

Original article

Pronation Adaptation during Gait in Adolescents with Thoracic Idiopathic Scoliosis

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Received: 04 June 2025

Revised: 12 July 2025

Accepted: 24 July 2025

Published: 31 August 2025

Citation: İnci Hazal Ayas, Alim Can Baymurat, Ulunay Kanatlı. Pronation Adaptation During Gait in Adolescents with Thoracic Idiopathic Scoliosis. *Trauma & Ortho Kaz*, 2025, 76 (4), jto014
<https://doi.org/10.52889/1684-9280-2025-76-4-jto014>

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Abstract

Adolescent idiopathic scoliosis (AIS) is associated with altered trunk posture and asymmetric lower limb biomechanics. Although gait asymmetries have been observed in AIS, phase-specific compensatory adaptations in dynamic foot posture remain underexplored. The pronation-supination index (PSI) offers a detailed view of foot posture during specific stance phases. This study aimed to analyse PSI values across five gait phases in adolescents with thoracic AIS, focusing on convex-concave foot asymmetry.

Methods. Thirty adolescents diagnosed with thoracic/thoracic dominant AIS (Lenke types 1–4) were included (mean age 14.90 ± 2.92 years; 23 female). The mean major Cobb angle was 35.27 ± 8.64 . PSI data were collected using the dynamic pedobarographic system while participants walked barefoot at a self-selected pace. PSI was calculated separately for the convex and concave feet during five stance phases: foot contact, early-midsupport, midsupport, late-midsupport, and toe-off. Side to side comparisons were conducted using paired t-tests.

Results. PSI was significantly higher on the convex side during the foot contact phase (54.01 ± 3.91 vs. 52.13 ± 4.70 , $p = 0.044$), indicating increased pronation. No significant differences were found in PSI during early-midsupport, midsupport, late-midsupport, or toe-off phases ($p > 0.05$).

Conclusion. Foot pronation increases specifically during initial contact on the convex side in adolescents with thoracic AIS. This reflects a selective pronation strategy at initial contact to maintain balance and compensate for coronal trunk asymmetry. These findings may have clinical relevance for developing targeted interventions that address dynamic gait stability in AIS patients.

Keywords: Adolescent idiopathic scoliosis; gait adaptation; pronation-supination index.

1. Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spinal deformity affecting the young population, most commonly presenting with thoracic curvature [1]. Beyond structural alterations, AIS is associated with changes in postural alignment and

gait, often leading to asymmetrical weight distribution and compensatory strategies during movement [2,3]. Previous pedobarographic studies have reported conflicting results regarding side-to-side plantar pressure asymmetries in AIS. Some indicate increased

loading on the concave side, while others report greater coronal variation on the convex side during static stance [2,4,5]. These inconsistencies suggest that loading patterns may differ based on curve morphology or postural compensation.

Despite growing interest in gait analysis in AIS, few studies have investigated how foot posture adapts dynamically during specific gait phases. Geometric indicators such as the PSI offer insight into phase-

specific foot behavior, but their role in scoliosis-related compensatory mechanisms remains unclear. Particularly, how the foot on the convex side responds during early stance phases is underexplored.

This study aimed to analyze PSI values across five stance phases in adolescents with thoracic idiopathic scoliosis to identify potential side-to-side pronation-supination adaptations during gait.

2. Materials and Methods

This observational cross-sectional study was approved by the local institutional ethics committee on June 11, 2024 (Approval number: B9A69930) and conducted in accordance with the Declaration of Helsinki.

Participants

Thirty adolescents diagnosed with thoracic or thoracic-dominant adolescent AIS were recruited from the scoliosis outpatient clinic of the Department of Orthopaedics and Traumatology at Gazi University between June 2024 and December 2024. Inclusion criteria were: diagnosis of idiopathic scoliosis with a Cobb angle between 10° and 45°, classification as Lenke Type 1 to 4, and no prior use of a spinal brace exceeding three months [6]. Patients with orthopaedics or neurological comorbidities affecting gait, prior spinal surgery, or Lenke Type 5/6 curves were excluded to ensure biomechanical consistency [7].

Assessment

The PSI data were collected using the Novel emed® pedobarographic system (Munich, Germany) during the gait, which provides reliable measures of pressure distribution and geometric parameters [8,9]. Participants walked barefoot at a self-selected pace across the pressure platform, and five valid trials were

averaged for analysis. PSI was calculated for the convex and concave feet during five stance phases: foot contact, early-midsupport, midsupport, late-midsupport, and toe-off. Higher PSI values indicate greater pronation.

The pronation-supination index is an established measure of foot posture that reflects the degree of pronation or supination occurring during gait [10]. It also provides valuable insight into medial-lateral control, referring to how effectively the foot manages balance and weight distribution across the inner and outer sides of the foot throughout the stance phase [10]. In individuals with postural or spinal asymmetries, such as those with AIS, alterations in medial-lateral control may serve as compensatory mechanisms to maintain stability during walking.

Statistical Analysis

Data were analysed using IBM SPSS Statistics for Windows, Version 23.0 (IBM Corp., Armonk, NY, USA). Normality was tested using the Shapiro-Wilk test. Side-to-side differences in PSI were compared using paired t-tests, and statistical significance was set at $p < 0.05$. Continuous variables are presented as mean \pm standard deviation.

3. Results

A total of 30 adolescents with thoracic or thoracic-dominant AIS were included in the final analysis. The mean age was 14.90 ± 2.92 years, and the mean Cobb angle of the major spinal curve was $35.27 \pm 8.64^\circ$. PSI values were calculated separately for the convex and concave feet during five distinct stance phases.

As presented in Table 1, the pronation supination index was significantly higher on the convex side

during the foot contact phase compared to the concave side (54.01 ± 3.91 vs. 52.13 ± 4.70 ; $p = 0.04$), indicating greater pronation at initial contact. No statistically significant differences were observed between sides during early-midsupport, midsupport, late-midsupport, or toe-off phases ($p > 0.05$).

Table 1 – Comparison of PSI values between convex and concave sides

Parameters (%)	Convex side	Concave side	P value
PSI - Foot Contact	54.01±3.91	52.13±4.70	0.04*
PSI - Early Midsupport	52.43±3.93	53.21±5.19	0.29
PSI - Midsupport	50.12±5.86	51.91±4.89	0.16
PSI - Late Midsupport	46.46±5.67	47.88±4.91	0.26
PSI - Toe Off	28.38±10.19	27.06±11.98	0.53

Note: * Statistically significant, $p < 0.05$. Data are presented as mean \pm standard deviation

4. Discussion

The key finding of this study was a significantly higher PSI on the convex side during the foot contact phase, suggesting increased pronation at initial contact. No significant differences were observed in PSI during the remaining stance phases, indicating that this pronation shift is phase specific rather than generalized throughout the gait cycle.

These results align with previous studies reporting asymmetrical plantar loading in AIS patients, but expand upon them by highlighting a selective adaptation during early stance. Increased vertical and anteroposterior ground reaction forces have been reported on the convex side, suggesting a compensatory mechanism aimed at stabilizing trunk alignment [11]. Our finding of elevated PSI during foot contact on the convex foot likely reflects a similar attempt to shift the center of pressure medially, improving balance in the presence of coronal trunk asymmetry.

While static evaluations have shown conflicting results regarding which side bears more load, our phase specific analysis demonstrates that dynamic compensations in AIS are not constant throughout the stance phase [4,5]. Instead, these adaptations are likely orchestrated to stabilize the body during critical gait transitions, such as initial contact. The preservation of symmetric PSI values during midsupport and toe-off further suggests that global foot alignment and

structure are largely maintained what changes is the dynamic functional response at specific moments of gait.

The increased PSI at foot contact may facilitate medial load transfer on the convex side, serving as a neuromechanical strategy to stabilize the center of mass early in the stance phase. Such targeted compensations may reflect an attempt to reduce energy cost or avoid further postural imbalance, in line with prior interpretations of center of pressure adaptations in AIS [12-13].

A noteworthy aspect of our study is its use of curve side specific PSI analysis across distinct gait phases, a methodology that has not been emphasized in earlier literature. For example, the influence of curve location on plantar pressure asymmetries has been highlighted in previous research, although the findings were based on static measurements or area-based indices [7]. In contrast, PSI provides a more sensitive, time dependent metric for identifying compensatory pronation, especially during dynamic loading transitions.

Study limitations include the lack of a healthy control group, which limits comparisons to normative gait patterns. In addition, only thoracic and thoracic-dominant curve types were included, improving sample homogeneity but reducing generalizability to other scoliosis subtypes such as lumbar or double major curves.

5. Conclusions

This study demonstrates that adolescents with thoracic idiopathic scoliosis exhibit a increase in foot pronation on the convex side during initial contact. This compensatory adaptation may serve to stabilize posture and maintain balance in response to coronal trunk asymmetry. Clinically, these findings underscore the importance of evaluating dynamic foot posture in AIS patients and suggest that early stance phase may

represent a critical window for targeted interventions aimed at optimizing postural control. Future research should include healthy controls and broader curve patterns to validate and expand upon these observations.

Conflicts of Interest. The authors declare no conflicts of interest.

Author Contributions: Authors equally contributed to this work. All authors have read and agreed to the published version of the manuscript.

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Кеуде аймағындағы идиопатиялық сколиозы бар жасөспірімдерде жүру кезіндегі пронация бейімделуі

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Түйіндеме

Жасөспірімдердің идиопатиялық сколиозы (ЖИС) тұлға қалпының өзгеруімен және төменгі аяқ-қол биомеханикасының асимметриясымен сипатталады. ЖИС кезінде жүру асимметриялары анықталғанымен, динамикалық табан қалпының фазалық компенсаторлық бейімделулері жеткілікті зерттелмеген. Пронация–супинация индексі (ПСИ) жүрудің нақты фазаларындағы табан қалпы туралы толық ақпарат береді. Бұл зерттеудің мақсаты – торакальді ЖИС бар жасөспірімдерде бес фазадағы ПСИ көрсеткіштерін талдау және дөңес–ойыс жақ арасындағы асимметрияны анықтау.

Әдістері. Зерттеуге торакальді/торакальді-доминантты ЖИС диагнозы қойылған 30 жасөспірім (Ленке типтері 1–4) енгізілді (орташа жас – $14,90 \pm 2,92$ жыл; 23 әйел). Негізгі Кобб бұрышының орташа көрсеткіші – $35,27 \pm 8,64^\circ$. ПСИ деректері динамикалық педобарографиялық жүйе арқылы жалаңаяқ қалыпта, өз қарқынымен жүру кезінде алынды. ПСИ дөңес және ойыс жақтағы аяқтар үшін бөлек есептелді, бес фазада: аяқ жанасуы, ерте- орташа тірек, орташа тірек, кеш-орташа тірек және итеріліп шығу. Жақтар арасындағы салыстыру жұптастырылған t- тест арқылы жүргізілді.

Нәтижелер. Аяқ жанасу фазасында дөңес жақта ПСИ едәуір жоғары болды ($54,01 \pm 3,91$ vs. $52,13 \pm 4,70$, $p = 0,044$), бұл пронацияның күшеюін көрсетті. Ерте-орташа тірек, орташа тірек, кеш-орташа тірек және итеріліп шығу фазаларында елеулі айырмашылық байқалмады ($p > 0,05$).

Қорытынды. Торакальді ЖИС бар жасөспірімдерде бастапқы жанасу фазасында дөңес жақта табан пронациясы артады. Бұл фронталды жазықтықтағы тұлға асимметриясын теңгеру үшін бастапқы жанасудағы селективті пронациялық стратегияны көрсетеді. Алынған нәтижелер ЖИС науқастарда динамикалық жүру тұрақтылығын арттыруға бағытталған нысаналы араласуларды әзірлеуде клиникалық тұрғыдан маңызды болуы мүмкін.

Түйін сөздер: Жасөспірімдердің идиопатиялық сколиозы; жүруге бейімделу; пронация–супинация индексі

Адаптация пронации во время ходьбы у подростков с идиопатическим сколиозом грудного отдела

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Резюме

Юношеский идиопатический сколиоз (ЮИС) ассоциирован с изменением положения туловища и асимметрией биомеханики нижних конечностей. Хотя при ЮИС были выявлены асимметрии походки, фазоспецифические компенсаторные адаптации динамической позиции стопы остаются малоизученными. Индекс пронации-супинации (ИПС) позволяет детально оценить положение стопы в определённых фазах опоры. Целью данного исследования было проанализировать значения ИПС на пяти фазах шага у подростков с торакальным ЮИС, с акцентом на асимметрию стоп со стороны вогнутости и выпуклости.

Методы. В исследование были включены 30 подростков с диагнозом торакального/торакально-доминантного ЮИС (типы Lenke 1–4) (средний возраст $14,90 \pm 2,92$ лет; 23 участницы женского пола). Средний угол по Cobb составил $35,27 \pm 8,64^\circ$. Данные ИПС собирались с использованием динамической педобарографической системы во время ходьбы босиком с произвольной скоростью. ИПС рассчитывался отдельно для стопы со стороны выпуклости и вогнутости на пяти фазах опоры: постановка стопы, ранняя середина опоры, середина опоры, поздняя середина опоры и отрыв носка. Для сравнения между сторонами применяли парные t-тесты.

Результаты. В фазе постановки стопы значения ИПС были статистически значимо выше на стороне выпуклости ($54,01 \pm 3,91$ против $52,13 \pm 4,70$; $p = 0,044$), что указывает на усиление пронации. В фазах ранней середины опоры, середины опоры, поздней середины опоры и отрыва носка достоверных различий выявлено не было ($p > 0,05$).

Заключение. Пронация стопы увеличивается избирательно в момент первоначального контакта на стороне выпуклости у подростков с торакальным ЮИС. Это отражает использование стратегии избирательной пронации при начальном контакте для поддержания равновесия и компенсации коронарной асимметрии туловища. Полученные результаты могут иметь клиническое значение для разработки таргетированных вмешательств, направленных на улучшение динамической стабильности походки у пациентов с ЮИС.

Ключевые слова: юношеский идиопатический сколиоз, адаптация походки; индекс пронации-супинации.