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# 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

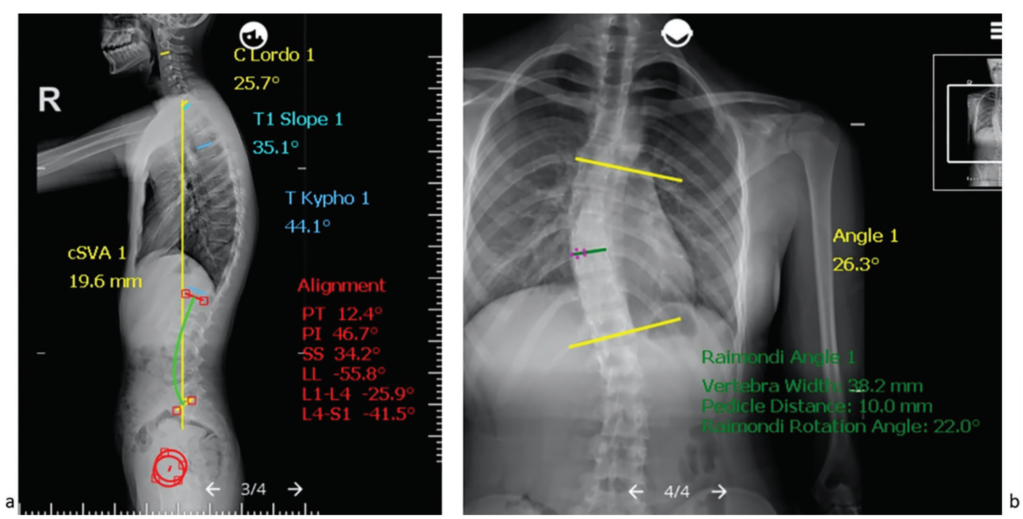


**Figure 1. (a)** Lateral radiograph of an adolescent idiopathic scoliosis patient showing sagittal alignment parameters, including C2-7, T1 slope, thoracic kyphosis, LL, SVA, and spinopelvic measurements (PT, PI, and SS). **(b)** Posteroanterior radiograph of the same patient demonstrating coronal Cobb 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

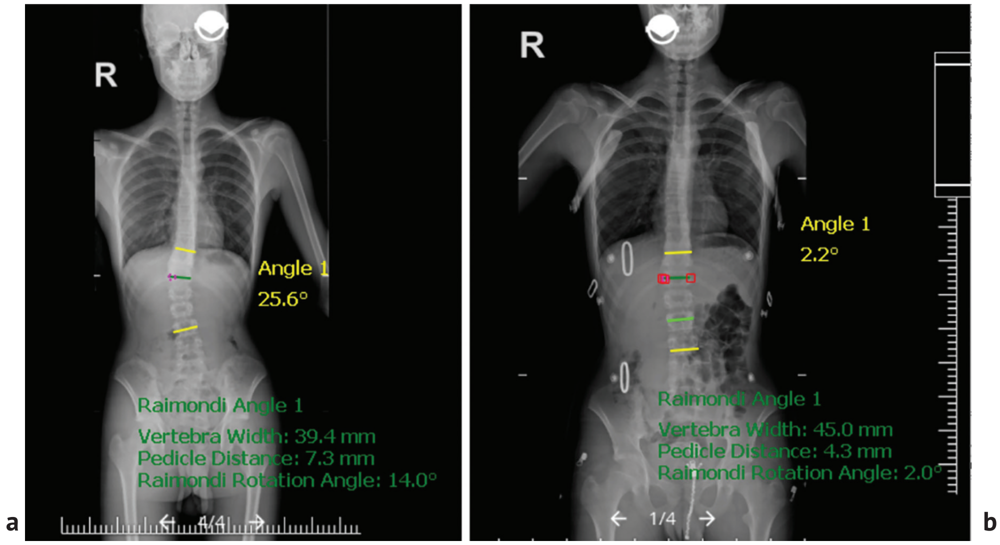


**Figure 2.** Representative AP radiographs of an AIS patient before and after TLSO treatment. **(a)** Pre-brace radiograph showing a thoracolumbar curve with a Cobb angle of 25.6° and Raimondi rotation angle of 14.0°. **(b)** Post-brace radiograph obtained after 12 months of TLSO treatment demonstrating 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

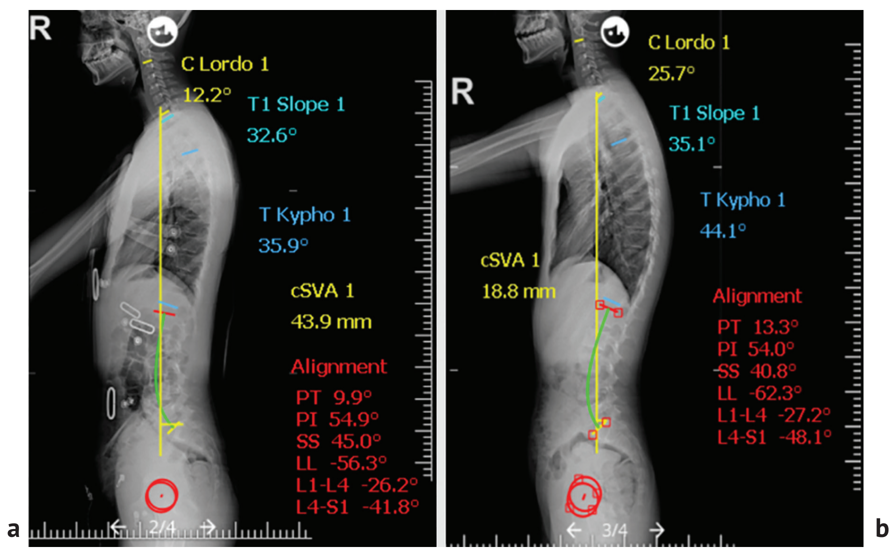


**Figure 3.** Representative standing lateral radiographs of an AIS patient before and after TLSO treatment. (a) Pre-brace: C2-7 =12.2°, T1 slope =32.6°, thoracic kyphosis (T Kypho) =35.9°, LL =56.3°, SS =45.0°, PT =9.9°, and PI =54.9°. Global sagittal alignment shows a cSVA of 43.9 mm. (b) Post-brace: 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 $\alpha$=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%)<br>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%)<br>Normal: 33 (100%)<br>High: 0 (0%) | Below: 0 (0%)<br>Normal: 33 (100%)<br>High: 0 (0%) |
| **LL** | 40-60 | Below: 9 (27.3%)<br>Normal: 24 (72.7%)<br>High: 0 (0%) | Below: 8 (24.2%)<br>Normal: 25 (75.8%)<br>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**<br>-0.72±8.19 | **95% CI (Lower-upper)**<br>-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**<br>-1.91±6.93 | **95% CI (Lower-upper)**<br>-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**<br>+0.70±6.61 | **95% CI (Lower-upper)**<br>-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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