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CORRELATION BETWEEN CYPHOSE AND LORDOSE WITH THE FOOT SUPPORT OF ADOLESCENTS WITH IDIOPATHIC SCOLIOSIS

CORRELAÇÃO ENTRE CIFOSE E LORDOSE COM O APOIO DOS PÉS DE ADOLESCENTES COM ESCOLIOSE IDIOPÁTICA

CORRELACIÓN ENTRE CIFOSIS Y LORDOSIS CON EL SOPORTE DE LOS PIES DE ADOLESCENTES CON ESCOLIOSIS IDIOPÁTICA

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ABSTRACT

Objective: To verify the correlation between the thoracic and lumbar Cobb angle and the type of foot, and the parameters of plantar support during gait in adolescents with idiopathic scoliosis. Material and Methods: Sixty adolescents with idiopathic scoliosis (AIS) were divided into three groups: normal foot (n=20), cavus foot (n=20), and flat foot (n=20). The Cobb angles of thoracic kyphosis and lumbar lordosis were evaluated by radiographic examination. The plantar arch was recorded the podoscope and calculated by the ratio between the midfoot and the total foot area. The adolescents performed the march on a 20-meter track, with their feet resting on the pressure platform, totaling an average of 12 steps of the foot (right and left). The variables evaluated were: contact area, peak pressure, and maximum force on the four regions of the feet: hindfoot (medial and lateral), midfoot, and forefoot. Results: There was a positive correlation between the Cobb angle of lumbar lordosis and the arch plantar cavus ($r=0.40$; $p=0.048$) and flat (0.25; $p=0.004$), with no significant correlations for the Cobb angle thoracic ($p>0.005$). The pressure peak strongly correlated with the cavus plantar arch ($r=0.92$, $p=0.001$) in the lateral hindfoot and forefoot region, while the flat foot with the midfoot region. Conclusion: The Cobb lumbar lordosis angle positively correlates with the plantar arch height and the plantar support pattern during gait in adolescents with idiopathic scoliosis. ***Level of Evidence II; Observational and Cross-Sectional Study.***

Keywords: Scoliosis; Talipes Cavus; Adolescents.

RESUMO

Objetivos: Verificar a correlação entre o ângulo de Cobb torácico e lombar e o tipo de pé e os parâmetros do apoio plantar durante a marcha de adolescentes com escoliose idiopática. Material e Métodos: Foram avaliados 60 adolescentes com escoliose idiopática (EIA), divididos em três grupos: pé normal (n= 20), pé cavo (n=20) e pé plano (n=20). Os ângulos de Cobb da cifose torácica e da lordose lombar foram avaliadas pelo exame radiográfico. O arco plantar foi registrado pelo podoscópio e calculado pela razão entre a área do mediopé e a área total do pé. Os adolescentes realizavam a marcha sobre uma pista de 20 metros, com o registo do apoio dos pés sobre a plataforma de pressão, totalizando em média 12 passos (direito e esquerdo). Foram avaliados: área de contato, pico de pressão e força máxima sobre 4 regiões dos pés: retropé (medial e lateral), mediopé e antepé. Resultados: Houve uma correlação positiva entre o ângulo de Cobb da lordose lombar e o arco plantar cavo (r=0,40; p=0,048) e plano (0,25; p=0,004), sem correlações significantes para o ângulo de Cobb torácico (p>0,005). O pico de pressão obteve uma correlação forte com o arco plantar cavo (r=0,92, p=0,001) em região de retropé lateral e antepé, enquanto que o pé plano com a região do mediopé. Conclusão: O ângulo de Cobb da lordose lombar tem correlação positiva com a altura do arco plantar e o padrão de apoio plantar durante a marcha de adolescentes com escoliose idiopática. ***Nível de Evidência II; Estudo Observacional e Transversal.***

Descritores: *Escoliose; Pé Cavo; Adolescentes.*

RESUMEN

Objetivos: Verificar la correlación entre el ángulo de Cobb torácico y lumbar y el tipo de pie y los parámetros de soporte plantar durante la marcha en adolescentes con escoliosis idiopática. Material y Métodos: Sesenta adolescentes con escoliosis idiopática (EIA) fueron divididos en tres grupos: pie normal (n=20), pie cavo (n=20) y pie plano (n=20). Los ángulos de Cobb de la cifosis torácica y la lordosis lumbar se evaluaron mediante examen radiográfico. El arco plantar fue registrado por el podoscopio y calculado por la relación entre el área del mediopié y el área total del pie. Los adolescentes realizaron la marcha sobre una pista de 20 metros, con los pies apoyados en

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la plataforma, totalizando un promedio de 12 pasos (derecho e izquierdo). Fueron evaluados área de contacto, pico de presión y *fuerza máxima en las 4 regiones de los pies: retropié (medial y lateral), mediopié y antepié. Resultados: Hubo correlación positiva entre el ángulo de Cobb de la lordosis lumbar y el arco cavo plantar (r=0,40; p=0,048) y plano (0,25; p=0,004), no existiendo correlaciones significativas para el ángulo de Cobb torácico (p> 0,005). El pico de presión obtuvo una fuerte correlación con el arco plantar cavo (r=0,92, p=0,001) en la región lateral del retropié y antepié, mientras que el pie plano con la región del mediopié. Conclusión: El ángulo de Cobb de la lordosis lumbar tiene una correlación positiva con la altura del arco plantar y el patrón de apoyo plantar durante la marcha en adolescentes con escoliosis idiopática.* ***Nivel de Evidencia II; Estudio Observacional y Transversal.***

Descriptores: *Escoliosis; Pie Cavo; Adolescentes.*

INTRODUCTION

Scoliosis is a three-dimensional abnormality of the spine, with the idiopathic type being the most prevalent among adolescents (80-90%),[1] affecting between 0.47% and 11.1% of the world's population.[2] The etiology of adolescent idiopathic scoliosis (AIS) remains unknown, but some risk factors are linked to its onset and progression, including hormonal, muscular, biomechanical, and genetic factors.[3] Biomechanical factors include postural changes,[4,5] reduced balance[6] and gait alterations,[7,8] which can contribute to pain symptoms in the spine, and significant functional limitations, which can compromise the adolescent's quality of life if not treated properly.[8]

AIS during the growth phase can result in changes in body sway due to the control of vertical forces received during simple tasks such as walking. These changes alter the integrative management between the visual, proprioceptive, and vestibular systems, directly reflecting changes in the stability and body balance of affected adolescents, which are associated with the progression of scoliotic curvature.[9,10] In this rationale, it is known that the medial longitudinal arch of the foot plays a fundamental role in maintaining body balance and supporting body weight.[10-12]

The most common alterations of the longitudinal plantar arch are observed in children and adolescents, namely cavus and flat feet.[13-15] In a normal and healthy plantar arch (normal foot), the longitudinal and transverse arches provide adequate absorption and distribution of the impact forces the feet receive. Therefore, any change in the plantar arch can lead to changes in the distribution of plantar loads.[14,15] Some evidence suggests that an elevated plantar arch can increase the plantar load on the anterior and posterior parts of the feet,[16,17] in addition to promoting less ankle mobility in the propulsion phase of walking, which results in difficulty and vertical stability of the spine.[17,18] On the other hand, a lowered plantar arch (flat feet) can result in greater overloads on the medial and posterior regions of the feet, increasing medial ligament tension, as well as postural adjustments for a better foot support strategy, with stability and body balance.[16-18]

Studies have suggested that changes in the function of the medial longitudinal plantar arch during gait and static posture can change the plantar load distribution on the surface of the feet, affecting adjacent joint segments such as the knees, hips, and spine.[18,19] Evidence from the literature suggests a positive correlation between increased lumbar curvature and a lowered medial longitudinal arch (flat feet) and between lumbar rectification and an elevated plantar arch (cavus feet) in young women with low back pain.[19] Other studies show that spinal deformities that affect overall position and body balance can affect the plantar arch of the feet.[20-23] In the case of AIS, it is a 3D spine deformity that affects spinopelvic alignment. Still, although it is thought-provoking, the relationship between AIS and changes in the plantar arch remains unclear. Epidemiological studies reveal associations between the presence of AIS and the prevalence of flat feet.[23]

Although the posture of the feet, verified by the plantar arch, is an important alteration during the growth phase, as reported by many authors,[17-23] the association between this parameter and changes in the spine and pelvis, characteristic of alterations in AIS, is still little known and understood. This fact makes conservative treatment of these patients difficult, especially concerning postural adjustment and balance on the base of support of the feet. This study aimed to verify the correlation between the height of the plantar arch and the Cobb angle of thoracic kyphosis and lumbar lordosis and the distribution of plantar pressure during static posture in adolescents with idiopathic scoliosis.

MATERIAL AND METHODS

Type of study and participants

Cross-sectional observational study. Adolescents with idiopathic scoliosis (AIS) were recruited from a specialized Clinical Center for Scoliosis Care in São Paulo-SP. Sixty adolescents with AIS were assessed and divided into three groups according to the classification of foot posture by the medial longitudinal arch index: the normal foot group (n=20), the cavus foot group (n=20), and the flat foot group (n=20).

All the adolescents with AIS were diagnosed radiographically, with the main scoliotic curvature being the thoracic curvature, with a Lenke classification between 1, 2, and 3, with a mean Cobb angle of 32.4° ± 8.5°.

Participants with AIS were excluded if they had leg length discrepancies greater than 1 cm or other musculoskeletal diseases, such as trauma, muscle atrophy or joint diseases, neurological diseases, a disorder or history of spinal or lower limb surgery, and the use of functional lower limb orthoses.

The Institution's Research Ethics Committee approved the study under opinion no. 2.729.155. All participants and their parents provided informed consent to participate in the study.

Radiographic assessment

All the adolescents underwent sagittal X-ray imaging of the spine to confirm the clinical diagnosis of idiopathic scoliosis. For the X-ray examination, the adolescents remained in an orthostatic posture, standing still with body weight support. The participants' feet remained aligned in the frontal plane, with a distance of 7.5 cm between them. In the lateral view, the adolescents stood with their arms crossed and their fingers resting on their clavicles to reduce artifacts due to the projection of the humerus over the spine. To measure the angle of thoracic kyphosis (TC), we used the tangent line between the cranial ends of the fourth thoracic vertebra (T4) and the caudal end of the 12th thoracic vertebra (T12), and for the angle of lumbar lordosis (LL), we used the tangent between the cranial end of L1 and the sacral end (S1), called L1-S1.[5] (Figure 1).

Analysis of the medial longitudinal plantar arch (foot posture)

For the photopodoscopy, the adolescents were positioned on a Carci® podoscope with bare feet, bipodal support, and orthostatic posture. A rectangle of ethyl vinyl acetate (E.V.A) 7.5 cm wide was used to maintain a standard distance between the feet. The image of the plantar impression reflected in the podoscope glass was captured using a 2.1-megapixel digital camera (SONY® - MAVICA FD 200) positioned on a tripod (FIRST MOONLIGHT® 6156), in front of it, at a distance of 24 cm and a height of 45 cm from the ground (Figure 2). The distance and height were set so that the image reflected in the podoscope mirror could be framed without zoom on the camera. These images were then archived at a resolution of 1600 x 1200 pixels for later analysis.

The images were analyzed using the AutoCAD 2000® program, originally developed for the exact sciences and currently

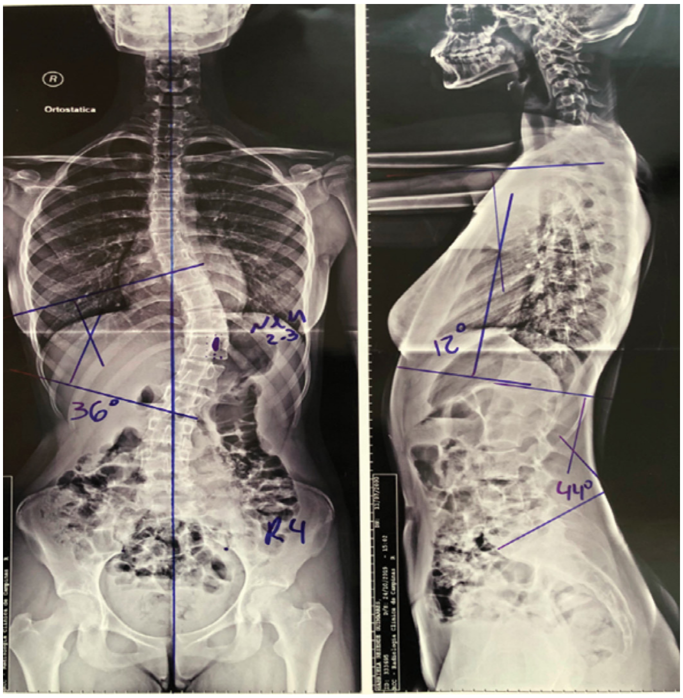

Figure 1. Representation of the sagittal angles of thoracic kyphosis and lumbar lordosis on the X-ray imaging of adolescents with idiopathic scoliosis.

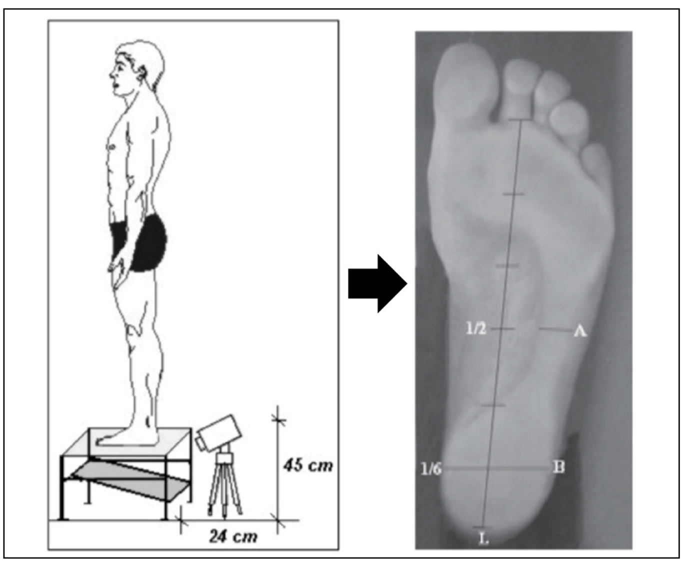

Figure 2. Representation of the recording of the plantar footprint and calculation of the medial longitudinal plantar arch index, adapted from Ribeiro et al. (2005).

used as a health area measuring tool. To classify the types of plantar arch, a horizontal straight line (labeled A) was drawn in the middle of the plantar isthmus using the computer mouse, and another straight line, also horizontal (labeled B), coinciding with the middle of the calcaneal impression. Line A was then divided by line B. For values between 0.3 and 1 cm, the feet were considered normal; for values greater than 1 cm, i.e., when the value of line A was greater than that of line B, the feet were classified as flat; for values less than 0.3 cm, the feet were considered cavus. A longitudinal line (called L) was drawn in the anteroposterior direction of the plantar isthmus and half of the calcaneal impression to standardize the exact locations of the plantar impression. Line A was drawn exactly halfway along line L, with line B coinciding with 1/6 of it (Figure 2). It is important to note that only one foot from each participant was selected for analysis according to the side of the main scoliotic curvature.

Analysis of plantar pressure distribution

The plantar pressure distribution data was collected using a plantar platform system (Loran Sensor Medica Inc., Rome, Italy), internal sensors with dimensions of 3240 mm long, 620 mm wide, 20 mm high, and 29 kg in weight, incorporating capacitance transducer sensors (4 sensors / cm^2), with a frequency of 100 Hz.

The adolescents walked at a pre-selected pace to ensure they reached the same speed. Everyone 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 less of a retroactive effect. After settling in, the adolescents walked on a 20-meter flat track at a pre-established speed, during which approximately 12 steps would be collected and captured in three attempts. The plantar pressure variables analyzed were:

- Maximum peak pressure value per selected area: represents the value of the maximum pressure (expressed in kPa) in the three regions of the foot.
- Foot contact area: represents the area in which the sensors were 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 20 and 80% (expressed in N).

All the variables were analyzed in 3 planting areas. The foot was divided into three large areas: rearfoot (30% of the foot's length), midfoot (30% of the foot's length), and forefoot and toes (40% of the foot's length).

Statistical Analysis

The normality of the data was guaranteed by the Shapiro-Wilks test. Analysis of variance-ANOVA was carried out to compare the anthropometric characteristics between the groups (type of feet). Pearson's correlation test was carried out between the different plantar arch indices: normal, hollow, and flat and the thoracic and lumbar Cobb angles, as well as the distribution of plantar pressure. Correlations were made according to the foot on the side of the greater scoliotic curve. A significance level of $p<0.05$ was considered. The tests used SPSS1™ *software* (Version 14.0; SPSS Inc. Chicago, IL, USA).

RESULTS

Table 1 shows no significant difference between the anthropometric characteristics of the different groups of feet assessed.

Table 2 shows a positive correlation between the Cobb angle of the lumbar lordosis and the flat and cavus plantar arch but no association with the Cobb angle of the thoracic kyphosis.

Tables 3, 4, and 5 show an association between the hollow and flat plantar arch and the plantar load directed towards the contact area, maximum force, and peak pressure of adolescents with AIS. An interesting finding was the strong association between a high plantar arch and peak pressure in the forefoot and lateral hindfoot.

DISCUSSION

The most important observations of this study were the positive and significant associations between changes in the medial longitudinal plantar arch (flat-footedness) and the lumbar Cobb angle in

Table 1. Anthropometric characteristics of adolescents with idiopathic scoliosis in different foot posture groups.

Anthropometry	Cavus foot (n = 20)	Normal foot (n = 20)	Flat foot (n = 20)	p
Age (years)	12.8 ± 2.1	13.3 ± 1.8	13.6 ± 1.7	0.512
Height (cm)	155.0 ± 5.8	156.7 ± 8.7	156.1 ± 5.5	0.184
Body mass (Kg)	46.0 ± 7.6	50.5 ± 9.4	48.6 ± 7.5	0.211
Body Mass Index - BMI (Kg/m^2)	14.0 ± 4.1	16.4 ± 6.1	15.4 ± 4.8	0.265

* Based on ANOVA, one-way test-independent measures (foot groups), considering differences of $p<0.05$ significant.

Table 2. Mean, standard deviation, and correlation between the plantar arch index and the Cobb angle parameters of the spine of adolescents with idiopathic scoliosis.

Column parameters	Cavus foot	Flat foot	Normal foot
Thoracic Cobb angle (degrees)	33.3 ± 9.5	30.7 ± 11.6	36.2 ± 9.7
Correlation (r) P	0.13 0.584	0.25 0.287	0.06 0.801
Lumbar Cobb angle (degrees)	31.4 ± 7.5	26.4 ± 7.6	33.7 ± 10.5
Correlation (r) P	0.40 0.048*	0.25 0.044*	0.05 0.853

* Based on ANOVA, one-way test-independent measures (foot groups), considering differences of $p<0.05$ significant.

Table 3. Mean, standard deviation, and correlation between the plantar arch index and plantar load parameters on the forefoot region of adolescents with idiopathic scoliosis.

Plantar pressure in the forefoot	Cavus foot	Flat foot	Normal foot
Peak pressure (Kpa.s)	79.8 ± 49.9	87.0 ± 54.6	103.1 ± 61.4
Correlation (r) P	0.90 0.010*	0.47 0.036*	0.16 0.500
Maximum force (N.s)	3.1 ± 2.3	3.7 ± 2.3	4.6 ± 3.3
Correlation (r) P	0.33 0.001*	0.52 0.018*	0.12 0.419
Contact area (cm^2)	7.2 ± 3.2	8.2 ± 2.8	9.4 ± 2.3
Correlation (r) p	0.41 0.007*	0.45 0.046*	0.23 0.329

* Based on ANOVA, one-way test-independent measures (foot groups), considering differences of $p<0.05$ significant.

Table 4. Mean, standard deviation, and correlation between the plantar arch index and plantar load parameters on the midfoot region of adolescents with idiopathic scoliosis.

Plantar pressure in midfoot	Cavus foot	Flat foot	Normal foot
Peak pressure (Kpa.s)	6.2 ± 3.5	75.7 ± 57.5	74.2 ± 37.3
Correlation (r) p	0.32 0.001*	0.12 0.024*	0.19 0.156
Maximum force (N.s)	0.08 ± 0.01	7.2 ± 3.6	5.2 ± 3.3
Correlation (r) p	0.10 0.045*	0.18 0.012*	0.21 0.260
Contact area (cm^2)	1.0 ± 0.2	30.7 ± 11.6	21.0 ± 11.0
Correlation (r) p	0.25 0.028*	0.12 0.032*	0.05 0.234

* Based on ANOVA, one-way test-independent measures (foot groups), considering differences of $p<0.05$ significant.

Table 5. Mean, standard deviation, and correlation between the plantar arch index and plantar load parameters on the medial and lateral hindfoot of adolescents with idiopathic scoliosis.

Plantar pressure in the medial rearfoot	Cavus foot	Flat foot	Normal foot
Peak Pressure (Kpa.s)	173.6 ± 96.2	173.3 ± 83.0	223.6 ± 88.1
Correlation (r) p	0.20 0.001*	0.24 0.031*	0.24 0.308
Maximum force (N.s)	10.3 ± 5.9	13.2 ± 8.4	15.7 ± 5.8
Correlation (r) p	0.41 0.019*	0.23 0.022*	0.27 0.248
Contact area (cm^2)	33.3 ± 9.5	30.7 ± 11.6	36.2 ± 9.7
Correlation (r) p	0.47 0.037*	0.12 0.025*	0.21 0.376
Plantar pressure in the lateral retrofoot	**Cavus foot**	**Flat foot**	**Normal foot**
Peak pressure (Kpa.s)	153.5 ± 79.8	159.4 ± 74.6	210.5 ± 86.1
Correlation (r) p	0.92 0.027*	0.25 0.031*	0.22 0.544
Maximum force (N.s)	8.0 ± 4.9	11.5 ± 7.8	13.2 ± 5.5
Correlation (r) p	0.18 0.046*	0.12 0.039*	0.17 0.456
Contact area (cm^2)	15.6 ± 4.3	19.5 ± 0.7	18.9 ± 3.0
Correlation (r) p	0.54 0.001*	0.10 0.022*	0.02 0.678

* Based on ANOVA, one-way test-independent measures (foot groups), considering differences of $p<0.05$ significant.

adolescents with AIS. Another important point was the strong association between a high plantar arch and lower distribution of plantar loads on the feet, especially peak pressure on the lateral hindfoot and forefoot areas. In addition, there were moderate correlations between a lowered plantar arch, i.e., flat feet, and increased peak pressure on the midfoot region, as well as reductions in plantar loads on the forefoot and medial and lateral hindfoot when compared to adolescents with normal feet.

In the literature, some studies have shown associations between an elevated plantar arch and changes in the plantar load on the forefoot, midfoot, and rearfoot in young individuals without spinal deformities, which may promote possible compensatory reactions of the trunk, spine, or postural asymmetries of the upper and lower kinetic chain.[24-26] This study showed an association between reduced plantar load and changes in foot posture, i.e., an elevated or flat plantar arch, in adolescents with spinal deformities, such as idiopathic scoliosis.

An elevated plantar arch or hyperplane can result in asymmetries in the distribution of the impact forces received by the lower limbs and thus promote important postural changes in the pelvic segment, lumbar spine[25,27-30] and shoulders.[29] According to Khamis et al.[28] a lowered arch with hyperpronation of the calcaneus can generate rotational changes in the tibia and femur and result in misalignment of the pelvic posture in asymptomatic individuals. Other studies have found no association between changes in the plantar arch and the posture of the pelvis and lumbar spine.[24] It is important to note that some authors still infer that changes in pelvic and trunk posture are due to the position of the feet as a result of the footwear predominantly used in their activities of daily living.[25,28] In this study, we aimed to verify the association between the plantar arch and the distribution of the plantar load in adolescents who already had spinal deformities, given the scoliotic curvatures present, and we found that changes in the lumbar lordosis were positively associated with the flat and cavus foot posture.

The associations between changes in plantar load distribution and foot type, as measured by the medial longitudinal plantar arch, were moderate to high, with the peak pressure being strongly associated with an elevated plantar arch in the lateral rearfoot and forefoot regions during the static posture. Despite the positive associations observed in this study, an important finding was the reduction in plantar loads in the forefoot, midfoot, and hindfoot regions, regardless of the elevated or flat plantar arch type, compared to normal feet. This fact has attracted attention, showing that the plantar loads are poorly absorbed and distributed over the support surface of the feet, which can cause greater impact forces on the lower kinetic chain and, consequently, on the lumbar spine, which can be confirmed by the association between the plantar arch and the Cobb angle of the lumbar spine observed in this study.

Some studies infer those changes in plantar load due to foot type over time can generate significant muscle overload in the lower kinetic chain, resulting in joint changes and significant pain symptoms during static posture and walking.[30-32] According to Woźniacka et al.[33] a high plantar arch can influence the asymmetry of the plantar load on the lower limbs and shoulder girdle, which is detrimental to body posture. According to the authors, corrective exercises should be performed to avoid worsening postural changes in the spine. Our results show the importance of treating the plantar arch and the changes in the destruction of the plantar load of the feet in adolescents with idiopathic scoliosis with exercises, given their association and importance in order not to increase the postural changes in the lower and upper kinetic chain, which already come from the deformity of the spine itself, and thus avoid the progression of scoliotic curvatures with improved postural stability and balance.

The clinical implications of this study indicate that the alignment of the plantar arch of the feet should be considered in the conservative and rehabilitative treatment of AIS, as this is a contributing factor to changes in plantar load and lumbar lordosis, which have a major influence on changes in the lower limbs, pelvis, spine, and thorax. However, there are some limitations to the study that should be addressed. All measurements were carried out in a static position, so the results should not be fully extrapolated to dynamic conditions. In the future, taking measurements, e.g., during walking, would be interesting, which could show how the plantar arch can influence the distribution of plantar load and body posture. We believe that a more comprehensive understanding of how the feet influence each part of the lower and upper kinetic chains could provide a better basis for conservative treatment of patients with AIS.

CONCLUSION

The Cobb angle of the lumbar lordosis positively correlates with the height of the plantar arch and the pattern of plantar support during gait in adolescents with idiopathic scoliosis.

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

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