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Research article

The effects of pediatric flat foot on the frontal alignment of proximal segment

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ABSTRACT: The purpose of this study was to determine the effects of flat foot on the frontal alignment of calcaneus and tibia in 23 children with flat feet, aged 7-9 (7.43±0.58 years old). To evaluate the foot, the Foot Posture Index-6 (FPI 6) was used, while the posture of the calcaneus and the tibia was analyzed using the Global Postural System 400. The statistical results indicate strong intensity links between flat foot and the frontal alignment of the calcaneus and the tibia, as follows: FPI 6 right foot score and calcaneus - right foot angle (r= 0.824; p < 0.001), tibia - right foot angle (r= 0.588; p < 0.001); FPI 6 left foot score and calcaneus - left foot angle (r= 0.824; p < 0.001), tibia - left foot angle (r= 0.853; p < 0.001). Our study demonstrates that pediatric flat foot has the capacity to significantly influence the values of the angle of the calcaneus and tibia in a frontal plane.

Keywords: pediatric flat foot, Foot Posture Index-6,proximal segments

INTRODUCTION

Most of the time the impact of climate and social changings are too fast and too aggressive for quieter evolution of man needs. Therefore, with the rapid evolution of society has emerged a growing number of children with physical and intellectual deficiencies, who require constant help and support (1), regardless of the condition inherited or acquired during growth and development.

Flat foot (pes planus) is described as a biomechanical problem with a multitude of clinical characteristics: excessive eversion of the subtalar joint, plantar flexion of the talus, plantar flexion of the calcaneus in relation to the tibia, dorsal flexion and abduction of the navicular bone, supination of the anterior foot, and valgus of the calcaneus (2,3). The available estimations regarding flat foot prevalence in children lead to disparate observations, depending on multiple factors: age, gender, family history, constitutional and ligamentous laxity, increased weight or obesity, age of the child when started wearing shoes and the quality of the shoes. For this reason, Evans and Rome present an interval of 0.6-77.9% for pediatric flat foot prevalence (4).

When the weight is loaded on the plantar surface, as it happens during the standing position, the medial longitudinal arch flattens. Together with the valgus of the calcaneus, this represents the clinical manifestation that is frequently encountered in the case of this disorder (5). Without the biomechanical intervention of the body weight and external forces acting on the body, the medial longitudinal vault returns to normal. This flexibility defines the flexible flat foot. The opposite case, where the plantar vault does not return to normal, represents the rigid flat foot (6).

The fact that most activities are performed in a closed kinetic chain, the lower limb structures should collaborate in an effective way. Based on this link, it has been said that any foot modification can perturb the posture and the movement of the proximal segments (7).

For example, biomechanical studies have shown that flat foot records higher contact values on the longitudinal medial vault in the central side of the anterior foot and in the hallucis (8). In static conditions, flat foot cases are reported for young Karate Do practitioners, as all plantar imbalances can affect body posture and cause joint pain, including the spine. There is a maximum pressure distribution (Pmax) for the rearfoot area (9,10). The overloading mechanism caused by these pressures demands the structures involved in the muscle chain to perform compensation motions. As a result, the static and dynamics of these structures can be perturbed. These modification in foot and ankle structures possibly make the foot to pronate. The pronation of the foot, characterized by the abduction, plantar flexion of the talus and the eversion of the calcaneus, modifies the alignment of the tibia and causes the exaggeration of internal rotation of the tibia during walking (11). There are few studies that try to determine the link between flat foot and frontal modifications of the proximal segments (calcaneus and tibia). As a result, the purpose of this study was to determine the effects of flat foot on the frontal alignment of calcaneus and tibia in children with flat feet, aged 7-9.

MATERIALS AND METHODS

Participants

The selection of the subjects used the Foot Posture Index-6 (FPI 6) assessment instrument. Out of a total number of 64 subjects, identified by the interdisciplinary team consisting of a physician, a physical therapist, and a physical education teacher, 51 children 25 (girls), 26 (boys) with flat feet were selected, aged between 7 and 9 (7.54±0.61 years old), with weight: 27,84 ± 7,79. After the FPI 6 analysis, 23 subjects (11 girls and 12 boys) aged 7.43±0.58 years old, with weight 28,65 ± 8,74, were proposed for the postural analysis. After this stage, the aim of the research was presented to the legal guardians of the selected subjects, in order to get their consent for the subjects' participation in the study.

The following inclusion criteria were applied: age of 7-9, an FPI 6 score higher than 6 points, a flexible flat foot. The exclusion criteria were: foot or leg traumas, foot or tibia surgeries, rigid flat foot, hip asymmetries, unequal lower limbs, any kind of musculoskeletal or neurological pathology, the use of plantar orthoses or supports.

Instruments of assessment and measurement

a) Evaluating the feet using FPI 6 is a quick, easy to apply method for the examination of the feet on the three anatomical planes. Created as a response to the need for a valid and reliable assessment instrument, the FPI 6 proved to be suitable for a series of clinical applications, with good results in getting qualitative linear measurable data (12,13).

The applicability of FPI 6, according to professional studies, is in the identification of the type of foot, but it can be used also for other purposes. According to Redmond et. al. (14), FPI 6 was used for multiple purposes: to determine the biomechanical risk factors, to verify the correlations between the type of foot and various pathologies, to investigate the causality relations between the type of foot and sports injuries, etc. Its current form is a revised version of the FPI 8 (an 8-item instrument), both based on the observation and palpation of the posterior, middle, and anterior foot.

The grading system uses a Likert-type scale, where the lowest score indicates a very supine foot, and the highest score expresses the excessive pronation of the foot.
According to its manual, Redmond present the following assessing protocol (15):
• palpation of the talar head (in a frontal and transversal plane);
• curvatures over and under the lateral malleolus (frontal and transversal planes);
• position of the calcaneus (frontal plane);
• prominence of the talonavicular joint (transversal and sagittal planes);
• shape of the medial longitudinal vault (sagittal plane);
• abduction/ adduction of the anterior foot (transversal plane).
The reference values that were used to interpret and select the subjects were the following:
• between 0 and +5 = neutral;
• between +6 and +9 = prone foot;
• between ≥ 10 = very prone foot;
• between -1 and -4 = supine foot;
• over -5 = very supine foot.
b) The global postural analysis - GPS 400 is a postural analyzer that facilizes the acquisition of digital pictures about the frontal/ sagittal plane of the body. It is composed of several components and software that determines the obtaining variables related to the morphology of the body. The hardware section comprises a digital camera, two vertical bars, a frame ruler, and a platform. The landmarks of the frame target: horizontality of eyes, nose-ear plan, the position of the head, shoulders position, the line created by the inferior angle of the shoulder blades, the position of the pelvic, position of the knees, position of the ankles.

Assessment procedures
a) Evaluating the feet using FPI 6
Before starting the evaluation, the subjects were instructed in regards to the assessment procedure. They were asked to take off their shoes and adopt a relaxed standing position while standing on a surface with a wooden base (40cm l x 44cm L x 20 cm h). They were also asked to stand still and look at a visual mark placed at their eye level, at a distance of 10 m. The reference values used to interpret the data and to select the subjects were the following: between 0 and +5 = neutral; between +6 and +9 = prone foot; between ≥ 10 = very prone foot; between -1 and -4 = supine foot; over -5 = very supine foot.
b) Evaluating the posture using GPS 400
The subjects were asked to undress and stand according to the indications on the surface of the platform. This way, the digital camera captured the whole body using the sliding wires as reference points. The system measures the calcaneus and tibia angles in accordance to the reference points offered by the system.

Statistical analysis
Statistical analysis was conducted using IBM SPSS software package (Version 25). For all tests, the level of significance was set as $p \le 0.01$ (2-tailed).

RESULT

The distribution of children with flat feet, based on the FPI 6 score for the right foot and left foot, presented an asymmetry with a crowding toward high values. In both cases of FPI 6-rf and FPI 6-lf, the median of the series had a value of 10, meaning that half of the subjects were under/over this value. There is a higher concentration of the FPI 6-lf score compared to the FPI 6-rf in the upper side of the figure (the Q3-maximum interval), which suggests that there are multiple subjects that recorded higher values for FPI 6-left foot than for the right foot (see figure 1).

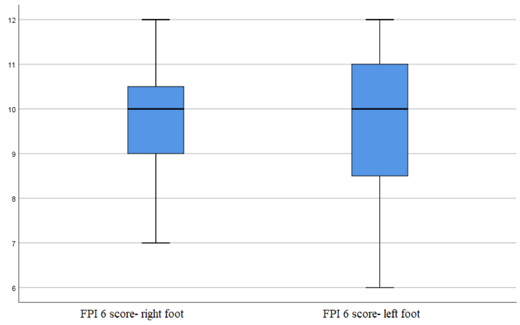

Figure 1. Distribution of the FPI 6 values for right foot and left foot scores

Table 1 summarizes the descriptive markers for the values recorded during the measurement of the calcaneus - left foot and right foot angles, and of the tibia - left foot and right foot angles.

Table 1. Descriptive markers for the distribution of the dependent variables' values

Statistical markers	angle of calcaneus (rf)- grades	angle of calcaneus (lf)- grades	angle of tibia (rf)	angle of tibia (lf)
Minimum	6.40	4.90	1.70	1.90
Maximum	20.00	20.30	14.30	15.90
m	12.53	11.77	5.93	7.59
Median	12	11.90	4.10	4.70
s	4.61	4.84	4.15	4.89

Note: m = arithmetical mean; s = standard deviation; rf= right foot; lf= left foot

One can see that the distribution of the calcaneus-rf angle and the calcaneus-lf angle values were asymmetrical (see figure 2). In the case of the graphical representation of the calcaneus-rf angle, the median had the value of 12, the data crowding toward high values. The graphical representation of the calcaneus-lf angle presents an asymmetry with a crowding toward high values.

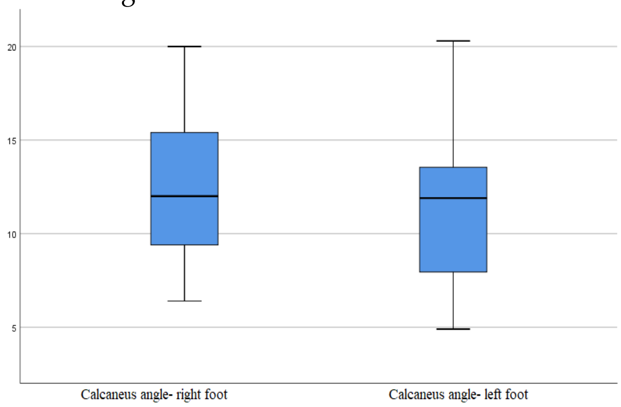

Figure 2. Distribution of the calcaneus angle values (right foot) and the calcaneus angle values (left foot)

In the case of the distribution of the values recorded for the tibia angles, both variables present an asymmetry toward low values. As presented in table 1 and figure 3, the median of the tibia - rf angle series had a value of 4.10 while the median of the tibia - lf angle series had a value of 4.70 (half of the subjects are above/below these values).

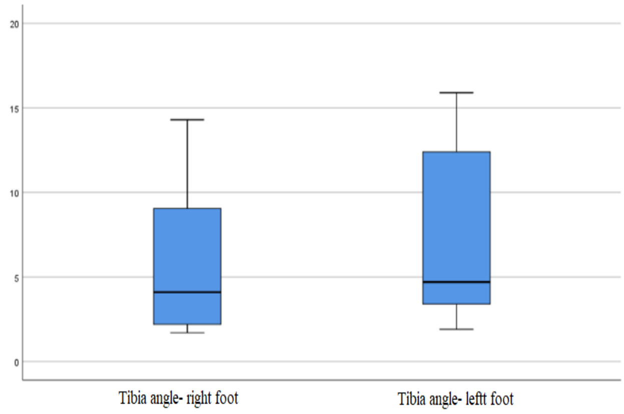

Figure 3. Distribution of the tibia angle values (right foot) and the tibia angle values (left foot)

The Pearson correlation coefficient for the FPI 6-right foot /FPI 6-left foot scores and the dependent variables

The Pearson correlation coefficient was used to establish the relationship and intensity between the independent variables (IV) and the dependent variables (DV) (see table 2 and table 3).

Table 2. Descriptive markers for the distribution of the dependent variables' values

The independent variables	the FPI 6 right foot score, the FPI 6 left foot score
The dependent variables	calcaneus - right foot angle calcaneus - left foot angle tibia - right foot angle tibia - left foot angle.

Table 3. The Pearson correlation coefficient for the independent and the dependent variables

		Calcaneus - rf angle	Calcaneus - lf angle	Tibia - rf angle	Tibia - lf angle
FPI 6 - rf score	r	.824**	-0.203	-.588**	.493
	p	0.000	0.353	0.003	0.017
	N	23	23	23	23
FPI 6 - lf score	r	-0.136	.816**	.421	-.853**
	p	0.535	0.000	0.045	0.000
	N	23	23	23	23

As seen in Table 3, the statistical results indicate the following:

• a positive significant correlation, of strong intensity, between FPI 6-rf and calcaneus-rf angle (r= .824**; p < .001);

• a negative significant correlation, of strong intensity, between FPI 6-rf and tibia-rf angle (r= .588**; p < .001);

• a positive significant correlation, of strong intensity, between FPI 6-lf and calcaneus-lf angle (r= .816**; p < .001);

• a negative significant correlation, of strong intensity, between FPI 6-lf and tibia-lf angle (r= -853**; p < .001).

Regression equation for the FPI 6-right foot /FPI 6-left foot scores and the dependent variables

A simple regression model was tested to determine the ability of the FPI 6-rf, FPI 6-lf (the independent variable) to influence the value of the dependent variables, with the following results:

1. The ability of FPI 6-rf to modify the value of the calcaneus-rf angle

From a statistical point of view, the regression equation passed the test F(1.21) = 44.28, P < 0.000, and the independent variable determines the dependent variable, with a value of R2 = 0.678. In other words, when the FPI-6 score for the right foot increases by one point, the calcaneus-rf angle will increase in average by 2.689 degrees (see figure 4).

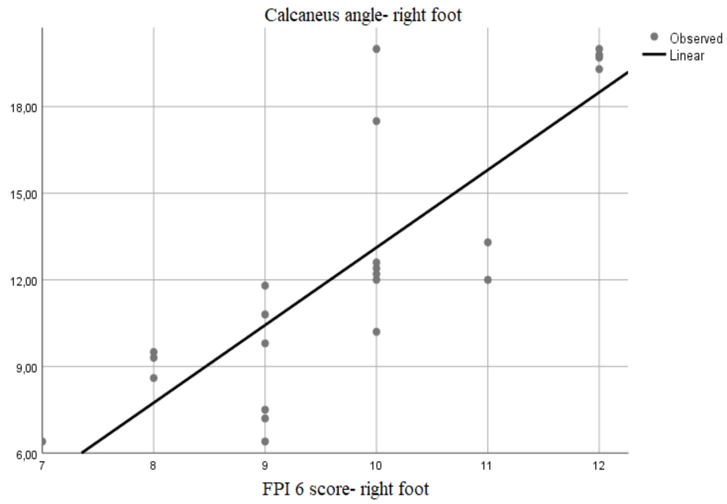

Figure 4. Linear regression analysys for FPI 6-rf and calcaneus-rf angle

2. The ability of FPI 6-rf to modify the value of the tibia-rf angle

The recorded results indicate that the regression equation passed the Fisher test, F(1.21) = 11.113, P < 0.003, with a R2 value of 0.346. Thus, the interpretation of the linear regression model was the following:

• when the FPI-6 score for the right foot increases by one point, the tibia-rf angle will decrease in average by -1.730 degrees (see figure 5).

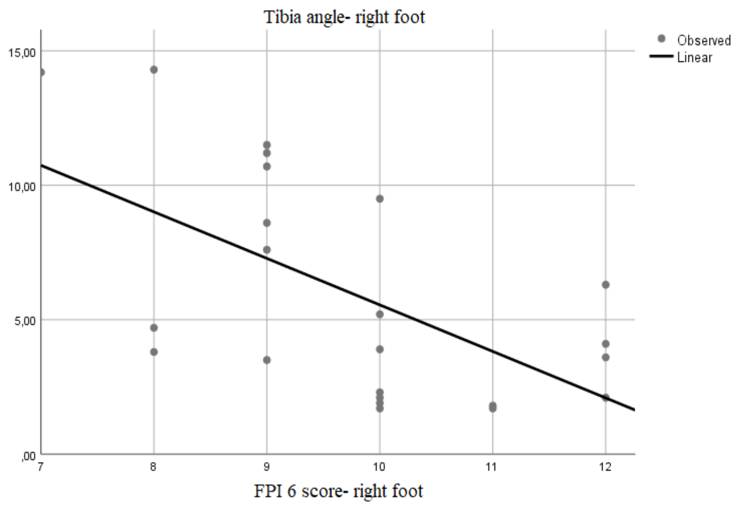

Figure 5. Linear regression analysys for FPI 6-rf and tibia-rf angle

3. The ability of FPI 6-lf to modify the value of the calcaneus-lf angle

After analyzing the chart resulted in the output, one can observe a strong link between FPI 6-lf and the calcaneus-lf angle, represented by a regression line (see figure 6). The regression equation passed the test F(1.21) = 41.909, P < 0.000, and the independent variable determines the dependent variable, with a value of R2 = 666. Thus:

• when the FPI 6 score for the left foot increases by one point, the calcaneus-lf angle will increase in average by 2.437 degrees.

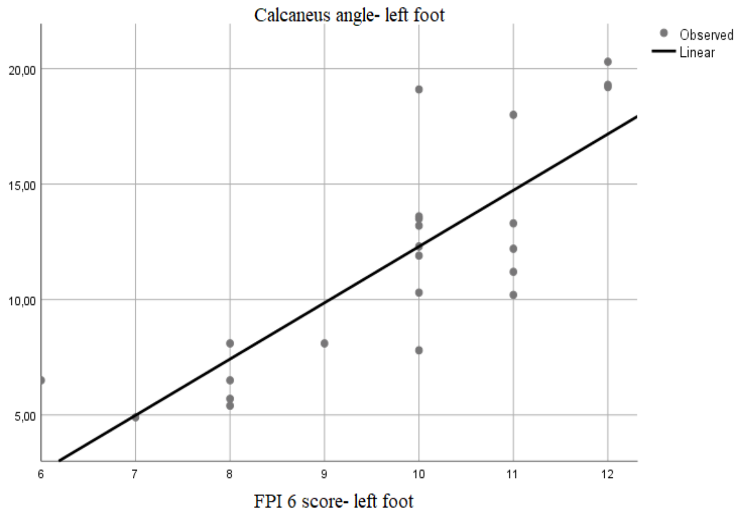

Figure 6. Linear regression analysys for FPI 6-lf and calcaneus-lf angle

4. The ability of FPI 6-lf to modify the value of the tibia-lf angle

The regression equation was significant, F(1.21) = 56.254, P < 0.000, with a R2 value of 0.728. Thus, the interpretation of the linear regression model was the following:

• when the FPI-6 score for the left foot increases by one point, the tibia-lf angle will decrease in average by -2.572 degrees.

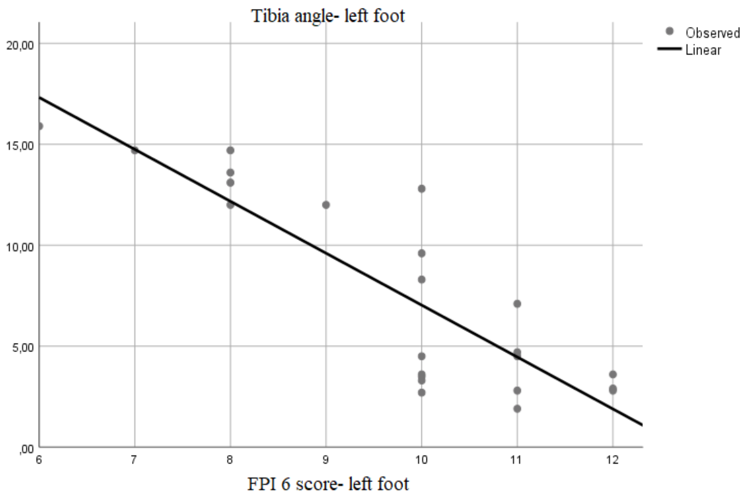

Figure 7. Linear regression analysys for FPI 6-lf and tibia -lf angle

DISCUSSION

FPI 6 score and the frontal alignment of the calcaneus

The statistical results suggest that there are positive significant correlations with a strong link between the FPI 6 score and the calcaneus angle with the right foot (r= 0.824; p < 0.001) and with the left foot (r= 0.816; p < 0.001). More than that, the FPI 6 score has the capacity to modify the value of the angles by 67.8% (right foot) and by 66.6% (left foot).

Similarly, Chuter et al., (16) recorded positive correlations between the FPI score and the frontal components. The descriptive statistics indicated that there are positive significant correlations between the FPI score and maximum eversion ($r = 0.92$, $p < 0.05$). There were also significant correlations between the FPI score higher than 6 points and the maximum eversion angle of the posterior foot ($r = 0.81$, $p < 0.05$). Testing of the linear regression equation has revealed that the FPI score has a very high capacity to predict the frontal moves of the posterior foot (r2 = 0.85, $p < 0.001$).

While some authors have reported a higher posterior foot eversion in flat foot subjects, others did not record results that would confirm this hypothesis (17).

Cho et al., (18) have tested the link between FPI and resting calcaneal stance position angle, both being clinical instruments used to evaluate and measure the pediatric flat foot. The analysis of the Pearson correlation coefficient has shown that there is a moderate correlation between the proposed variables (kappa value: 0.704 right foot, 0.710 left foot), thus the authors were unable to draw firm conclusions in regard to the link between the two variables.

FPI 6 score and the frontal alignment of the tibia

The results suggest that there are negative significant correlations with a strong intensity between the FPI 6 score and the tibia angle with the right foot (r= -0.588**; $p < 0.001$), and the left foot (r= -0.853**; $p < 0.001$). Also, the statistics suggests that the FPI 6 score for the right foot determines a modification by 34.6% of the tibia-right foot angle, while the FPI 6 score for the left foot determines a modification by 72.8% of the tibia-left foot angle. In other words, an increase in the FPI 6 score (prone or very prone foot) will cause a shrinking of the tibial angle, getting it closer to the median axis of the body.

Similarly, Burssenss et al., (19) have tested the link between the frontal alignment of the posterior foot and the alignment of the lower limb. The statistical analysis indicated that in the case of the subjects with a more accentuated valgus posterior foot, there were the following modifications in the tibia: the valgus of the mechanical angle of the tibia ($r = -0.46$; $p < 0.001$) and the valgus of the mechanical angle of the tibia-femur ($r = -0.4$; $p < 0.001$).

Based on the link between the foot and the leg, numerous studies have started from the premise that the excessive eversion of the subtalar joint (a component of the flat foot) causes the medial translational movement of the talus, influencing the movement of the tibia. Khamis and Yizhar (20) have proven that the eversion angle determined by the modification of the slope angle by 10 and 20 degrees, respectively, can cause significant changes in the alignment of the calf ($r = 0.943$–0.984, $p < 0.0001$).

Under dynamic conditions, multiple authors have recorded data that confirm that tibial movements are exaggerated in the subjects with flat foot, compared to the subjects with neutral foot. Levinger et al. (21) have shown that in the subjects with flat foot, the tibia performs a posterior movement greater than in the subjects with neutral foot, during the initial contact with the floor (-17.88°±3.18° vs. -14.08° ±2.48°; $p = 0.008$). The authors have attributed these results to the subjects' tendency to perform large steps ($p = 0.07$). Even if the recorded statistics did not suggest significant differences between groups in regard to the frontal and transversal tibial modifications, the authors highlighted the fact that the tibia performed a greater internal rotation during the stance phase of walking.

The posture of the posterior foot modifies the static and function of the proximal segments (22). Due to the fact that there is proof confirming that even the smallest changes in the link between the posterior foot eversion and the internal tibial rotation, the authors of this study believe that the modification in the transversal alignment of the tibia (during the tibial rotation) and the frontal alignment influence each other. For example, the retraction of the Achilles tendon, often encountered in the clinical manifestation of flat foot, can cause significant sagittal deformations, which, in turn, will influence the transversal and frontal alignment of the structures involved in the balance (23) and motion (24). In other words, according to the biomechanics of the joint that manifests predominantly in a certain plane, there will be compensations also in the other planes of motion, based on the

deformation forces, very important in ground contact (25). Further studies are needed, however, to test this supposition.
Singh et al. (26) have analyzed the modifications in the alignment of the bone structures in case of flat feet and concluded that it modifies both the position of the posterior foot and the position of the tibia. More than that, the values of their measurements were directly influenced by the severity of the flattening of the medial longitudinal vault.

LIMITATIONS

Our study has several limitations. First, the small size of children can be considered as a limitation of the study. Secondly, we think for a better understanding of the mechanism of producing effects of flatfoot (pes planus) on the posture of the child, would be recommended the longitudinal researches. Another limitation is possible due to the method by which we can measure the modification of the calcaneus and tibia alignment. These two structures make a combination of motions that includes more than the frontal plane, therefore, the method that we used in the present study may not be sensitive enough to extract accurate and isolate data from just the frontal plane.

CONCLUSION

In conclusion, we demonstrate, that there are significant correlations with a strong link between the flat foot and the frontal alignment of the calcaneus and the tibia. Moreover, we show that pediatric flat foot has the capacity to significantly influence the values of the angle of the calcaneus and tibia in a frontal plane.

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