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EFFECT OF PROGRESSION OF ADOLESCENT IDIOPATHIC SCOLIOSIS ON GAIT PARAMETERS

EFEITO DA PROGRESSÃO DA ESCOLIOSE IDIOPÁTICA DO ADOLESCENTE SOBRE OS PARÂMETROS DA MARCHA

EFECTO DE LA PROGRESIÓN DE LA ESCOLIOSIS IDIOPÁTICA DEL ADOLESCENTE SOBRE LOS PARÁMETROS DE LA MARCHA

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ABSTRACT

Objectives: To evaluate the influence of the degree of severity of adolescent idiopathic scoliosis (AIS) on the distribution of plantar load on the feet during gait. Material and Methods: 40 patients with AIS were evaluated and divided into severity groups: 13 with mild AIS; 13 with moderate AIS; and 14 with severe AIS. Cobb angles (degrees) were evaluated by radiography. Gait was assessed using the pressure platform at a frequency of 100 Hz. The adolescents walked on a 20-meter track, with their feet resting on the platform, totaling an average of 12 steps. The following were evaluated: contact area, peak pressure, and maximum force on the 4 regions of the feet: hindfoot (medial and lateral), midfoot, and forefoot. Results: Adolescents with moderate and severe AIS showed an increase in peak pressure and maximum force on the medial (p=0.014; p=0.045, respectively) and lateral (p=0.035; p=0.039, respectively) hindfoot and a reduction on the midfoot (p=0.024) when compared to mild AIS. The contact area showed no differences between groups. Conclusion: The moderate and severe degree of AIS severity promoted increased plantar load on the medial and lateral hindfoot (heel) during gait compared to adolescents with a mild degree of scoliotic curvature. In this way, gait training in the milder stages of disease severity can minimize the overload and the increase in force vectors on the spine, preventing the progression of severe scoliotic curvature. ***Level of Evidence II; Cross-sectional study***.

Keywords: Scoliosis; Adolescent; Gait; Patient Acuity.

RESUMO

Objetivos: Avaliar a influência do grau de severidade da escoliose idiopática do adolescente (EIA) sobre a distribuição da carga plantar dos pés durante a marcha. Material e Métodos: 40 pacientes com EIA foram avaliados e divididos em grupos de severidade: 13 com EIA leve; 13 com EIA moderada; e 14 com EIA grave. Os ângulos de Cobb (graus) foram avaliados pela radiografia. A marcha foi avaliada pela plataforma de pressão, a uma frequência de 100 Hz. Os adolescentes caminhavam sobre uma pista de 20 metros, com o registo do apoio dos pés sobre a plataforma, totalizando em média 12 passos. Foram avaliadas área de contato, pico de pressão e força máxima sobre as 4 regiões dos pés – retropé (medial e lateral), mediopé e antepé. Resultados: Os adolescentes com EIA moderada e grave mostraram um aumento do pico de pressão e força máxima sobre o retropé medial (p=0,014; p=0,045, respectivamente) e lateral (p=0,035; p=0,039, respectivamente) e uma redução sobre o mediopé (p=0,024) quando comparados a EIA leve. Não houve diferenças quanto a área de contato entre os grupos. Conclusão: O grau de severidade moderada e grave da EIA promoveu um aumento da carga plantar sobre retropé medial e lateral (calcanhar) durante a marcha em comparação aos adolescentes com grau leve da curvatura escoliótica. Desta forma, o treino de marcha nos estágios mais leve de severidade da doença pode minimizar a sobrecarga e o aumento dos vetores de força sobre a coluna, evitando a progressão da curvatura escoliótica grave. ***Nível de evidência II; Estudo transversal.***

Descritores: *Escoliose; Adolescente; Marcha; Gravidade do Paciente.*

RESUMEN

Objetivos: Evaluar la influencia del grado de severidad de la escoliosis idiopática del adolescente (EIA) sobre la distribución de la carga plantar en los pies durante la marcha. Material y Métodos: Se evaluaron 40 pacientes con EIA y se dividieron en grupos de gravedad: 13 con EIA leve; 13 con EIA moderada; y 14 con EIA grave. Los ángulos de Cobb (grados) se evaluaron mediante radiografía. La marcha se evaluó utilizando la plataforma de presión a una frecuencia de 100 Hz. Los adolescentes caminaron sobre una pista de 20 metros, con los pies apoyados en la plataforma, totalizando un promedio de 12 pasos. Se evaluaron: área de contacto, presión pico y fuerza máxima en las 4 regiones de los pies: retropié (medial y lateral), mediopié y antepié. Resultados: Los adolescentes con EIA moderado y severo mostraron un aumento en la presión pico y la fuerza máxima en el retropié medial (p=0,014; p=0,045, respectivamente) y lateral (p=0,035; p=0,039,

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respectivamente) y una reducción en el mediopié (p=0,024) en comparación con EIA leve. El área de contacto no mostró diferencias entre los grupos. Conclusión: El grado moderado y severo de severidad de la EIA promovió un aumento de la carga plantar en el retropié medial y lateral (talón) durante la marcha en comparación con adolescentes con un grado leve de curvatura escoliótica. De esta manera, el entrenamiento de la marcha en las etapas más leves de la gravedad de la enfermedad puede minimizar el aumento de la sobrecarga y el aumento de los vectores de fuerza en la columna, evitando la progresión de la curvatura escoliótica severa.

Nivel de Evidencia II; Estudio transversal.

Descriptores: *Escoliosis; Adolescente; Marcha; Gravedad del Paciente.*

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional spine deformity affecting about 3% of adolescents aged 10-17 years,[1,2] being the most prevalent type among idiopathic scoliosis.[2,3] Prevalence is higher in females and may reach a 9:1 sex ratio, according to the progression of Cobb's angle above 40 degrees.[4]

The main symptoms of AIS are changes in body posture, such as uneven shoulders, rib prominence, or asymmetry of the shoulder girdle.[5,6] Because of spinal mobility and changes in body posture, locomotion patterns may be altered in different functional activities of adolescents, especially walking.[7] Unfortunately, the underlying mechanisms linking the severity in degrees of spinal deformity in individuals with AIS to the foot support characteristics during gait performance remain unclear.

The foot's structure can significantly influence the dynamic function of plantar support, and the relationship between foot morphology and function has long been studied.[8,9] For example, the medial displacement of the center of body sway may be related to the morphology of the clubfoot (elevated plantar arch).[10] Previous studies have indicated that foot posture can directly affect the center of body sway, particularly in the propulsive phase of plantar support during gait.[11]

Gait assessment through plantar pressure is widely accepted as a vital biomechanical parameter for the quantitative evaluation of gait, which can provide useful information about foot function in the different phases of support during gait and assist in the development of more effective preventive and interventional strategies, especially on pathologies that affect the spine and lower limbs.[12-18]

Some studies have shown that the trajectory of the center of pressure (COP) in patients with AIS differs from control patients without the disease.[14,18-20] Another recent study, 2021, showed that severe and moderate scoliotic curvature negatively influences gait performance.[15] Other studies targeting patients with untreated AIS showed a difference in gait patterns compared to healthy adolescents; on the other hand, other studies found no significant differences in gait analyses.[7,21-25] Thus, there is still great controversy in the existing literature, especially when targeting this understanding of disease progression.

The magnitude of AIS severity is determined based on the Cobb angle as follows: mild scoliosis, Cobb angle <20˚; moderate scoliosis, Cobb angle of 20˚ to 39˚; and severe scoliosis with Cobb angle >40˚ or 45˚.[15,25,26] None of these studies linked differences in plantar pressure distribution and gait to different levels of AIS severity, and the relationship between AIS severity levels and walking performance needs to be investigated. Thus, this study aimed to evaluate the influence of the degree of severity (mild, moderate, and severe) of adolescent idiopathic scoliosis (AIS) on the plantar foot load distribution during gait.

MATERIAL AND METHODS

A cross-sectional observational type study was conducted with 40 participants with AIS, who were divided into three groups: 13 with mild AIS (Cobb angle <20˚), 13 with moderate AIS (Cobb angle of 20˚ to 39˚), and 14 with severe AIS (>40˚ or 45˚).[15,26] Recruitment was carried out through the Public Hospital of the State of São Paulo/SP, Brazil, and the Instituto Científico Especializado em Reabilitação-REAB, Campinas/SP, Brazil. The study was reviewed and approved by the Research Ethics Committee under number: 2,729,155, under the ethical regulations of the Declaration of Helsinki. All patients evaluated provided the Informed Consent Form and the adolescent's legal guardian's consent form regarding the radiographic and biomechanical evaluation.

The eligibility criteria were female patients aged 15-20 years, with AIS of scoliotic curvature of different degrees, confirmed radiographically by the Cobb angle between 10 and 50 degrees. The exclusion criteria were the presence of another spinal deformity or pathology besides AIS, orthopedic pathologies in the hip, pelvis, or lower limbs; the presence of other musculoskeletal disorders such as neuropathies, obesity, rheumatoid arthritis, and back pain for more than three consecutive months, presence of prostheses and orthoses in the lower limbs.[15]

Radiographic evaluations: panoramic radiographs

For biplane radiography, i.e., two-dimensional radiography, all patients underwent X-ray imaging in the sagittal profile of the spine as part of the medical request for follow-up and confirmation of the clinical diagnosis of AIS (Figure 1). The patients remained standing with body weight support to perform the X-ray examination. The patients' feet remained in the same alignment in the frontal plane, being at a distance of 7.5 cm between them. To reduce artifacts due to the projection of the humerus over the spine, in the lateral view, the adolescents remained with arms crossed and fingers resting on the clavicles. All images were focused on the spine and performed by a technician experienced in radiographic examinations. The X-ray images were scanned and transferred to a computer as digital images and evaluated by the attending physician using Surgimap Spine imaging software (Nemaris Inc., New York, USA).[27]

The parameters for sagittal measurement of the Cobb angle were: thoracic kyphosis angle (CT) was between the tangent line at the cranial ends of the fourth thoracic vertebra (T4), and the caudal end of the 12th thoracic vertebra (T12) and the lumbar lordosis angle (LL) was between the tangent at the cranial end of L1 and sacral (S1), called L1 - S1. It is worth noting that the same radiologist always performed the radiographic evaluations to maintain a standard in the radiographs (Figure 1).[27]

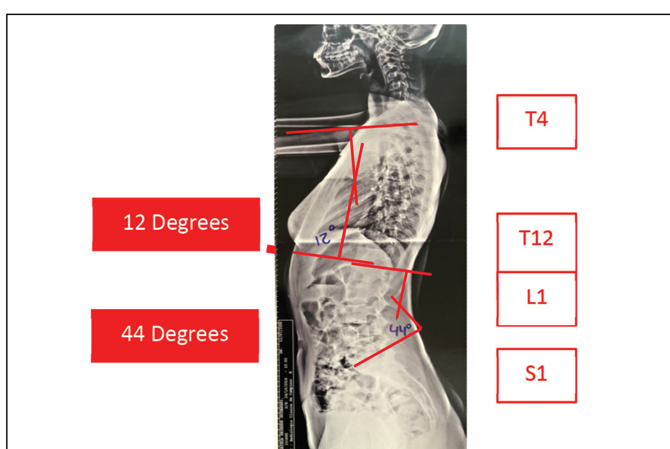

Figure 1. Representation of Cobb angle measurement by X-ray imaging of adolescents with AIS.

Biomechanical Assessment of Gait: Plantar Pressure Distribution

The plantar pressure distribution (plantar load) was evaluated using the Pressure Platform system (Loran, Italy). It is part of the equipment, homogeneously distributed resistive sensors, with resolution depending on the size of the platform, approximately one sensor/cm^2.[28]

The adolescents walked at a pre-selected cadence to ensure they had reached the same speed. All went through a phase of adaptation to the established speed to get the adolescents used to the collection environment and the instruments, so there would be a decrease in the backlash. After the ambiance, the adolescents walked on a 20-meter flat track at a pre-established speed, in which approximately 12 steps were collected and captured in three trials (Figure 2). The plantar pressure variables analyzed were:

• Maximum peak pressure value per selected area: represents the maximum pressure value (expressed in kPa) in the three regions of the foot.

• Foot contact area: represents the area where the sensors have been activated (pressed) in each step (expressed in cm^2).

• Maximum force: represents the value of the maximum force (expressed in N).

• Peak vertical force and transient impact force (impact rate of the first vertical force between a percentage of 20-80% (expressed in N).

All variables were analyzed in 3 planting areas. Thus, the foot was divided into three major areas: hindfoot (30% of foot length), midfoot (30% of foot length), and forefoot and toes (40% of foot length).[28]

Statistical Analysis

The sample size of 40 patients was calculated based on the mean Cobb angle of the main curvature for the different degrees of AIS severity using the G-Power 3.0 software. A moderate effect size (f=0.25), a power of 80%, and a significance level of 5% were used in the calculation**.** First, the normality of the data was tested by the Shapiro-Wilk test. After that, the gait biomechanical parameters were compared between the disease severity groups using the one-way ANOVA test, independent measures, followed by Tukey's posthoc, considering a significance level of $p<0.05$. The tests were performed by SPSS™ *software* (Version 14.0; SPSS Inc. Chicago, IL, USA).

RESULTS

Of the 40 female volunteers with AIS evaluated, the mean Cobb angle of the main curvature was 36.6°± 15.7°, which were compared according to the levels of disease severity (mild, moderate, and severe). No statistical differences were observed for any of the variables . Therefore, the anthropometric measurements were evaluated (p> 0.05) only for the Cobb angles, as expected for the characterization of the degrees of severity of AIS. (Table 1)

Table 2 shows the means and standard deviations found for the gait biomechanical measurements of all the participants evaluated. The results show that AIS in the moderate grades showed an increase in peak pressure and maximum force on the medial (p=0.014; p=0.045, respectively) and lateral (p=0.035; p=0.039, respectively) hindfoot and a decrease on the midfoot (p=0.024) when compared to mild AIS. The contact area showed no significant differences between the groups. These increases in plantar overload showed the effect of AIS progression on the gait performance of the evaluated adolescents (Table 2).

Table 1. Comparison of anthropometric aspects among adolescents with idiopathic scoliosis (AIS) in different degrees of severity: mild, moderate, and severe.

Variables	AIS			
	Light (n = 13)	**Moderate (n = 13)**	**Severe (n = 14)**	**p**
Age (years)	12.3±1.1	13.8±1.8	12.8±2.5	0.232
Mass (Kg/cm^2)	50.1±6.6	50.4±6.2	50.2±5.4	0.125
Height (cm)	1.5±2.2	1.5±3.3	1.6±0.7	0.116
BMI (Kg/cm^2)	15.0±0.2	16.0±0.3	16.0±0.2	0.174
Cobb angle (degrees)	20.5±3.1	37.6±4.5	51.8±4.7	0.001*

*One-way ANOVA test, Tukey's posthoc, significant differences p<0.05.

Table 2. Comparison of aspects of plantar pressure distribution during gait among groups of adolescents with idiopathic scoliosis at mild, moderate, and severe levels.

Variables	AIS	Forefoot	Midfoot	Hindfoot Medial	Hindfoot Lateral
Contact Area (cm^2)	Light	9.1 ± 2.1	13.2 ± 9.8	16.1 ± 2.0	16.6± 2.7
	Moderate	9.3 ± 1.7	11.0 ± 4.9	17.1 ± 2.4	17.2 ± 2.6
	Severe	9.1 ± 1.6	10.3 ± 3.5	17.2 ± 2.4	17.9 ± 2.5
	p (inter-group)	0.893	0.487	0.155	0.167
Peak pressure (kPa)	Light	242.1 ± 34.5	101.6 ± 52.2	258.3 ± 52.5	254.8 ± 50.8
	Moderate	251.5 ± 42.0	75.2 ± 34.9	278.8 ± 78.2	275.4 ± 80.4
	Severe	250.1 ± 49.2	77.6 ± 52.1	283.8 ± 63.5	283.1 ± 65.1
	p (inter-group)	0.403	0.024*	0.045*	0.035*
Maximum Strength (N/PC)	Light	11.4 ± 3.2	5.0 ± 3.6	20.4 ± 5.9	20.8 ± 6.4
	Moderate	12.0 ± 3.3	6.6 ± 3.1	23.2 ± 7.9	22.5 ± 7.6
	Severe	12.0 ± 3.6	7.8 ± 2.8	25.2 ± 7.4	24.5 ± 7.7
	p (inter-group)	0.667	0.036*	0.014*	0.039*

*One-way ANOVA test, Tukey's posthoc, significant differences p<0.05.

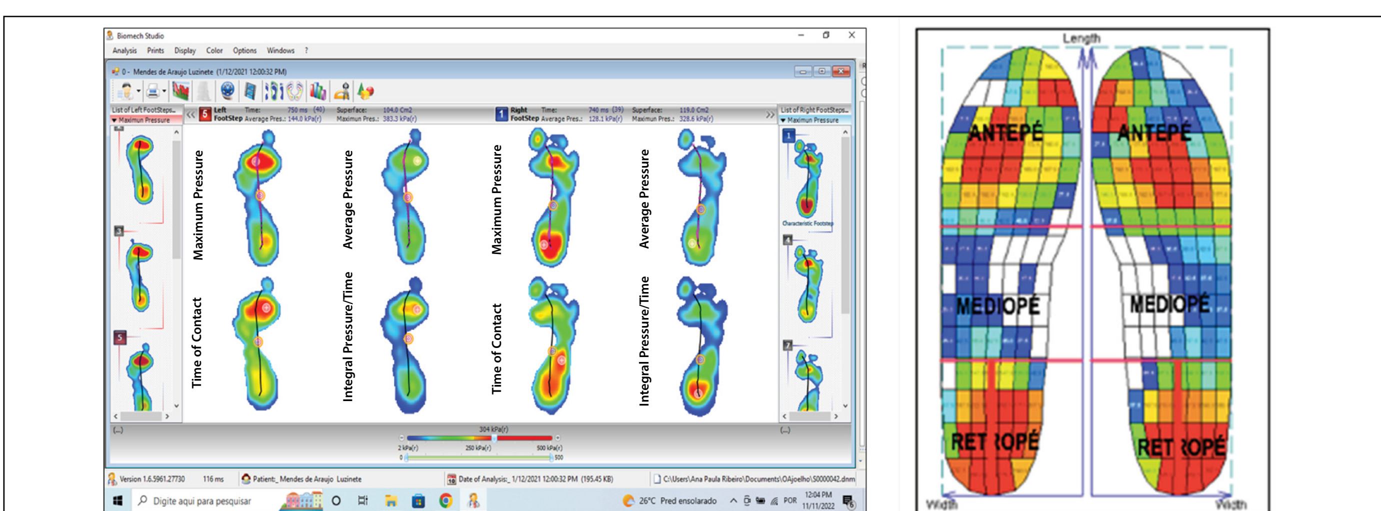

Figure 2. Representation of plantar pressure distribution parameters during gait of adolescents with AIS.

DISCUSSION

In this study, we verified the effect of scoliotic curvature severity on the gait parameters of adolescents with AIS, in which it was possible to observe an increase of plantar overload on the heel (hindfoot) for the severe and moderate levels, as well as a reduction of the plantar load on the midfoot, during the performance of the functional activity of walking. A similar finding was observed by Zhu et al.,[15] in which the authors evaluated 96 patients with AIS in different degrees of disease severity and observed changes in gait performance, such as a longer delay in the propulsion phase and increased adjustment of the pressure sway center on the feet in patients with severe and moderate levels of AIS. Although this study did not evaluate the center of pressure oscillation, only the plantar load, our findings reveal the greater disturbance of force on the hindfoot that promotes faster support, in which the adolescent will have to adjust in a longer time when receiving the load on the forefoot for gait propulsion, as verified in the described study.

Currently, it is observed in the literature with patients with AIS that plantar pressure and gait are affected by various factors, such as age, gender, BMI, and walking speed.[29,30] Therefore, the plantar pressure distribution and gait in adolescents with mild, moderate, and severe AIS were analyzed and compared, considering that age, sex, and BMI were similar so that there would be no bias on the biomechanical parameters of the plantar load evaluated, given the lower imposition of plantar load on the midfoot in adolescents with moderate and severe AIS compared to adolescents with mild AIS with higher plantar pressure in this region. The justification for this care in the anthropometric similarity of the different levels of severity of the groups with AIS (mild, moderate, and severe) was to observe the foot support during gait of these adolescents, without imposition and influence of body weight, since some studies have reported that in cases of severe scoliosis, body weight, and BMI were lower compared to mild and moderate degrees, indicating that, particularly severe scoliosis, can influence body growth and the imposition of body load on the feet of these adolescents.[30,31]

This study shows that the initial heel contact phase during gait was increased, with a greater medial and lateral plantar heel (hindfoot) overload at the severe and moderate AIS severity levels. A possible explanation for the initial support phase with greater burden was that patients with severe and moderate AIS tend to increase the propulsion phase of the gait, which results in acute and high-impact support on the heel (hindfoot), that is, the patient is prepared to quickly transfer the plantar load from the hindfoot to the forefoot to maintain more time in the terminal contact phase to generate the necessary force to propel the body forward against the ground, an explanation that is corroborated by some studies.[11,15]

Another finding observed in this study that explains this need to propel forward quickly and with great impact on the heel was the reduced plantar load on the midfoot. According to some authors, the structure of the clubfoot (high plantar arch) or flat foot (flat plantar arch), with or without contact with the midfoot on the ground, can significantly influence the dynamic function of the foot, especially the gait.[11,32] In a systematic review that investigated the relationship between foot posture and plantar pressure during walking, the authors concluded that plantar pressure characteristics differ according to foot posture.[33] In this study, it could be observed that during walking, patients with severe and moderate AIS had more arched feet, making plantar support in this region more difficult when compared to patients with mild AIS.

The present study is unprecedented, considering the impact of different levels of AIS severity on plantar load parameters since structural spinal deformity can influence the foot support base. However, this study has methodological considerations and limitations that should be explained here. First, it had a cross-sectional design, and causal connections could not be inferred from the results. Second, it was difficult to conclude the influences of foot posture and scoliosis on whole-foot function due to device limitations, such as the absence of associated data, including electromyography data and kinetic gait parameters. However, the care taken in the present study is worth mentioning to measure the magnitude of the scoliotic curvature of adolescents with AIS to determine the severity of the disease by measuring the Cobb angle, considering the sagittal radiograph.

CONCLUSION

Moderate and severe degrees of AIS severity promoted increased plantar load on the medial and lateral hindfoot (heel) during gait compared to adolescents with a mild degree of scoliotic curvature. Thus, gait training in the milder stages of disease severity can minimize the increase in overload and the increase in force vectors on the spine, preventing the progression of scoliotic curvature to a severe state.

All authors declare no potential conflict of interest related to this article.

CONTRIBUTIONS OF THE AUTHORS: Each author contributed individually and significantly to the development of the manuscript. DLG, CEGB, GSC, and APR were the main contributors to writing the manuscript. DLG, CEGB, GSC, RMA, APT, and APR performed the patient assessments, gathered clinical data, and evaluated the statistical analysis data. In addition, DLG and APR performed the literature search and manuscript review and contributed to the intellectual concept of the study.

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