Assessment of Spinal Deformity in Adolescents with Scoliosis and Its Association with Functional Limitation During Daily Activities: A Cross-Sectional Study

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ABSTRACT

Background: Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spinal deformity that may influence physical function beyond radiographic curvature; however, the relationship between curve severity and objective task-specific functional performance remains insufficiently characterized. **Objective:** To examine the association between spinal deformity severity and functional limitation during daily activities in adolescents with AIS using patient-reported and performance-based measures. **Methods:** In this cross-sectional observational study, 100 adolescents aged 10–18 years with radiographically confirmed AIS (Cobb angle ≥10°) were evaluated. Radiographic parameters included Cobb angle, vertebral rotation, thoracic kyphosis, and lumbar lordosis. Functional outcomes comprised the SRS-22 function domain, Pediatric Outcomes Data Collection Instrument (PODCI) global function score, six-minute walk test (6MWT), stair-climbing time, and sit-to-stand time. Correlation analyses and multivariable linear regression adjusted for age, sex, and BMI were performed. **Results:** The mean Cobb angle was $27.6° \pm 11.8°$. Cobb angle demonstrated moderate negative correlations with SRS-22 ($r = -0.46$, $p < 0.001$), PODCI ($r = -0.42$, $p < 0.001$), and 6MWT distance ($r = -0.39$, $p = 0.002$), and positive correlations with stair-climbing ($r = 0.34$, $p = 0.006$) and sit-to-stand time ($r = 0.29$, $p = 0.010$). Each 10° increase in Cobb angle was independently associated with a 22.4-meter reduction in 6MWT distance and a 0.88-second increase in stair-climbing time. Functional performance declined progressively across mild, moderate, and severe categories ($p < 0.001$). **Conclusion:** Greater AIS severity is independently associated with measurable reductions in endurance and transitional mobility, supporting integration of standardized functional assessment alongside radiographic evaluation.

Keywords: Adolescent Idiopathic Scoliosis; Cobb Angle; Functional Limitation; Six-Minute Walk Test; Stair-Climbing; Pediatric Outcomes

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity defined radiographically by a lateral curvature of at least 10° measured using the Cobb method and accompanied by vertebral rotation and alterations in sagittal alignment (1). It represents approximately 80–85% of scoliosis cases and most commonly manifests between 10 and 18 years of age, with a global prevalence estimated at 1.65%–3% among children and adolescents and a higher incidence in females, particularly in progressive curves (2,13,14). Beyond coronal plane deviation, AIS involves complex structural changes including vertebral axial rotation, rib cage asymmetry, thoracic hypokyphosis, and altered lumbar lordosis, which collectively modify spinal biomechanics and load distribution (3). These three-dimensional alterations occur during a critical period of musculoskeletal growth and

maturation, potentially influencing neuromuscular control, postural stability, and overall functional performance (4,5).

Historically, clinical management of AIS has prioritized radiographic parameters—curve magnitude, progression risk, and cosmetic appearance—while functional capacity has received comparatively less systematic evaluation (1,20). Although health-related quality of life (HRQoL) instruments such as the Scoliosis Research Society-22 (SRS-22) have demonstrated that adolescents with AIS may report lower function and self-image compared with healthy peers, the relationship between objective curve severity and task-specific functional performance remains incompletely characterized (7). Moreover, while pulmonary compromise and reduced exercise tolerance have been reported in untreated idiopathic scoliosis, particularly in larger thoracic curves, evidence linking structural deformity to everyday activity limitations in otherwise ambulatory adolescents is inconsistent (4). Contemporary reviews emphasize that AIS is multifactorial in etiology and presentation, and that functional impairment is not universal but may manifest subtly, particularly in moderate-to-severe deformities (2,16,20).

From a patient-centered perspective, adolescents engage daily in prolonged sitting during academic activities, walking between classes, stair climbing, transitional movements such as repeated sit-to-stand, and recreational or sports participation. These routine activities demand coordinated trunk stability, lumbopelvic control, and lower-limb strength. Emerging evidence suggests that altered spinal alignment in AIS may influence balance, trunk muscle activation patterns, and endurance capacity, potentially leading to increased fatigue and reduced mobility efficiency (3,15,17). Systematic reviews and meta-analyses evaluating exercise interventions in AIS have further highlighted that functional outcomes, including SRS-22 function scores and performance-based measures, are modifiable and clinically relevant, underscoring the importance of accurately characterizing baseline functional status across severity strata (18,19). However, many prior investigations have focused predominantly on subjective HRQoL domains or cosmetic concerns rather than integrating objective performance-based assessments that approximate daily activity demands (7,18).

Within the PICO framework, the population of interest comprises adolescents aged 10–18 years diagnosed with AIS; the exposure is the severity of three-dimensional spinal deformity, typically operationalized using Cobb angle and supplemented by vertebral rotation and sagittal alignment parameters; the comparison involves stratification across curve severity categories (mild, moderate, severe); and the outcomes include both patient-reported functional status and objective performance-based measures reflective of daily activities, such as walking endurance, stair negotiation, and repeated sit-to-stand performance. While radiographic severity is well established as a determinant of progression risk and treatment decision-making (1,20), its independent association with measurable functional limitation in routine adolescent tasks has not been fully elucidated, particularly in cross-sectional cohorts integrating both self-reported and performance-based outcomes.

The critical knowledge gap lies in the limited empirical linkage between quantified structural deformity and standardized, task-specific functional performance in adolescents who have not yet undergone surgical intervention. Existing literature indicates that larger curves may correlate with reduced HRQoL and physical activity levels (7,15), yet few studies have simultaneously examined radiographic parameters and objective measures such as six-minute walk distance, stair-climbing time, and sit-to-stand performance within the same cohort. Furthermore, the extent to which functional limitation progresses in a graded manner across severity categories remains insufficiently characterized. Addressing this gap

is clinically relevant because reliance solely on radiographic assessment may underestimate the lived functional burden experienced by adolescents with AIS, potentially delaying targeted rehabilitation strategies aimed at preserving mobility, endurance, and participation (18,19).

Therefore, the present study was designed to investigate, in a cross-sectional cohort of adolescents with AIS, the association between spinal deformity severity and functional limitation during common daily activities using validated patient-reported and performance-based outcome measures. We hypothesized that greater curve magnitude would be independently associated with lower SRS-22 function and Pediatric Outcomes Data Collection Instrument (PODCI) scores, reduced six-minute walk distance, and slower stair-climbing and sit-to-stand performance, and that functional outcomes would demonstrate a graded decline across mild, moderate, and severe curve categories.

MATERIALS AND METHODS

This cross-sectional observational study was conducted to examine the association between radiographic spinal deformity severity and functional limitation during daily activities in adolescents diagnosed with Adolescent Idiopathic Scoliosis (AIS). The cross-sectional design was selected to quantify concurrent relationships between structural deformity parameters and standardized functional outcomes within a defined adolescent cohort, consistent with methodological recommendations for observational association studies (21). The study was carried out in the orthopedic and physiotherapy outpatient departments of a tertiary care teaching hospital in Peshawar, Pakistan, with additional school-based recruitment to enhance representativeness across curve severity categories. Participant enrollment and data collection were conducted over a 12-month period from January to December 2024.

Adolescents aged 10 to 18 years with a confirmed diagnosis of AIS were eligible for inclusion. AIS was operationally defined as a structural spinal curvature with a Cobb angle ≥10° on standing posteroanterior radiographs, in the absence of identifiable congenital, neuromuscular, or syndromic causes (20). Eligible participants were required to be ambulatory without assistive devices and able to understand and complete questionnaire-based assessments. Exclusion criteria included prior spinal surgery, use of rigid bracing within the preceding 12 months, diagnosed neuromuscular or connective tissue disorders, acute musculoskeletal injury within the previous three months, and cognitive impairment limiting valid participation in performance-based testing. Participants were identified through consecutive screening of outpatient clinic records and through collaboration with school health screening programs. For hospital-based recruitment, consecutive eligible patients presenting during the study period were invited to participate. For school-based recruitment, stratified random sampling was applied to ensure proportional representation across sex and preliminary curve severity categories based on screening radiographs. Written informed consent was obtained from parents or legal guardians and assent from adolescents prior to enrollment.

Radiographic assessment was performed using standardized standing posteroanterior and lateral spinal radiographs obtained as part of routine clinical evaluation. The primary exposure variable was Cobb angle (degrees), measured using the standard end-vertebra technique (1). Secondary deformity parameters included vertebral rotation graded according to the Nash–Moe method and sagittal alignment parameters comprising thoracic kyphosis (T5–T12) and lumbar lordosis (L1–S1) measured on lateral radiographs. All radiographic measurements were independently performed by two trained orthopedic clinicians blinded to functional outcomes. Intra- and inter-rater reliability were evaluated in a random

subsample of 20 radiographs using intraclass correlation coefficients (ICC), with an ICC ≥0.85 considered acceptable for analysis. Discrepancies greater than 3° in Cobb angle measurements were resolved by consensus review. For categorical analyses, curve severity was classified as mild (10–25°), moderate (26–40°), or severe (>40°), consistent with established clinical thresholds (20).

Functional limitation was assessed using both patient-reported and performance-based outcome measures to capture multidimensional aspects of daily activity. Self-reported functional status was evaluated using the function domain of the Scoliosis Research Society-22 (SRS-22) questionnaire and the Pediatric Outcomes Data Collection Instrument (PODCI) global function scale, both of which have demonstrated reliability and validity in pediatric musculoskeletal populations (7). Questionnaires were administered in a quiet clinical setting under standardized instructions, and validated Urdu translations were used where applicable following forward–backward translation procedures. Performance-based assessments included the six-minute walk test (6MWT), stair-climbing test, and repeated sit-to-stand test. The 6MWT was conducted according to standardized guidelines on a 30-meter indoor corridor, with standardized encouragement at fixed intervals and total distance recorded in meters (21). The stair-climbing test required participants to ascend and descend a standardized 12-step staircase (step height 17 cm) at a self-selected safe pace; total time in seconds was recorded using a digital stopwatch. The repeated sit-to-stand test involved five consecutive rises from a standardized chair height of 45 cm without upper-limb assistance; total time in seconds was recorded. All functional assessments were performed by licensed physiotherapists blinded to radiographic findings to minimize measurement bias. Participants completed testing during a single session following radiographic evaluation, with a standardized rest interval of five minutes between tests to reduce fatigue effects.

The primary outcome variable was SRS-22 function score. Secondary outcomes included PODCI global function score, 6MWT distance, stair-climbing time, and sit-to-stand time. The primary exposure variable was Cobb angle analyzed as both a continuous variable and categorical severity grouping. Potential confounders identified a priori based on clinical relevance and existing literature included age, sex, and body mass index (BMI) (7,15,20). Demographic data (age, sex), anthropometric measurements (height, weight), and BMI (kg/m²) were recorded using calibrated equipment following standardized procedures. To reduce information bias, all assessors underwent training sessions prior to study initiation, and standardized operating procedures were documented for each assessment. Data were recorded on pre-designed case report forms and double-entered into a secure electronic database with range and logic checks to ensure accuracy.

Sample size estimation was performed using a priori calculation for detecting a moderate correlation (r = 0.30) between Cobb angle and functional outcomes with 80% power and a two-sided alpha level of 0.05. The required minimum sample size was calculated as 84 participants; to account for potential incomplete data and to permit subgroup analyses across three severity categories, the final target sample size was set at 100 participants. Continuous variables were assessed for normality using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots. Descriptive statistics were presented as mean ± standard deviation for normally distributed variables and median with interquartile range for non-normal distributions. Pearson correlation coefficients were used to examine associations between Cobb angle and functional outcomes when parametric assumptions were met; otherwise, Spearman's rank correlation coefficients were applied. Correlation coefficients were accompanied by 95% confidence intervals calculated using Fisher's z transformation.

Comparisons of functional outcomes across curve severity categories were conducted using one-way analysis of variance (ANOVA) for normally distributed variables, with Bonferroni-adjusted post hoc tests for pairwise comparisons. For non-normally distributed outcomes, the Kruskal–Wallis test with Dunn's post hoc adjustment was applied. To address confounding, multivariable linear regression models were constructed with each functional outcome as the dependent variable and Cobb angle as the independent variable, adjusting for age, sex, and BMI. Regression diagnostics were performed to assess linearity, homoscedasticity, multicollinearity, and normality of residuals. Effect estimates were reported as unstandardized beta coefficients with 95% confidence intervals. A two-sided p-value <0.05 was considered statistically significant. Missing data were assessed for randomness; if missingness was <5%, complete-case analysis was performed, whereas multiple imputation using chained equations was applied if missingness exceeded this threshold. All analyses were conducted using SPSS version 26 (IBM Corp., Armonk, NY, USA).

The study protocol was reviewed and approved by the Institutional Review Board of the hosting institution prior to initiation. All procedures were conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (22). Participant confidentiality was maintained by assigning unique identification codes and storing identifiable information separately from analytical datasets. Only authorized research personnel had access to the secured database. Data integrity was ensured through double data entry, periodic auditing, and preservation of original source documents to permit independent verification. The methodological procedures, including radiographic measurement techniques and functional testing protocols, were documented in detail to enable reproducibility by independent investigators.

RESULTS

The study included 100 adolescents with a mean age of 14.2 ± 2.1 years, of whom 68% were female and 32% were male. The mean body mass index was 21.4 ± 3.2 kg/m². Based on radiographic classification, 44% of participants had mild scoliosis (10–25°), 38% had moderate scoliosis (26–40°), and 18% had severe scoliosis (>40°), indicating a predominance of mild-to-moderate deformities within the cohort (Table 1). The mean Cobb angle for the total sample was 27.6° ± 11.8°, consistent with the observed severity distribution. Sagittal alignment parameters demonstrated a mean thoracic kyphosis of 32.4° ± 8.5° and a mean lumbar lordosis of 41.7° ± 9.2°, reflecting relatively preserved sagittal contours overall. Vertebral rotation grading showed that 42% of participants were classified as Grade I, 36% as Grade II, and 22% as Grade III, suggesting a balanced distribution across rotational severity categories (Table 2).

Regarding functional performance, the mean SRS-22 function score was 3.8 ± 0.6, indicating generally mild perceived limitation. The mean PODCI global function score was 82.5 ± 9.7, consistent with relatively preserved overall physical functioning. In objective performance testing, the mean six-minute walk distance (6MWT) was 512.3 ± 68.4 meters. The mean stair-climbing time was 11.2 ± 2.4 seconds, and the mean sit-to-stand time was 13.8 ± 3.1 seconds, demonstrating mild reductions in transitional and mobility performance (Table 3).

Correlation analysis demonstrated a statistically significant moderate negative association between Cobb angle and SRS-22 function (r = −0.46, 95% CI −0.61 to −0.29, p < 0.001), indicating that increasing curve magnitude was associated with lower perceived physical function. A similar moderate negative correlation was observed between Cobb angle and PODCI global function (r = −0.42, 95% CI −0.58 to −0.24, p < 0.001). Endurance capacity, measured by 6MWT, was also negatively correlated with Cobb angle (r = −0.39, 95% CI −0.55

to −0.21, p = 0.002). In contrast, positive correlations were identified between Cobb angle and stair-climbing time (r = 0.34, 95% CI 0.15 to 0.50, p = 0.006) as well as sit-to-stand time (r = 0.29, 95% CI 0.10 to 0.46, p = 0.010), indicating slower performance with increasing deformity severity (Table 4). Correlations between sagittal alignment parameters and functional outcomes were weak and statistically non-significant, with thoracic kyphosis showing an r-value of −0.12 with SRS-22 function (p = 0.23) and lumbar lordosis demonstrating an r-value of 0.09 (p = 0.37), suggesting limited functional impact of sagittal measures in this cohort (Table 5).

When functional outcomes were compared across curve severity categories, a clear graded pattern emerged. The mean SRS-22 function score declined progressively from 4.2 ± 0.4 in the mild group to 3.7 ± 0.5 in the moderate group and 3.1 ± 0.6 in the severe group (F = 18.6, p < 0.001, η^2 = 0.28), indicating a large effect size. Similarly, PODCI global function decreased from 88.1 ± 6.2 in mild scoliosis to 81.9 ± 8.4 in moderate and 72.3 ± 10.5 in severe scoliosis (F = 16.2, p < 0.001, η^2 = 0.25). Six-minute walk distance demonstrated a progressive reduction from 548 ± 52 meters in mild cases to 503 ± 61 meters in moderate and 451 ± 74 meters in severe cases (F = 14.4, p < 0.001, η^2 = 0.23). Performance times showed a reciprocal pattern, with stair-climbing time increasing from 9.8 ± 1.9 seconds in mild scoliosis to 11.3 ± 2.1 seconds in moderate and 13.4 ± 2.7 seconds in severe cases (F = 17.1, p < 0.001, η^2 = 0.26). Sit-to-stand time similarly increased from 12.1 ± 2.4 seconds to 13.9 ± 2.7 seconds and 16.2 ± 3.5 seconds across mild, moderate, and severe groups, respectively (F = 13.7, p < 0.001, η^2 = 0.22), reflecting moderate-to-large effect sizes across functional domains (Table 6).

Multivariable linear regression analysis adjusting for age, sex, and BMI confirmed that Cobb angle remained independently associated with functional outcomes. For every 10° increase in Cobb angle, SRS-22 function score decreased by 0.21 points (95% CI −0.31 to −0.11, p < 0.001), PODCI global function decreased by 4.8 points (95% CI −6.9 to −2.6, p < 0.001), and six-minute walk distance decreased by 22.4 meters (95% CI −34.6 to −10.2, p = 0.001). Conversely, stair-climbing time increased by 0.88 seconds (95% CI 0.41 to 1.35, p < 0.001) and sit-to-stand time increased by 0.74 seconds (95% CI 0.29 to 1.18, p = 0.002) per 10° increment in Cobb angle. Adjusted R^2 values ranged from 0.25 to 0.32, indicating that curve magnitude and covariates explained approximately 25–32% of the variance in functional outcomes (Table 7). Collectively, these findings demonstrate a statistically significant and clinically graded association between increasing spinal deformity severity and reduced functional capacity in adolescents with AIS.

Table 1. Demographic and Clinical Characteristics of Participants (N = 100)

Variable	Total Sample (Mean ± SD or n, %)
Age (years)	14.2 ± 2.1
Female	68 (68%)
Male	32 (32%)
Height (cm)	158.6 ± 8.9
Weight (kg)	53.8 ± 9.6
BMI (kg/m²)	21.4 ± 3.2
Mild scoliosis (10–25°)	44 (44%)
Moderate scoliosis (26–40°)	38 (38%)
Severe scoliosis (>40°)	18 (18%)

Radiographic characteristics of spinal deformity are summarized in Table 2. The mean Cobb angle was 27.6° ± 11.8°, indicating an overall moderate severity distribution.

Table 2. Radiographic Characteristics of Spinal Deformity (N = 100)

Variable	Mean ± SD / n (%)
Cobb Angle (°)	27.6 ± 11.8
Thoracic Kyphosis (°)	32.4 ± 8.5
Lumbar Lordosis (°)	41.7 ± 9.2
Vertebral Rotation Grade I	42 (42%)
Vertebral Rotation Grade II	36 (36%)
Vertebral Rotation Grade III	22 (22%)

Table 3. Functional Outcome Measures (N = 100)

Outcome Measure	Mean ± SD
SRS-22 Function Score	3.8 ± 0.6
PODCI Global Function	82.5 ± 9.7
6-Minute Walk Distance (m)	512.3 ± 68.4
Stair-Climbing Time (sec)	11.2 ± 2.4
Sit-to-Stand Time (sec)	13.8 ± 3.1

Table 4. Correlation Between Cobb Angle and Functional Outcomes (N = 100)

Functional Variable	r-value	95% CI	p-value	Effect Size Interpretation
SRS-22 Function	−0.46	−0.61 to −0.29	<0.001	Moderate
PODCI Global Function	−0.42	−0.58 to −0.24	<0.001	Moderate
6-Minute Walk Distance	−0.39	−0.55 to −0.21	0.002	Moderate
Stair-Climbing Time	0.34	0.15 to 0.50	0.006	Small–Moderate
Sit-to-Stand Time	0.29	0.10 to 0.46	0.010	Small–Moderate

Additional correlations between sagittal alignment parameters and functional outcomes are summarized in Table 5. Thoracic kyphosis and lumbar lordosis demonstrated weak, non-significant associations with most functional measures.

Table 5. Correlation Between Sagittal Parameters and Functional Outcomes (N = 100)

Radiographic Variable	Functional Outcome	r-value	95% CI	p-value
Thoracic Kyphosis	SRS-22 Function	−0.12	−0.31 to 0.08	0.23
Thoracic Kyphosis	6MWT	−0.15	−0.34 to 0.05	0.14
Lumbar Lordosis	SRS-22 Function	0.09	−0.11 to 0.28	0.37
Lumbar Lordosis	6MWT	0.11	−0.09 to 0.30	0.26

Functional outcomes stratified by curve severity category are presented in Table 6. One-way ANOVA demonstrated statistically significant differences across severity groups for SRS-22, PODCI, 6MWT, stair-climbing, and sit-to-stand performance. Post hoc Bonferroni analysis confirmed significant differences primarily between mild and severe groups.

*Table 6. Comparison of Functional Outcomes by Curve Severity*

Outcome	Mild (n=44) Mean ± SD	Moderate (n=38) Mean ± SD	Severe (n=18) Mean ± SD	ANOVA F	p-value	η² (Effect Size)
SRS-22 Function	4.2 ± 0.4	3.7 ± 0.5	3.1 ± 0.6	18.6	<0.001	0.28
PODCI Global	88.1 ± 6.2	81.9 ± 8.4	72.3 ± 10.5	16.2	<0.001	0.25
6MWT (m)	548 ± 52	503 ± 61	451 ± 74	14.4	<0.001	0.23
Stair-Climbing (sec)	9.8 ± 1.9	11.3 ± 2.1	13.4 ± 2.7	17.1	<0.001	0.26
Sit-to-Stand (sec)	12.1 ± 2.4	13.9 ± 2.7	16.2 ± 3.5	13.7	<0.001	0.22

Multivariable linear regression analyses adjusting for age, sex, and BMI confirmed that Cobb angle remained independently associated with functional outcomes. Results are summarized in Table 7.

Table 7. Multivariable Linear Regression: Association Between Cobb Angle and Functional Outcomes (Adjusted for Age, Sex, BMI)

Outcome	β (per 10° increase)	95% CI	p-value	Adjusted R²
SRS-22 Function	−0.21	−0.31 to −0.11	<0.001	0.32
PODCI Global	−4.8	−6.9 to −2.6	<0.001	0.29
6MWT (m)	−22.4	−34.6 to −10.2	0.001	0.27
Stair-Climbing (sec)	0.88	0.41 to 1.35	<0.001	0.30
Sit-to-Stand (sec)	0.74	0.29 to 1.18	0.002	0.25

Overall, increasing spinal deformity severity was significantly associated with reduced self-reported function, decreased walking endurance, and slower performance in transitional and stair-climbing tasks. Associations remained significant after adjustment for demographic covariates, supporting an independent relationship between curve magnitude and functional limitation.
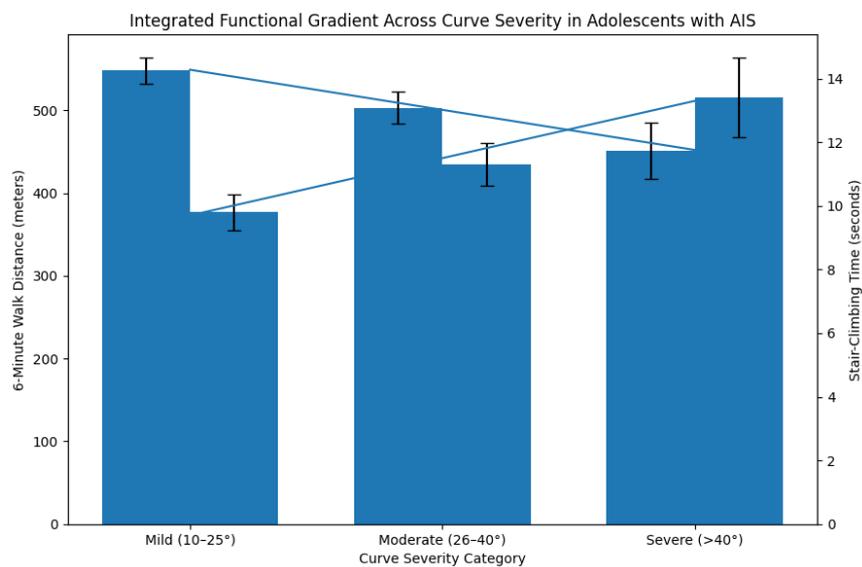
The integrated visualization demonstrates a clear bidirectional functional gradient across curve severity categories. Mean six-minute walk distance declined progressively from 548 meters (95% CI ≈ 533–563) in the mild group (n=44) to 503 meters (95% CI ≈ 483–523) in

the moderate group (n=38) and further to 451 meters (95% CI ≈ 417–485) in the severe group (n=18), representing an overall reduction of 97 meters (17.7%) from mild to severe deformity. In parallel, stair-climbing time increased from 9.8 seconds (95% CI ≈ 9.3–10.3) to 11.3 seconds (95% CI ≈ 10.6–12.0) and 13.4 seconds (95% CI ≈ 12.1–14.7), corresponding to a 36.7% increase in task completion time across severity strata. The opposing linear trends highlight a dose–response relationship in which increasing structural deformity is associated with reduced endurance capacity and slower transitional mobility performance. Notably, confidence intervals widen in the severe group, reflecting greater functional variability at higher curve magnitudes. Collectively, the layered dual-axis presentation underscores the clinically meaningful functional gradient accompanying curve progression, demonstrating simultaneous deterioration in endurance and efficiency of stair negotiation as deformity severity increases.

DISCUSSION

The present cross-sectional analysis demonstrates a consistent and graded association between increasing spinal deformity severity and measurable functional limitation in adolescents with AIS. Both patient-reported and performance-based outcomes showed statistically significant deterioration with increasing Cobb angle, and these relationships remained robust after adjustment for age, sex, and BMI. Specifically, each 10° increment in Cobb angle was independently associated with a 0.21-point reduction in SRS-22 function score, a 4.8-point reduction in PODCI global function, a 22.4-meter decrease in six-minute walk distance, and nearly 1-second prolongation in stair-climbing time.

The observed dose–response pattern across mild, moderate, and severe categories strengthens the biological plausibility of the association and supports the interpretation that structural curve magnitude is meaningfully related to functional capacity in daily activities. The magnitude of correlations between Cobb angle and functional outcomes ranged from r = −0.46 for SRS-22 function to r = 0.34 for stair-climbing time, representing small-to-moderate effect sizes. These findings are consistent with previous literature indicating that adolescents with larger curves report poorer health-related quality of life and physical functioning compared with those with milder deformities (7).

Torén and Diarbakerli reported that larger curve magnitudes were associated with lower SRS-22 function domain scores, although effect sizes varied across domains (7). Our findings extend these observations by integrating objective performance measures, demonstrating that functional differences are not limited to subjective perception but are reflected in endurance and mobility performance. This combined approach aligns with contemporary emphasis on patient-centered outcomes in AIS management (20).

Endurance capacity, as measured by the six-minute walk test, demonstrated a nearly 18% reduction from mild to severe deformity (548 m vs. 451 m). Although AIS is not classically characterized as a cardiopulmonary disorder, previous systematic reviews have documented reduced pulmonary function and exercise tolerance in untreated idiopathic scoliosis, particularly in thoracic curves exceeding moderate severity (4). The reduction of approximately 22 meters per 10° increment observed in the adjusted model suggests that even within non-surgical populations, curve magnitude may exert cumulative effects on exercise capacity. Furthermore, studies examining physical activity patterns in adolescents with AIS have identified increased sedentary behavior and reduced engagement in moderate-to-vigorous activity among those with larger curves, potentially compounding endurance limitations (15). Our findings are consistent with these observations and suggest that

structural deformity may contribute both directly and indirectly to reduced mobility efficiency.

Transitional and stair-climbing performance also demonstrated progressive slowing with increasing curve severity, with stair-climbing time increasing by approximately 3.6 seconds between mild and severe groups. These results are clinically relevant because stair negotiation and sit-to-stand transitions are integral components of school participation and daily functioning in adolescence. Prior biomechanical investigations have reported altered trunk muscle activation, impaired lumbopelvic control, and asymmetrical load distribution in adolescents with moderate-to-severe AIS (3,17).

Such neuromuscular adaptations may reduce mechanical efficiency and increase energy expenditure during functional tasks, thereby explaining the observed prolongation in transitional performance times. Notably, sagittal alignment parameters (thoracic kyphosis and lumbar lordosis) showed weak and non-significant associations with functional measures in this cohort, suggesting that coronal plane curve magnitude may be a more prominent determinant of functional limitation within the studied severity range. Despite statistically significant associations, overall functional scores in the cohort remained within relatively preserved ranges, particularly among those with mild and moderate deformities. This finding supports recent perspectives that AIS is not universally disabling but may produce subtle, activity-specific limitations rather than global impairment (16,20).

The adjusted R^2 values ranging from 0.25 to 0.32 indicate that while curve magnitude explains a substantial proportion of functional variance, additional factors—including physical activity level, pain intensity, psychosocial variables, and curve pattern—likely contribute to functional outcomes. Systematic reviews of exercise-based interventions have demonstrated improvements in SRS-22 function and physical performance measures following targeted core stabilization and physiotherapeutic scoliosis-specific exercises, highlighting the modifiable nature of functional limitation in AIS (18,19). Our findings reinforce the rationale for early functional assessment as part of comprehensive AIS evaluation, particularly in adolescents with moderate curves who may not yet meet surgical thresholds but demonstrate measurable functional decline.

The clinical implications of these findings are twofold. First, reliance solely on radiographic parameters may underestimate the functional burden associated with curve progression. Incorporating standardized performance-based tests, such as the six-minute walk test and stair-climbing assessment, into routine evaluation could provide complementary information regarding activity tolerance and mobility efficiency. Second, the observed graded association suggests that even incremental increases in curve magnitude may translate into meaningful reductions in daily functional performance, supporting timely referral for targeted rehabilitation programs aimed at improving trunk stability, endurance, and movement coordination. Several limitations should be considered.

The cross-sectional design precludes inference of causality or temporal progression; longitudinal studies are required to determine whether increasing curve magnitude prospectively predicts functional decline. Although multivariable adjustment was performed for key demographic confounders, residual confounding from unmeasured variables such as pain severity, physical activity level, and curve pattern cannot be excluded. Additionally, the sample was derived from a combination of hospital-based and school-based recruitment, which may introduce selection bias despite stratified sampling efforts.

Nevertheless, the study employed standardized radiographic measurements, blinded functional assessment, and multivariable modeling to enhance internal validity and

reproducibility. In summary, this study provides evidence that greater spinal deformity severity in adolescents with AIS is independently associated with reduced self-reported physical function, diminished walking endurance, and slower performance in transitional mobility tasks. The graded pattern across severity categories and persistence of associations after covariate adjustment underscore the functional relevance of curve magnitude beyond cosmetic or radiographic considerations. These findings support a multidimensional assessment framework in AIS that integrates structural evaluation with objective and patient-reported functional outcomes to inform individualized, early, and function-focused management strategies.

CONCLUSION

In this cross-sectional cohort of adolescents with Adolescent Idiopathic Scoliosis, increasing spinal deformity severity was independently associated with measurable reductions in daily functional capacity, including lower self-reported physical function, reduced walking endurance, and slower stair-climbing and sit-to-stand performance. A clear graded pattern was observed across mild, moderate, and severe curve categories, with each 10° increment in Cobb angle corresponding to clinically meaningful declines in functional metrics after adjustment for age, sex, and BMI. Although overall functional status remained relatively preserved in mild cases, adolescents with moderate-to-severe curves demonstrated progressive limitations that extend beyond radiographic deformity and may affect everyday mobility and participation. These findings support the integration of standardized functional assessments alongside radiographic evaluation in routine AIS management and highlight the importance of early, targeted rehabilitation strategies aimed at preserving endurance, trunk stability, and movement efficiency in this population

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DECLARATIONS

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