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Article

Lumbar and Thoracolumbar Curves Are Associated with Coronal Lower Limb Malalignment in Adolescent Idiopathic Scoliosis

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Abstract

Background: Adolescent idiopathic scoliosis (AIS) may influence pelvic orientation and lower limb alignment, but data after completion of spinal correction are limited. **Methods:** In this retrospective study, 70 consecutive AIS patients (61 females, 9 males; mean age 17.0 ± 3.2 years, range 13–30 years) treated surgically ($n = 52$) or with brace therapy ($n = 18$) between 2010 and 2020 were analyzed. Patients were grouped by main curve location as thoracic ($n = 28$), lumbar ($n = 21$) or thoracolumbar ($n = 21$). Pre-treatment standing full-spine radiographs were used to measure Cobb angles, coronal balance and pelvic coronal obliquity angle (PCOA). After completion of spinal correction, full-length weight-bearing lower limb radiographs were obtained to assess femoral and tibial lengths, mechanical axis deviation (MAD), femoral neck–shaft angle (NSA), and distal/proximal femoral mechanical and anatomical angles. **Results:** Mean PCOA for the whole cohort was $2.3 \pm 1.9^\circ$, and mean MAD was -0.41 ± 10.2 mm on the right and -0.7 ± 8.0 mm on the left. PCOA, coronal balance, MAD, right anatomical lateral distal femoral angle (aLDFA) and right mechanical lateral distal femoral angle (mLDFA) differed significantly among the three groups ($p < 0.05$). Thoracolumbar versus thoracic curves showed higher PCOA and greater coronal imbalance ($p = 0.011$ and $p = 0.004$). The lumbar group demonstrated bilateral valgus alignment with more negative MAD values than the thoracic group (right MAD -5.88 ± 8.8 mm, left MAD -3.5 ± 7.5 mm; $p = 0.004$ and $p = 0.005$). The thoracic group had higher right aLDFA and mLDFA than lumbar and thoracolumbar groups (all $p < 0.05$). No between-group differences were found in femoral or tibial lengths or NSA ($p > 0.05$). **Conclusions:** After spinal correction, AIS patients show subtle but measurable differences in coronal lower limb alignment according to curve location. Pelvic obliquity and MAD are more pronounced in lumbar and thoracolumbar curves, whereas limb lengths and NSA remain comparable among groups. These small deviations may influence long-term load distribution and should be considered in the clinical assessment of AIS, particularly in patients with distal curve patterns.

Keywords: adolescent idiopathic scoliosis; pelvic obliquity; mechanical axis deviation; femoral neck–shaft angle; lower limb alignment

1. Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity that primarily affects the frontal plane and accounts for approximately 70% of all scoliosis cases with onset before the age of 10 [1,2]. AIS can alter trunk balance and pelvic orientation, potentially affecting the

biomechanics of the lower extremities [3–5]. Previous studies have shown that upper extremity function on the concave side of the curve may be reduced in patients with main thoracic curves compared with those with lumbar curves and healthy subjects, and that hip motion—particularly adduction—can be limited on the dominant side [6,7].

With regard to the lower limbs, functional leg length inequality and changes in pelvic obliquity have been reported, especially in curves with a lumbar apex [8–11]. However, it remains unclear whether AIS leads to consistent deformities in lower extremity morphology or alignment, and whether these potential alterations are related to curve type or location. Studies assessing proximal femoral parameters in AIS have yielded conflicting results: some authors have reported increased femoral neck–shaft angles, whereas others have found decreased values compared with earlier series [3,12,13].

Most investigations have focused on patients during the growth phase, while data on lower limb parameters after completion of spinal correction are scarce [3,14–16]. It has been suggested that most lower limb biomechanical development is completed before the age of 10, implying that later spinal deformity might have only limited influence on mature limb morphology [14–16]. Nonetheless, long-standing coronal imbalance and pelvic obliquity could still leave residual changes in lower limb alignment [8–11,17].

We hypothesized that lower extremity alignment may remain altered after spinal correction in AIS and that these alterations would be related to curve location in the coronal plane. The primary aim of this study was to investigate lower extremity morphology and coronal alignment in AIS patients after completion of spinal treatment. The secondary aim was to evaluate the relationship between the location of the main spinal curve (thoracic, lumbar, thoracolumbar) and lower limb biomechanical parameters.

2. Materials and Methods

2.1. Study Design and Ethical Approval

This retrospective observational study included consecutive patients with AIS treated at a single tertiary referral center between January 2010 and December 2020. The study protocol was approved by the institutional ethics committee (08/02/2022, 2022 910), and all procedures were conducted in accordance with the Declaration of Helsinki. Written informed consent for the use of clinical and radiographic data was obtained from all patients and/or their legal guardians at the time of treatment.

2.2. Patient Selection

We screened all patients who were diagnosed with AIS and treated either surgically or with brace therapy during the study period. Inclusion criteria were:

- diagnosis of AIS according to Scoliosis Research Society criteria,
- age between 13 and 30 years at the time of final radiographic evaluation,
- completion of spinal treatment (posterior fusion or brace therapy) with no further planned intervention, and
- availability of standardized standing full-spine radiographs at initial presentation and full-length weight-bearing lower limb radiographs obtained after completion of spinal treatment.

Exclusion criteria were:

- history of lower extremity surgery related to tumor, avascular necrosis, trauma or deformity correction,
- revision posterior instrumentation,
- neuromuscular or syndromic scoliosis or other neurological disorders affecting the lower limbs,
- developmental dysplasia of the hip or other primary hip pathology, and
- incomplete imaging, inadequate radiograph quality, or loss to follow-up.

Among 278 AIS patients initially identified, 208 were excluded according to these criteria, leaving 70 patients for the final analysis. Of these, 52 were treated surgically and 18 with brace therapy. The patient selection process is summarized in a flowchart (**Figure 1**)

Figure 1. Flowchart demonstrating the study design, including patient selection, grouping according to curve location (thoracic, lumbar, and thoracolumbar), and the sequence of radiographic measurements.

2.3. Curve Classification and Grouping

All curves were classified using the Lenke classification system based on pre-treatment standing posteroanterior and lateral full-spine radiographs [18]. For the purposes of this study, patients were then grouped according to the location of the main coronal curve apex and the corresponding Lenke types as follows:

- Thoracic group (Group 1): main thoracic curve; included patients with Lenke type 1 or 2 curves (main thoracic patterns), n = 28 (40%).
- Lumbar group (Group 2): main lumbar or thoracolumbar/lumbar curve; included patients with Lenke type 5 or 6 curves (thoracolumbar/lumbar patterns), n = 21 (30%).
- Thoracolumbar group (Group 3): double-curve patterns with both thoracic and thoracolumbar/lumbar components; included patients with Lenke type 3 or 4 curves, n = 21 (30%).

2.4. Radiographic Acquisition

At initial presentation, all patients underwent standard standing full-spine posteroanterior and lateral radiographs including the pelvis to determine Cobb angles, coronal balance, pelvic coronal obliquity angle (PCOA) and Lenke classification (**Figure 2A, Figure 3A**).

Figure 2. Preoperative standing full-length anteroposterior and lateral radiographs of a patient with thoracic idiopathic scoliosis showing a Lenke type 3C curve pattern and pelvic obliquity.

Figure 3. Standing full-length anteroposterior radiographs of a patient with lumbar idiopathic scoliosis and a Lenke type 5C curve who was treated non-operatively with bracing, demonstrating pelvic obliquity and lower limb alignment.

After completion of spinal correction (postoperative or after brace treatment), patients were re-evaluated with standardized full-length weight-bearing lower limb radiographs, obtained with the patellae facing directly forward and knees in full extension (**Figure 2B, Figure 3B**). These radiographs were acquired after approval of the institutional ethics committee.

2.5. Radiographic Measurements

Spinal parameters were measured on standing full-spine radiographs. Cobb angles of structural curves were recorded. Coronal balance was defined as the horizontal distance between the C7 plumb line and the central sacral vertical line. The pelvic coronal obliquity angle (PCOA) was defined as the angle between a line connecting the most superior points of both iliac crests and a true horizontal reference line [9,10].

On lower limb radiographs, the following parameters were evaluated bilaterally:

- **Femoral length:** distance from the superior aspect of the femoral head to the distal medial femoral condyle.
- **Tibial length:** distance from the proximal tibial joint line to the distal articular surface of the tibial plafond.
- **Mechanical axis deviation (MAD):** perpendicular distance (mm) from the mechanical axis line (center of the femoral head to the center of the ankle joint) to the center of the knee joint; negative values indicated valgus alignment and positive values varus alignment [3,12,13].

- **Femoral neck–shaft angle (NSA):** angle between the axis of the femoral neck and the longitudinal axis of the femoral shaft, corresponding to the standard femoral neck–shaft (caput-collum-diaphyseal) angle [3,12,13].
- **Mechanical lateral distal femoral angle (mLDFA):** lateral angle between the mechanical axis of the femur and the distal femoral joint line.
- **Mechanical lateral proximal femoral angle (mLPFA):** lateral angle between the mechanical axis of the femur and the proximal femoral joint line.
- **Anatomical lateral distal femoral angle (aLDFA):** lateral angle between the anatomical axis of the femur and the distal femoral joint line.
- **Anatomical medial proximal femoral angle (aMPFA):** medial angle between the anatomical axis of the femur and the proximal femoral joint line.

All radiographic measurements were performed using a picture archiving and communication system (PACS) workstation (Extreme PACS, Ankara, Turkey). Two senior orthopedic surgeons independently measured all parameters twice, with at least a 1-week interval between sessions, and the mean of the four measurements was used for analysis. Intra- and interobserver reliability were assessed using intraclass correlation coefficients (ICC).

2.6. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 24.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean ± standard deviation (SD), minimum and maximum values. The Shapiro–Wilk test was used to assess the normality of continuous variables. Comparisons among the three curve location groups (thoracic, lumbar, thoracolumbar) were performed using one-way analysis of variance (ANOVA) for normally distributed variables, followed by Bonferroni post hoc tests for pairwise comparisons. The chi-square test was applied to compare categorical variables among groups. Statistical significance was set at $p < 0.05$ with a 95% confidence interval for all analyses. With the available sample size, the study was considered adequately powered to detect large between-group differences, whereas smaller effects may have remained undetected.

3. Results

A total of 70 patients with AIS were included in the study, with a mean age of 17.04 ± 3.2 years (range, 13–30 years). There were 61 females (87.1%) and 9 males (12.9%). Based on the location of the main coronal curve, 28 patients (40%) had thoracic scoliosis (Group 1), 21 (30%) had lumbar scoliosis (Group 2), and 21 (30%) had thoracolumbar scoliosis (Group 3). Baseline demographic characteristics of the three groups are presented in Table 1.

Table 1. Demographic characteristics of the three curve-location groups.

Variable	Thoracic scoliosis (n = 28)	Lumbar scoliosis (n = 21)	Thoracolumbar scoliosis (n = 21)
Age, years (mean ± SD, min–max)	17.4 ± 3.1 (14–30)	17.1 ± 3.5 (14–25)	16.4 ± 3.0 (13–23)
Gender, F/M	24 / 4	19 / 2	18 / 3
Risser sign, 2/3/4/5	3 / 8 / 14 / 3	1 / 6 / 10 / 4	2 / 4 / 12 / 3
Lenke type, 1/2/3/4/5/6	19 / 3 / 0 / 6 / 0 / 0	0 / 0 / 0 / 0 / 17 / 4	0 / 0 / 0 / 0 / 16 / 5

SD: Standard deviation; Min: Minimum; Max: Maximum; F: Female; M: Male.

For the entire cohort, the mean PCOA was $2.3 \pm 1.9^\circ$ (range, $0\text{--}12^\circ$), and the mean coronal balance was -1.14 ± 1.57 cm (range, -4.6 to 3.0 cm). The mean right femoral length was 479 ± 37 mm (range, $349\text{--}566$ mm), and the mean left femoral length was 479 ± 37 mm (range, $352\text{--}567$ mm). The mean right tibial length was 391 ± 32 mm (range, $283\text{--}456$ mm), and the mean left tibial length was 392 ± 32 mm (range, $289\text{--}460$ mm). The mean right MAD was -0.41 ± 10.2 mm (range, -27 to 20 mm), and the mean left MAD was -0.7 ± 8.0 mm (range, -16 to 16 mm). The mean right NSA was $133 \pm 4^\circ$ (range, $124\text{--}150^\circ$), and the mean left NSA was $133 \pm 5^\circ$ (range, $122\text{--}150^\circ$). The mean right aLDFA was $83.3 \pm 4.5^\circ$ (range, $77\text{--}92^\circ$), and the mean left aLDFA was $83.5 \pm 2.9^\circ$ (range, $77\text{--}93^\circ$). The mean right mLDFA was $88.8 \pm 3.1^\circ$ (range, $82\text{--}98^\circ$), and the mean left mLDFA was $89.0 \pm 2.9^\circ$ (range, $83\text{--}99^\circ$). The mean right aMPFA was $87.5 \pm 4.2^\circ$ (range, $77\text{--}99^\circ$), and the mean left aMPFA was $87.6 \pm 4.9^\circ$ (range, $74\text{--}101^\circ$). The mean right mLPFA was $86.7 \pm 4.1^\circ$ (range, $75\text{--}97^\circ$), and the mean left mLPFA was $86.4 \pm 4.5^\circ$ (range, $76\text{--}99^\circ$). Detailed radiological parameters for each group are shown in **Table 2**.

Table 2. Radiographic parameters according to curve-location group (mean $\pm$ SD, min–max).

Parameter	Thoracic scoliosis (n = 28)	Lumbar scoliosis (n = 21)	Thoracolumbar scoliosis (n = 21)	p value
Pelvic obliquity ($^\circ$)	1.57 ± 1.33 (0–4)	2.67 ± 1.37 (0–5)	3.15 ± 2.92 (0–12)	0.032*
Coronal balance (cm)	-0.47 ± 1.4 (–4.6–1.8)	-1.54 ± 1.4 (–4–2)	-2.06 ± 1.1 (–4–0)	0.014*
Right femoral length (mm)	480 ± 46 (349–566)	488 ± 29 (435–548)	467 ± 32 (407–512)	0.290
Left femoral length (mm)	481 ± 45 (352–567)	487 ± 29 (432–549)	468 ± 30 (408–507)	0.345
Right tibial length (mm)	388 ± 39 (283–456)	399 ± 23 (356–440)	387 ± 31 (332–428)	0.509
Left tibial length (mm)	389 ± 40 (289–460)	399 ± 22 (357–438)	389 ± 32 (332–429)	0.581
Right MAD (mm)	3.65 ± 7.9 (–8–20)	-5.88 ± 8.8 (–24–7)	0.81 ± 12 (–27–15)	0.012*
Left MAD (mm)	3.75 ± 7.0 (–10–16)	-3.5 ± 7.5 (–16–11)	-1.07 ± 8.3 (–11–13)	0.015*
Right NSA ($^\circ$)	132.6 ± 5.0 (128–150)	133.2 ± 4.0 (124–141)	133.6 ± 4.0 (126–139)	0.816
Left NSA ($^\circ$)	132.1 ± 6.0 (122–150)	134.2 ± 4.0 (125–143)	134.6 ± 3.0 (128–139)	0.294
Right aLDFA ($^\circ$)	84.7 ± 3.0 (79–92)	82.6 ± 3.0 (77–89)	82.2 ± 2.0 (79–87)	0.023*
Left aLDFA ($^\circ$)	84.2 ± 3.0 (80–93)	83.3 ± 3.1 (77–92)	82.8 ± 2.3 (79–88)	0.374
Right mLDFA ($^\circ$)	90.4 ± 3.1 (85–98)	88.1 ± 3.3 (82–94)	87.4 ± 2.0 (84–93)	0.012*
Left mLDFA ($^\circ$)	89.6 ± 3.3 (84–99)	88.9 ± 3.2 (83–99)	88.2 ± 2.0 (85–93)	0.457

Right aMPTA (°)	86.3 ± 3.5 (81–95)	88.6 ± 5.1 (77–99)	87.7 ± 3.7 (77–92)	0.259
Left aMPTA (°)	87.0 ± 5.0 (74–97)	87.6 ± 5.5 (76–101)	88.5 ± 4.3 (76–93)	0.674
Right mLPFA (°)	87.3 ± 3.8 (75–93)	86.2 ± 4.5 (78–97)	86.5 ± 4.1 (81–96)	0.731
Left mLPFA (°)	86.5 ± 4.4 (77–99)	86.5 ± 4.8 (76–98)	86.0 ± 4.5 (80–98)	0.946

MAD, mechanical axis deviation; NSA, neck–shaft angle; aLDFA, anatomical lateral distal femoral angle; mLDFA, mechanical lateral distal femoral angle; aMPTA, anatomical medial proximal tibial angle; mLPFA, mechanical lateral proximal femoral angle; SD, standard deviation.

Significant differences among the three groups were found for PCOA, coronal balance, MAD, right aLDFA and right mLDFA ($p<0.05$). Post hoc analysis revealed that PCOA and coronal balance were significantly different between thoracolumbar and thoracic groups ($p = 0.011$ and $p = 0.004$, respectively), whereas no significant differences were observed between thoracic and lumbar or between lumbar and thoracolumbar groups for these parameters.

For MAD, there were significant differences between the lumbar and thoracic groups for both limbs (right MAD, $p = 0.004$; left MAD, $p = 0.005$), whereas no significant differences were found between thoracic and thoracolumbar groups or between lumbar and thoracolumbar groups. Patients in the lumbar group demonstrated bilateral valgus knee alignment, with mean right MAD of -5.88 ± 8.8 mm and mean left MAD of -3.5 ± 7.5 mm.

Regarding distal femoral angles, the thoracic group had significantly higher right aLDFA and right mLDFA compared with the lumbar group ($p = 0.026$ and $p = 0.022$, respectively) and the thoracolumbar group ($p = 0.014$ and $p = 0.006$, respectively). No significant differences were observed between the lumbar and thoracolumbar groups for these parameters ($p = 0.920$ and $p = 0.796$, respectively).

No significant differences were found among the three groups with respect to femoral length, tibial length or NSA on either side ($p>0.05$).

4. Discussion

In this study, we investigated coronal lower limb morphology and alignment in patients with AIS after completion of spinal correction and compared radiographic parameters according to curve location. Our main findings were that pelvic obliquity and MAD differed significantly among curve-location groups, whereas femoral and tibial lengths and NSA did not. Lumbar curves were associated with bilateral valgus alignment and more negative MAD values, while the thoracic group demonstrated significantly higher right aLDFA and right mLDFA compared with lumbar and thoracolumbar groups.

Previous studies have shown that AIS affects the orientation of the pelvis and may influence lower limb biomechanics [3–5]. Saji et al. reported increased femoral NSA in AIS compared with healthy subjects, suggesting that proximal femoral morphology may adapt to spinal deformity [12]. In contrast, Markus et al. observed lower NSA values than those reported by Saji et al., highlighting discrepancies between AIS cohorts and measurement techniques [13]. In our series, the mean NSA values were $133 \pm 4^\circ$ on the right and $133 \pm 5^\circ$ on the left, within the range of previously published data, and no significant differences were found between the three curve-location groups ($p>0.05$) [3,12,13]. These findings suggest that once skeletal maturity is nearly reached, proximal femoral morphology is relatively stable and may not be strongly influenced by the location of the spinal curve. A summary of previous studies investigating lower limb morphology and pelvic obliquity in AIS is presented in Table 3.

Table 3. Previous studies evaluating lower limb morphology and pelvic obliquity in AIS.

Authors	Year	Study design (LOE)	Main findings related to lower limbs and pelvis
Saji et al.	1995	Case-control (Level III)	Increased femoral neck–shaft (collodiaphyseal) angle in AIS compared with controls.
Markus et al.	2018	Case-control (Level III)	On the decompensated side, femur length, tibial length, total limb length, collodiaphyseal angle and mTFA were decreased; mTFA showed varus deviation on the decompensated side.
Sekiya et al.	2018	Prospective comparative (Level II)	AIS patients frequently had functional LLD; structural LLD was smaller. The difference between functional and structural LLD reflected compensation for the lumbar curve through flexion–extension of the lower limbs.
Chan et al.	2019	Case-control (Level III)	76.4% of AIS cases had pelvic obliquity <10 mm. Distal (L5–L6) curves showed a higher rate of right hemipelvis elevation than more proximal (L1–L2) curves.
Burkus et al.	2019	Retrospective (Level III)	AIS patients had lower collodiaphyseal angles and a higher angle between mechanical and anatomical femoral axes compared with reference values.

Pelvic obliquity is a critical link between spinal deformity and lower limb alignment [8–11,17]. Cho et al. and Ploumis et al. reported that pelvic obliquity is relatively common in AIS and is associated with trunk imbalance and curve progression, particularly in lumbar curves [9,11]. Chan et al. further demonstrated that pelvic obliquity is more frequent and more severe in patients with Lenke 5 and 6 curves than in those with thoracic curves [10]. In our cohort, the mean pelvic obliquity for all patients was $2.3 \pm 1.9^\circ$ (range, 0–12°), and significant differences were observed between thoracolumbar and thoracic groups ($p = 0.011$ for pelvic obliquity and $p = 0.004$ for coronal balance). These results are consistent with previous literature, indicating that curves with a more distal apex, particularly thoracolumbar and lumbar curves, tend to produce greater pelvic tilt [8–11,17].

MAD has been used as an indicator of overall coronal lower limb alignment and load distribution at the knee [3,12,13]. In our study, MAD differed significantly among curve-location groups ($p < 0.05$), and the lumbar group showed bilateral valgus alignment with more negative MAD values (right MAD -5.88 ± 8.8 mm, left MAD -3.5 ± 7.5 mm) compared with the thoracic group. The thoracic group, on the other hand, exhibited significantly higher right aLDFA and right mLDFA than the lumbar and thoracolumbar groups ($p = 0.026$ and $p = 0.022$ vs. lumbar; $p = 0.014$ and $p = 0.006$ vs. thoracolumbar, respectively). Although these absolute differences were small, they suggest that long-standing lumbar and thoracolumbar curves may lead to subtle valgus alignment at the knee level, while thoracic curves may be associated with relatively higher distal femoral angles.

The relationship between AIS, leg length discrepancy (LLD) and lower limb morphology has been addressed in only a few studies [8,12,13]. Sekiya et al. used EOS imaging and showed that AIS patients predominantly have functional (apparent) LLD rather than structural (true) LLD, and that lumbar deformity contributes more to functional inequality [8]. In the present study, no significant differences were observed between groups in femoral or tibial lengths, supporting the concept that AIS does not typically cause substantial structural LLD. Combined with the absence of significant differences in NSA, our findings reinforce the notion that lower limb discrepancies in AIS are largely functional and related to pelvic tilt and spinal imbalance rather than true bony length differences [3,8,12,13].

Our study focused on patients after spinal correction, either surgically or with brace treatment, rather than during the active growth phase. Experimental and radiographic data have suggested that most lower limb biomechanical development is completed before the age of 10, whereas the onset and progression of AIS generally occur later in adolescence [14–16]. It has been argued that, once lower limb alignment is established, subsequent changes in the spinal column may have limited impact on limb morphology [14–16]. Despite this, we found persistent differences in pelvic obliquity, MAD and distal femoral angles between curve-location groups even after completion of spinal correction. These subtle but measurable alterations may represent residual effects of long-standing spinal and pelvic imbalance, although they are unlikely to be evident as clinically obvious deformity.

This study has several limitations. First, its retrospective design and the requirement for standardized full-length lower limb radiographs introduce a potential selection bias, because patients without such imaging were not included. Nonetheless, we attempted to reduce this bias by including all consecutive AIS patients who met strict inclusion and exclusion criteria over a 10-year period at a single tertiary institution. Second, we did not include an internal control group of age-matched individuals without scoliosis. For ethical and practical reasons, obtaining full-length weight-bearing radiographs in healthy adolescents is not feasible in our setting; therefore, our results were interpreted in light of published normative data on lower limb alignment in children and adolescents [14–16]. Third, sagittal plane parameters of the lower limbs and pelvis were not evaluated, which may have provided additional information on three-dimensional compensation. Based on an a priori sample size consideration for one-way ANOVA, approximately 152 patients would have been required to detect medium-sized between-group differences with 80% power at a 5% significance level. Therefore, the present sample of 70 patients was likely sufficient only for large effects.

Despite these limitations, this study adds to the limited body of evidence on lower limb biomechanics in AIS after spinal correction. Our results indicate that AIS, particularly with lumbar and thoracolumbar curves, may be associated with subtle changes in coronal lower limb alignment, characterized by increased pelvic obliquity and more negative MAD, whereas femoral and tibial lengths and NSA remain comparable between curve locations [3,8–13]. From a clinical perspective, these differences are small and unlikely to manifest as overt deformity, but they may still be relevant for long-term joint loading and should be considered when planning treatment and follow-up in patients with distal curve patterns. Future prospective, multicenter studies including three-dimensional evaluation of the pelvis and lower limbs, as well as appropriately matched control cohorts, are needed to better clarify the complex interaction between spinal curvature and lower extremity biomechanics in AIS [14–16].

5. Conclusions

Adolescent idiopathic scoliosis may affect not only the spine but also the coronal alignment of the lower extremities after spinal correction. In our cohort, lumbar and thoracolumbar curves were associated with greater pelvic obliquity and more negative MAD, indicating a tendency toward valgus knee alignment, whereas femoral and tibial lengths and femoral neck–shaft angles were similar across curve-location groups. Although these differences are small and unlikely to result in clinically obvious deformity, they may influence lower limb load distribution and should be taken into account when evaluating and following AIS patients, particularly those with distal curve patterns.

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