th}-75^{th} percentile) and frequency (percentage) for categorical variables. Between groups comparisons of continuous variables were performed using the Student's t-test or Mann-Whitney U test depending normality of distribution. Repeated measurements of normally distributed continuous variables were analyzed using two-way repeated measures analysis of variance. Repeated measurements of non-normally distributed continuous variables were analyzed using the Wilcoxon signed-ranks test. Between groups comparisons of categorical variables were performed using the chi-square test or Fisher's exact test.

RESULTS

A total of 113 patients were enrolled, with 39 in the lumbar group and 74 in the sacral group. The two groups were similar in age (p=0.407) but differed significantly in sex distribution (p=0.002), as the sacral group had a notably higher proportion of female patients (93.24% versus 69.23%). There were no significant between-group differences in BMD (p=0.486), implant type (p=0.140), number of fused segments (p=0.525), or cage utilization (p=0.213). The lumbar group did, however, have a significantly longer follow-up period than the sacral group (p=0.022). A complete summary and comparison of patient characteristics is provided in Table 1.

Both groups exhibited significant postoperative reductions in back pain VAS scores relative to baseline (both p<0.001), with no significant difference in the degree of improvement between groups (p=0.471). Leg pain VAS scores also improved significantly after surgery in both the lumbar and sacral groups (both p<0.001), and the extent of improvement was comparable (p=0.279). ODI scores decreased significantly from preoperative values in both groups (both p<0.001). Notably, however, the sacral group demonstrated a significantly greater reduction in disability compared to the lumbar group (p=0.032).

With regard to spinopelvic parameters, SVA remained unchanged in the lumbar group (p=0.387) but decreased significantly in the sacral group (p<0.001); nonetheless, the magnitude of change was similar between groups (p=0.222).

Table 1. Patient demographics, operative parameters, and pre- versus post-surgical findings between lumbar and sacral groups

	Lower level		
	Lumbar (n=39)	Sacral (n=74)	p-value (between groups)
Age	70.67±7.02	69.36±8.32	0.407†
Sex			
Female	27 (69.23%)	69 (93.24%)	0.002#
Male	12 (30.77%)	5 (6.76%)	
BMD, femur neck	-1.94±1.10	-2.14±1.04	0.486†
Type of implant			
Titanium	9 (50.00%)	53 (71.62%)	0.140#
Chrome cobalt	9 (50.00%)	21 (28.38%)	
Number of levels	9.77±1.98	10.08±2.69	0.525†
Cage	2 (5.13%)	11 (14.86%)	0.213‖
Follow-up time, months	66 (39-74)	54 (31-65)	0.022§
Back pain VAS			
Preoperative	8 (8-9)	8 (7-9)	0.158§
Postoperative	4 (2-5)	4 (2-6)	0.692§
p-value for pre-post comparison	<0.001¶	<0.001¶	
Difference(1)	-4 (-6--2)	-4 (-6--2)	0.471§
Leg pain VAS			
Preoperative	8 (6-8)	8 (7-9)	0.405§
Postoperative	4 (2-5)	3 (1-5)	0.227§
p-value for pre-post comparison	<0.001¶	<0.001¶	
Difference(1)	-4 (-5--3)	-4 (-6--2)	0.279§
ODI (%)			
Preoperative	64.74±18.80	70.41±18.82	0.131‡
Postoperative	48.56±21.27	45.72±22.00	0.510‡
p-value for pre-post comparison	<0.001‡	<0.001‡	
Difference(1)	-16.18±19.62	-24.69±19.95	0.032‡
SVA (mm)			
Preoperative	84 (46-131)	95.5 (60-130)	0.221§
Postoperative	68 (37-110)	69.5 (45-100)	0.923§
p-value for pre-post comparison	0.387¶	<0.001¶	
Difference(1)	-11 (-52-32)	-21.5 (-48-2)	0.222§
Pelvic tilt (°)			
Preoperative	27.72±11.53	26.65±9.26	0.593‡
Postoperative	29.44±6.81	28.57±9.31	0.608‡
p-value for pre-post comparison	0.306‡	0.116‡	
Difference(1)	1.72±11.41	1.92±9.87	0.923‡
Sacral slope (°)			
Preoperative	30.64±6.54	28.01±10.93	0.172‡
Postoperative	25.23±6.99	22.96±8.11	0.141‡
p-value for pre-post comparison	0.002‡	<0.001‡	
Difference(1)	-5.41±8.53	-5.05±11.70	0.867‡
Pelvic incidence (°)			
Preoperative	57.85±9.66	54.82±13.21	0.210‡
Postoperative	55.56±9.76	51.18±12.92	0.069‡

Table 1. Continued

	Lower level		
	Lumbar (n=39)	Sacral (n=74)	p-value (between groups)
p-value for pre-post comparison	0.330†	0.035†	
Difference(1)	-2.28±15.37	-3.63±14.10	0.641‡
Lumbar lordosis (°)			
Preoperative	33.62±16.96	28.62±14.44	0.103‡
Postoperative	39.18±15.48	32.31±10.16	0.005‡
p-value for pre-post comparison	0.026†	0.042†	
Difference(1)	5.56±20.97	3.69±11.52	0.540‡
Thoracic kyphosis (°)			
Preoperative	35.23±19.62	30.83±16.43	0.212‡
Postoperative	31.31±11.71	34.07±11.10	0.240‡
p-value for pre-post comparison	0.155†	0.124†	
Difference(1)	-3.92±20.32	3.13±15.11	0.041†
TPA			
Preoperative	22 (19-37)	27 (23-36)	0.411§
Postoperative	25 (20-33)	29.5 (23-38)	0.162§
p-value for pre-post comparison	0.542¶	0.761¶	
Difference(1)	-2 (-6-5)	0 (-5-6)	0.510§
Complication(2)	19 (48.72%)	38 (51.35%)	0.946#
Implant failure	7 (17.95%)	18 (24.32%)	0.591#
Screw malposition	1 (2.56%)	5 (6.76%)	0.663ǁ
CSF fistula	1 (2.56%)	3 (4.05%)	1.000ǁ
Fracture	0 (0.00%)	2 (2.70%)	0.544ǁ
Infection	0 (0.00%)	4 (5.41%)	0.297ǁ
Hematoma	0 (0.00%)	1 (1.35%)	1.000ǁ
PJK	5 (12.82%)	11 (14.86%)	0.990#
PJF	2 (5.13%)	5 (6.76%)	1.000ǁ
Distal adjacent segment disease	4 (10.26%)	0 (0.00%)	0.013ǁ
Reoperation	11 (28.21%)	35 (47.30%)	0.078#

†: Student's t-test, ‡: Two-way repeated measures analysis of variance (ANOVA), §: Mann-Whitney U test, ¶: Wilcoxon signed-ranks test, #: Chi-square test, ǁ: Fisher's exact test, (1): Difference between postoperative and preoperative measurements, negative values represent decrease and positive values represent increase in measurements, (2): Patients may have more than one of the followings, BMD: Bone mineral density, VAS: Visual analog scale, ODI: Oswestry disability index, SVA: Sagittal vertical axis, TPA: T1 pelvic angle, CSF: Cerebrospinal fluid, PJK: Proximal junctional kyphosis, PJF: Proximal junctional failure

PT showed no significant change in either group (lumbar: p=0.306; sacral: p=0.116). SS decreased significantly in both groups (lumbar: p=0.002; sacral: p<0.001), with comparable changes observed (p=0.867). PI did not change significantly in the lumbar group (p=0.330) but decreased significantly in the sacral group (p=0.035), though the difference in change between groups was not significant (p=0.641). LL improved significantly in both groups (lumbar: p=0.026; sacral: p=0.042), and postoperative LL values were significantly higher in the lumbar group (p=0.005), despite similar magnitudes of change (p=0.540). TK did not change significantly in either group (lumbar: p=0.155; sacral: p=0.124), yet the direction of change differed significantly between groups (p=0.041)-the lumbar group showed a decrease while the sacral group showed an increase. TPA remained stable in both groups (lumbar: p=0.542; sacral: p=0.761), with no intergroup differences (p=0.510).

Overall complication rates were similar between groups (p=0.946). The most frequently observed complications were implant failure (lumbar: 17.95%; sacral: 24.32%) and PJK (lumbar: 12.82%; sacral: 14.86%). Of note, distal adjacent segment disease developed in 4 of 39 patients (10.26%) in the lumbar group but was not observed in any patient in the sacral group (p=0.013). Reoperation rates were 28.21% in the lumbar groups and 47.30% in the sacral group, though this difference did not reach statistical significance (p=0.078).

DISCUSSION

When conservative treatment fails and spinal instability or advanced degenerative disc disease is present, spinal fusion has become a cornerstone in the surgical management of ASD[10]. Despite its widespread use, there is still no consensus regarding the level for long-segment fusions[6,11], which often leaves the decision to the surgeons who may have different opinions or experiences regarding the balance between the purpose of radiographic correction and clinical outcomes. In this context, our study directly compares patients undergoing long spinal fusions terminating at either lumbar or sacral levels. The present results demonstrate that both methods are largely similar in terms of radiographic outcomes; however the sacral fusion group showed significantly greater improvement in functional status as measured by ODI. LL increased significantly in both groups, with higher postoperative values observed in the lumbar group, whereas TK demonstrated opposite trends between groups. These findings suggest that distal fusion level selection influences functional outcomes and segmental alignment, even when overall sagittal balance parameters remain similar.

Previous evidence indicates that in ASD patients, long posterior spinal fusion terminating at either L5 or the sacrum consistently results in significant postoperative reductions in back and leg pain and meaningful improvements in functional outcomes, with no substantial differences observed between distal fusion levels[3]. Consistent with previous reports, both lumbar and sacral distal fusion in ASD patients resulted in significant postoperative reductions in back and leg pain and meaningful improvements in functional capacity, and our data also supports prior research in terms of the similarities between the two methods[3,10,12-15]. However, the significantly greater ODI improvement observed in the sacral group suggests that sacral fusion may provide superior functional recovery, which warrants further investigation.

The absence of significant differences in pain scores between groups suggests that distal fusion level has a limited impact on pain control and functional outcomes. Therefore, both lumbar and sacral distal fusions, when applied in appropriately selected patients, provide comparable pain relief, allowing surgeons flexibility in distal level selection based on patient characteristics and surgical objectives. Furthermore, as postoperative outcome assessment in this study was limited to a minimum of 2 years of follow-up, representing early to mid-term outcomes (which is also the case for many studies in the literature), there is a need for further research into the long-term effects of these approaches.

In long-segment spinal fusion for deformity correction, distal fusion terminating at either L5 or S1 has been reported not to compromise early sagittal or coronal balance, with comparable long-term clinical outcomes[10,11,14]. In the present study, LL increased significantly in both groups, with the lumbar group demonstrating significantly higher postoperative values compared to the sacral group (p=0.005). SS decreased significantly in both groups, while SVA decreased significantly only in the sacral group. PI decreased significantly in the sacral group but not in the lumbar group. In terms of TK, the opposing trajectories of change in the two groups (decrease in the lumbar group vs. increase in the sacral group) resulted in a significant difference in the amount of change between groups (p=0.041), which may be an important finding that would necessitate further studies into the exact nature of this change (other than the direct impact of fusion level) and how it might influence clinical outcomes. Nonetheless, the similarities in PT and TPA suggest that both distal fusion levels preserve sagittal balance in the early to mid-term period and have minimal impact on overall spinopelvic alignment. Furthermore, the similarity in spinopelvic outcomes between groups may reflect the homogeneity of baseline deformity severity, number of fused segments and surgical technique among patients.

Although lumbar distal fusion preserves the motion segment, long-term follow-up has shown that advanced L5-S1 disc degeneration and adjacent segment disease can develop in patients undergoing lumbar distal fusion[8,13]. In a study by Wang et al.[16] the biomechanical consequences of spinal fusion on adjacent segments were evaluated, demonstrating increased stress within the annulus fibrosus, nucleus pulposus, facet joints and intervertebral discs of the adjacent segments. It is therefore crucial to perform careful monitoring of biomechanical load accumulation in the distal segments of patients undergoing lumbar distal fusion. Several studies have also indicated that sacral distal fusion restores LL more effectively than L5 and improves overall sagittal balance[12,13,17]. In contrast to these reports, our study showed that LL increased significantly in both groups, with the lumbar group achieving higher postoperative LL values. This finding suggests that lumbar fusion may also effectively restore lordosis, although the clinical implications of this difference require further investigation. Conversely, the higher postoperative lordosis values observed in the lumbar group may reflect the preservation of the natural biomechanical flexibility of the L5-S1 segment and the maintained motion segment. However, it is important to note that while pain outcomes were similar between groups, the sacral group demonstrated significantly greater functional improvement.

As mentioned previously, lumbar fusion has been associated with lower rates of pseudarthrosis, implant-related complications and proximal adjacent segment disease, whereas sacral fusion may be contributing to the preservation of sagittal alignment and maintenance of distal segment integrity[3]. Several studies have reported that although sacral fusion provides superior LL restoration and increased stability, it may be associated with higher complication rates compared with lumbar distal fusion.[12,17,18]. Conversely, selected patients undergoing lumbar fusion have been

reported to have an increased risk of revision surgery due to the potential need for additional fusion[19]. In the present study, when overall complications were considered, no significant differences in complication rates were observed between lumbar and sacral distal fusion groups, consistent with previous reports[3,15]. Although the reoperation rate was numerically higher in the sacral group (47.30% vs. 28.21%), this difference did not reach statistical significance (p=0.078). Nevertheless, the types of complications arising among patients is an important factor, as some complications cause greater risks. Complications such as CSF fistula, PJK/PJF and distal adjacent segment disease originate from different places and have differing mechanisms. PJK is typically related to the proximal fusion endpoint, whereas distal adjacent segment disease is influenced by distal level selection and biomechanical load distribution. In our study, distal adjacent segment disease occurred in 10.26% of patients in the lumbar group, suggesting that while lumbar distal fusion appears safe in the short term, biomechanical stress accumulation at the lower segment may predispose to long-term degeneration. In contrast, in line with previously reported findings[17,19], adjacent segment disease did not occur in the sacral fusion group -possibly due to the additional stability achieved by sacral fusion. Although adjacent segment disease frequently associated with lumbar fusion is often linked to loss of LL or positive sagittal imbalance, the likelihood of symptomatic presentation is relatively low[13]. The higher incidence of distal adjacent segment disease in the lumbar group observed in this study, despite comparable pain outcomes between groups, draws further attention to the criticality of this result.

Consistent with previous meta-analysis and retrospective series[3,11,15], the present study demonstrates that distal fusion at either lumbar or sacral levels yields comparable outcomes in terms of pain and overall complications. However, the sacral group demonstrated significantly greater functional improvement, which may be an important consideration in surgical planning. The motion-preserving advantage of lumbar fusion may be crucial for select patients; however, sacral fusion may provide superior functional recovery and may be improving stability, which may be important for other cases. To summarize, in patients with a healthy L5-S1 disc and minimal lower lumbar deformity, lumbar distal fusion maintains postoperative pain control while preserving motion segments and minimizing operative time and intraoperative trauma. Conversely, in cases with significant lower lumbar deformity or where functional recovery and spinal stability are prioritized, sacral distal fusion could be the preferred option to facilitate long-term stability. Recent advances, ranging from minimally invasive surgical techniques to other tools for risk prediction, may improve surgical planning in spinal deformity management[1,20]. Despite the similarities in short- to mid-term clinical outcomes, distal fusion level is a strategic decision that should integrate patient-specific morphological characteristics, deformity severity, functional expectations and potential long-term complications.

Study Limitations

Although the sample size was larger than many similar studies, the retrospective design could introduce potential biases in patient selection and data collection. The lumbar or sacral fusion decisions were based on the changes in management strategies according to available guidelines and expert opinions, resulting in a lack of randomization and potential selection bias, which may particularly limit the interpretation of clinical and radiographic differences between groups. The significant difference in sex distribution between groups (93.24% female in the sacral group vs. 69.23% in the lumbar group) and the difference in follow-up duration may have influenced the outcomes and should be considered when interpreting the results. Additionally, missing data for BMD, implant type and TPA in a subset of patients in the lumbar group may have affected the analyses of these parameters. Radiographic analyses were restricted to preoperative and final postoperative measurements, and therefore, we do not have analyses showing the trends in these parameters. Pain and functional outcomes were assessed using patient-reported measures, which are subjective and may be influenced by individual perceptions. Additionally, the mid-term follow-up limits the assessment of late complications, including pseudarthrosis and late-onset distal segment degeneration. Despite these limitations, the present study provides valuable evidence comparing the clinical and radiographic impact of distal fusion levels throughout at least 2 years of follow-up.

CONCLUSION

In long posterior spinal fusion surgery, distal fusion level at either lumbar or sacral levels appears to yield comparable outcomes in terms of postoperative pain and changes in spinopelvic parameters. However, sacral fusion demonstrated significantly greater functional improvement as measured by ODI. While both groups showed significant increases in LL, the lumbar group achieved higher postoperative values. Lumbar fusion preserves motion segments and limits surgical manipulation, but is associated with a significantly higher risk of distal adjacent segment disease. Both approaches have a similar safety profile with respect to overall complications and reoperations; however, patients undergoing lumbar distal fusion are more susceptible to distal adjacent segment disease which may necessitate reoperation.

Ethics

Ethics Committee Approval: Prior to data collection, the study protocol was approved by the Medline Hospital Local Ethics Committee (approval no: 06, date: 10.07.2025).
Informed Consent: Retrospective design.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: T.E., M.Ç., M.A., M.G., Concept: T.E., M.Ç., Design: T.E., M.Ç., M.G., Data Collection or Processing: T.E., M.Ç., M.A., M.G., Analysis or Interpretation: T.E., M.Ç., M.G., Literature Search: T.E., M.Ç., Writing: T.E.

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