Effect of the Cavus and Planus Foot on Biomechanics Aspect of the Plantar Pressure in Adolescents With Idiopathic Scoliosis

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Research

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Abstract

Purpose: To verify the effect of cavus and planus feet on plantar pressure during static posture in adolescents with idiopathic scoliosis (AIS).

Methods: Cross-sectional study. Sixty adolescents with idiopathic scoliosis (AIS) were evaluated and divided into three groups: normal foot (n=20), cavus foot (n=20), and planus foot (n=20). The scoliosis was confirmed by a spine X-ray exam (Cobb angle). The plantar arch index (AI) was calculated from the ratio between the midfoot area and the total area of the foot. Distribution plantar pressure data was collected using a plantar pressure system. The contact area, maximum force, and peak pressure were acquired over areas: forefoot, midfoot, and lateral and medial rearfoot.

Results: The Cobb angle of the AIS of the major curves averaged 33.7°±10.7°, the mean TK was 32.6° ±6.7°, and the mean LL was 31.4°±8.3°. AIS with cavus feet showed a reduction in contact area and peak pressure on the midfoot and lateral rearfoot when compared to planus and normal feet, as well as maximum force on the midfoot and rearfoot (medial and lateral). Planus feet showed increased peak pressure and maximum force on the midfoot when compared to cavus and normal feet. Another observation was that planus feet also promoted an increase in peak pressure and maximum force on rearfoot in relation to cavus feet.

Conclusions: Foot posture influences plantar pressure of patients with AIS. Cavus feet decrease the plantar load on the midfoot and rearfoot while planus feet increased plantar pressure in these regions. *Level of evidence: III*

Introduction

Adolescent idiopathic scoliosis (AIS) is considered a three-dimensional spinal abnormality which is most prevalent in adolescents (80–90%) between 10 and 16 years of age [1–3]. Generally, AIS affects between 0.47% and 11.1% of the world population [2, 3]. The etiology of AIS remains unknown, but is accompanied by physical alterations in the body system involving hormonal, neuromuscular, biomechanical, or genetic factors.[3] Among them, the biomechanical factors promoted by postural alterations [4, 5] balance reduction [6], and gait changes [7, 8] can also cause pain and impair the adolescent's quality of life, if not effectively treated according to the progression of the spine curve [8]. Changes in gait pattern of AIS expose the body to an abnormal loading pattern and increase the risk of accumulated musculoskeletal injury to the segments between the spine and the foot [7, 9]. Patients with AIS showed decreased hip and pelvic motion, excessive energy cost of gait, stepping pattern asymmetry, and ground reaction force asymmetry [7]. Therefore, understanding the effect of foot type on plantar pressure during static posture is pivotal for prevention of musculoskeletal discomfort.

The foot arch plays a key role in maintaining body balance and supporting body weight [10]. Foot types, characterized by a medial longitudinal plantar arch that is cavus or planus, have a significant impact on plantar fascia of mechanical function of foot support during gait movement and the development of musculoskeletal lower limb injuries [11, 12]. The correlation of AIS and cavus foot has been previously reported in the literature, in studies over several decades [12–15]. This correlation can be explained by the possible change in body balance related to muscular imbalance, which is influenced by the central nervous system and caused by spine deformity, such as scoliosis [14–16]. Another study reported the predisposition to planus foot in scoliosis, that is, a flattening of the longitudinal plantar arch, explained by the presence of greater ligament relaxation present in AIS [17]. Regardless of the postural asymmetry of the feet, studies on AIS have shown that any postural asymmetry is associated with the risk of progression in idiopathic scoliosis, arising from an imbalance of the feet (medial longitudinal plantar arch) supporting the body weight in static and dynamic balance; therefore, it was reported that a change in plantar pressure during gait can affect the prognosis of the disease [6, 18, 19].

Several studies have shown differing gait patterns between participants with untreated AIS and their healthy peers. The literature suggests that AIS affects walking cadence and step length [20, 21], pelvic, hip, and knee motion [22, 23], spinal electromyographic activity asymmetry [9] loading and unloading of the feet [8, 24], ground reaction force asymmetry [8, 24], and energy expenditure [8, 9]. According to scientific evidence, lower limb joint changes, especially of the foot, are associated with AIS [13–17]. Thus, while scoliotic spinal deformity occurs in the frontal plane, postural adjustments in the sagittal plane can lead to adjustments in foot support during gait with respect to different foot types, and, consequently, to possible changes in plantar load distribution in patients with AIS, which can lead to worse balance and progression of the Cobb angle in scoliosis [25]. Therefore, it is suggested that monitoring of plantar pressure in different foot types during static posture is needed to assess the disease and treatment outcomes. For better effectiveness of conservative clinical treatment and postoperative AIS, deeper understanding of this topic is required. Thus, the objective of this study was to verify the effect of cavus and planus feet on plantar pressure during static posture in adolescents with idiopathic scoliosis (AIS).

Methods

Study Design and Participants

A cross-sectional study with an observational design. From August to November of 2019, idiopathic scoliosis patients were recruited as volunteers from the State Public Servant Hospital and Clinical Center in Scoliosis Care. Sixty adolescents with idiopathic scoliosis were evaluated and divided into three groups: normal foot (n = 20), cavus foot (n = 20), and planus foot (n = 20). All the adolescents with AIS were determined radiographically to have a single thoracic curve (Lenke 1, 2, and 3) [5] with mean Cobb angles of 32.2°±9.9°. The groups of AIS patients were recruited from middle schools and comparable in terms of age, weight, height, and body mass index (BMI) (Table 1).

Table 1
Anthropometric characteristics between foot groups: normal, cavus and planus of the patients with adolescent scoliosis idiopathic.

Variables	**Cavus Foot** **(n = 20)**	**Normal Foot** **(n = 20)**	**Planus 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 weight (Kg)	46.0 ± 7.6	50.5 ± 9.4	48.6 ± 7.5	0.211
Body weight 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.*

Adolescents 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, weight less than 50 kg, any disorder or history of surgery of the spine or lower limbs, which would affect their gait performance, and they were required to be able to stand without assistance. The study was approved by the Institutional Research Ethics Committee under Opinion Number: 2.729.155. All participants and their parents provided informed consent for participation in the study.

Radiographic Evaluations

Posterior–anterior radiographs were taken of the recruited patients on large 36×14-in cassettes in the standing posture. The parameters of the spine: Cobb angle, Thoracic kyphosis (TK), and Lumbar Lordosis (LL) were recorded. The three most important radiological measures were captured by two attending spine surgeons with the means recorded as the actual values.[9,19] The Cobb angle measurement was performed using Lenke's method for classification. The thoracic kyphosis (TK: angle between the superior end-plate of T5 and the inferior endplate of T12), and lumbar lordosis (LL: angle between the endplate of S1 and the inferior endplate of T12) were also measured [9, 19].

Outcome on Static Posture: Foot Type by Medial Longitudinal Plantar Arch Index (AI)

The AI was calculated from a footprint obtained using a plantar pressure system (Loran Sensor Medica Inc., Rome, Italy) during quiet static posture taken with the participant standing in relaxed bipedal stance for 60 seconds with a distance of 7.5 cm between the feet. Footprints were captured on the plantar pressure system and transferred to AutoCAD 2005H software for AI calculation. In this software, a vertical straight line (L) was drawn from the second metatarsal to the center of the calcaneus. Then, the (L) line was divided into three parts for the delimitation of the forefoot, midfoot, and rearfoot areas. To measure the medial longitudinal arch, the midfoot area was divided by the total foot area: forefoot + midfoot + rearfoot (Fig. 1) [12]. Footprint analyses were chosen because of the advantages of previously confirmed reliability and validity. For values between 0.22 and 0.25, the foot was classified as normal; values of 0.21 indicated cavus foot; and 0.26 planus foot. It is important to report that only one foot of each participant was selected for testing according to the major curve side of the Cobb angle measurement of Thoracic kyphosis and Lumbar lordosis of the AIS.

Outcome on Plantar Pressure Distribution during Static Posture

Distribution plantar pressure data were collected using a plantar pressure system (Loran Sensor Medica Inc., Rome, Italy), with four sensors inside and with dimensions of 3240mm in length, 620mm in width, 20mm in height, and 29 kg in weight, incorporating capacitance transducer sensors (4 sensors/cm2) sampling at a frequency of 100 Hz. The platform was embedded in the center of a walkway and data were collected during quiet static posture taken with the participant standing in a relaxed bipedal stance for 60 seconds with a distance of 7.5 cm between the feet. A five-minute adaptation period was allowed for participants to become comfortable with the data collection procedure. For analysis, the foot was divided into three areas: lateral and medial rearfoot, midfoot, and forefoot. The following variables were extracted: peak pressure (kPa), maximum force (N), contact area (cm^2), and maximum mean pressure (kPa) (Fig. 2) [12].

Statistical Analysis

Statistical analysis was performed using SPSS 25 (IBM Corp., Armonk, NY, USA). Data normality was ensured using the Shapiro-Wilk test. We used one-way ANOVA for comparisons between foot groups: normal, cavus, and planus, for each foot area on plantar pressure distribution parameters. The comparisons were performed of the radiographic findings (TK or LL) on the major curve side. All data are described as mean and standard deviation. The statistical significance was set at $p < 0.05$ with a 95% confidence interval.

Results

The major curves presented a mean of 33.7°±10.7°, the mean TK was 32.6°±6.7°, and the mean LL was 31.4°±8.3°. In 41 cases, the major curve pointed to the right and in 19 cases the major curve pointed to the left. The participants were comparable with respect to age, height, body weight, and BMI, and all were right-limb dominant (Table 1).

Table 1

The static posture condition of AIS with cavus feet showed a reduction in contact area and peak pressure on the midfoot and lateral rearfoot when compared to planus and normal feet, as well as the maximum force on the midfoot and rearfoot (medial and lateral). The planus feet showed increased peak pressure and maximum force on the midfoot when compared to cavus and normal feet. Another observation was that planus feet also promoted an increase in peak pressure and maximum force on the medial and lateral rearfoot in relation to cavus feet and a decrease compared to normal feet.

Table 2

Table 2
Mean, standard deviation and inter-group comparison of plantar pressure distribution during the static posture between foot posture groups: cavus, normal and planus of the patients with adolescent scoliosis idiopathic.

Variable	Foot Groups	Forefoot	Midfoot	Medial Rearfoot	Lateral Rearfoot
Contact Area (cm^2)	Cavus (1)	7.2 ± 3.2	1.2 ± 0.9	15.7 ± 4.2	15.6 ± 4.3
	Normal (2)	9.4 ± 2.3	23.0 ± 5.4	18.6 ± 2.0	19.0 ± 3.0
	Planus (3)	8.2 ± 2.8	21.0 ± 11.4	16.3 ± 4.8	17.0 ± 4.5
	p (inter-groups)	0.070	$< 0.001^{1-2;1-3}$	0.054	$0.038^{1-2;2-3}$
Peak Pressure (kPa)	Cavus (1)	79.8 ± 49.9	6.2 ± 3.5	173.6 ± 86.2	153.5 ± 79.8
	Normal (2)	103.1 ± 61.4	74.2 ± 37.3	223.6 ± 88.1	210.5 ± 86.1
	Planus (3)	86.9 ± 54.3	76.7 ± 57.5	178.3 ± 83.0	160.4 ± 74.6
	p (inter-groups)	0.396	$0.001^{1-2;1-3;2-3}$	0.137	$0.021^{1-2;1-3;2-3}$
Maximum Force (N/BW)	Cavus (1)	3.1 ± 2.3	1.0 ± 0.1	10.3 ± 5.9	8.0 ± 4.9
	Normal (2)	4.6 ± 3.3	5.1 ± 3.6	15.7 ± 6.0	13.2 ± 5.5
	Planus (3)	3.6 ± 2.3	7.2 ± 6.9	13.2 ± 8.4	11.5 ± 8.8
	p (inter-groups)	0.188	$0.001^{1-2;1-3;2-3}$	$0.043^{1-2;1-3;2-3}$	$0.047^{1-2;1-3;2-3}$

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

Discussion

The main results of the current study showed that in static posture, AIS with cavus feet demonstrated a reduction in contact area and peak pressure on the midfoot and lateral rearfoot when compared to planus and normal feet, as well as the maximum force on the midfoot and rearfoot (medial and lateral). Planus feet showed an increase in peak pressure and maximum force on the midfoot when compared to cavus and normal feet. In addition, planus feet also promoted an increase in peak pressure and maximum force on the medial and lateral rearfoot in relation to cavus feet and a decrease compared to normal feet. The foot is part of the kinetic chain connecting the lower limb to the spine, via the pelvis [26], which is responsible for maintaining support for the static posture and dissipating the plantar load during walking [26–28]. Another issue is that bone maturation and hormonal changes during adolescence can promote substantial alterations in the arch morphology and feet support in patients with AIS [4, 6]. The clinical relevance of the present study was to show that cavus (high medial longitudinal arch) and planus feet (low medial longitudinal arch) have an effect on plantar pressure in different foot areas in patients with AIS.

In a normal, healthy foot, the longitudinal and transverse arches provide the most optimal foot loading and proper force distribution. However, foot arch alterations may lead to structural changes and/or affect load distribution [29, 30]. In the current study, AIS with cavus feet showed a reduction in contact area and peak pressure on the midfoot and lateral rearfoot when compared to planus and normal feet, as well as in the maximum force on the midfoot and rearfoot (medial and lateral).

Cavus feet (increased medial longitudinal arch) can cause lower mobility of the foot[12,30] and a weak force absorption mechanism which predisposes to injuries [12–15]. This worse mechanism of distribution of impact forces in the contact of the heel with the floor can also be explained by the lower angle of the calcaneus in relation to the first metatarsal, favoring an elevated longitudinal plantar arch [10]. Another line of reasoning is that with increasing age, healthy female adolescents, interestingly, tended to increase their toe and forefoot plantar pressures compared to males, which may be a possible risk factor for further foot impairments [31]. The differential of this study was to show that adolescents with AIS have lower plantar pressure on the midfoot and rearfoot areas, which can promote greater difficulty in maintaining body balance. This finding can be supported by the association between balance changes due to the reduction in the contact area of the forefoot and rearfoot and alterations in body posture in adolescents with AIS [26, 32].

A key tool in the analysis of foot and lower limb biomechanics is the measurement of the direction and magnitude of force applied to the plantar surface of the foot [4]. A recent systematic review found some evidence of distinctive plantar pressure characteristics in planus and cavus feet [5]. Specifically, when normal and cavus feet were compared, planus feet displayed higher pressure, force, and contact area values in the medial arch, central forefoot, and hallux, while these variables were lower in the lateral and medial forefoot. In contrast, when compared to normal and planus feet, cavus feet displayed higher pressure in the heel and lateral forefoot and lower pressure, force, and contact area in the midfoot and hallux. Another caution in this study was the use of tools for measuring the plantar arch (feet posture), which are reliable and valid for clinical use, and present normative values that been used in previous studies on foot posture [33–35].

Planus feet showed an increase in peak pressure and maximum force on the midfoot when compared to cavus and normal feet. In addition, planus feet also promoted an increase in peak pressure and maximum force on the medial and lateral rearfoot in relation to cavus feet and a decrease compared to normal feet. Studies have reported that planus feet (low medial longitudinal arch) can result in greater plantar loads over the calcaneal medial area, which, in turn, induces greater stretch in the plantar fascia

[36–38]. In this study, adolescents with AIS with planus feet presented increased load of plantar pressure on the heel (medial and lateral), as well as on the midfoot, intensifying and worsening the stretching forces on the plantar fascia, which could be a clinical predictor of plantar overload on the heel in adolescents with AIS, as observed in adult runners in a study conducted by Lee and Hertel [39].

The contribution of the present study was to understand the influence of foot posture on plantar pressure during static posture in AIS. The limitation of this study was that it did not evaluate the plantar pressure during gait between different types of foot posture to better understand foot support in AIS. Future studies addressing AI and dynamic variables on plantar load, may further enhance the understanding of the association between these variables in patients with AIS.

Conclusion

Foot posture influences plantar pressure in the midfoot and rearfoot regions of adolescents with AIS. Cavus feet decreased plantar load on the midfoot and rearfoot while planus feet increased plantar pressure in these regions, both changes in relation to normal feet of patients with AIS. This finding suggests that greater attention should be paid by health professionals training plantar support for each foot posture (cavus or planus) for better effectiveness of the rehabilitation process of adolescents with AIS.

Abbreviations

Adolescent idiopathic scoliosis (AIS); Body mass index (BMI); Thoracic kyphosis (TK); Lumbar Lordosis (LL); Medial Longitudinal Plantar Arch Index (AI).

Declarations

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Authors’ contributions

All authors have significantly contributed to this study and are willing to take public responsibility for all its aspects: its design, data acquisition, and analysis and interpretation of data. All authors have been actively involved in the drafting and critical revision of the manuscript and provided final approval of this version. The corresponding author had full access to all the data and final responsibility for publication submission.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards approved by the institutional review board at University of Santo Amaro on the number: 2.729.155, in accordance with the 1964 Helsinki declaration and regulations.

Informed consent: All participants read and signed an informed consent prior to participation in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare they have no competing interests.

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