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Plantar pressure distribution and foot morphology of children with Cerebral Palsy and typical development

Distribuição da pressão plantar e morfologia do pé de crianças com paralisia cerebral e crianças com desenvolvimento típico

Distribución de la presión plantar y morfología del pie de los niños con parálisis cerebral y las niñas con el desarrollo típico

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ABSTRACT | Cerebral Palsy (CP) is characterized as movement and posture disorders that cause performance limitations in activities easily performed by children with typical development (TD). Our study aimed to compare plantar pressure distribution and foot morphology between children with CP and TD, using an observational analytical research, of cross-sectional and comparative type, with 32 children between 6 and 11 years old, paired by gender and age, distributed in study group (SG) and control group (CG). We assessed the plantar distribution with the Footwork electronic baropodometry system and classified foot type by the Chippaux-Smirak Index. The SG obtained greater values on anterior weight-bearing and lower on posterior weight-bearing (p=0.02). In addition, SG showed lower mean pressure values for right (p=0.00) and left feet (p=0.01), when compared with the CG. Most children showed the same type of foot bilaterally, with the prevalence of flat feet in SG and cavus feet in the CG. Children with spastic CP who presented preserved locomotor performance, or with some dysfunction, revealed antepulsion posture, smaller mean plantar pressures, and flat foot prevalence when compared with children with TD.

Keywords | Foot Deformities; Foot, Children, Cerebral Palsy, Evaluation.

RESUMO | A paralisia cerebral (PC) é caracterizada por desordens de movimento e postura, que causam limitações na execução de atividades facilmente desempenhadas por crianças com desenvolvimento típico (DT). Este estudo objetivou comparar a distribuição da pressão plantar e a morfologia do pé entre crianças com PC e DT, utilizando uma pesquisa analítica observacional transversal do tipo comparativa, com 32 crianças entre 6 e 11 anos, pareadas por sexo e idade e distribuídas em grupo estudo (GE) e grupo controle (GC). A distribuição plantar foi avaliada por meio do sistema de baropodometria eletrônica Footwork e o tipo de pé classificado pelo índice de Chippaux-Smirak. O GE obteve maior descarga de peso no sentido anterior e menor no sentido posterior (p=0,02), além de menores valores das pressões médias dos pés direito (p=0,00) e esquerdo (p=0,01) em relação ao GC. A maioria das crianças apresentou o mesmo tipo de pé bilateralmente, com prevalência de pés planos no GE e cavos no GC. Crianças com PC espástica, que apresentaram o desempenho locomotor preservado ou com alguma disfunção, revelaram antepulsão corporal, menores pressões plantares médias e prevalência do pé plano, em comparação às crianças com DT.

Descritores | Deformidades do Pé; Pé; Criança; Paralisia Cerebral; Avaliação.

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RESUMEN | El parálisis cerebral (PC) es caracterizado por desórdenes de movimiento y postura, que causan limitaciones en la ejecución de las actividades fácilmente desempeñadas por los niños con el desarrollo típico (DT). Este estudio tuvo el objetivo de comparar la distribución de la presión plantar y la morfología del pie entre los niños con el PC y el DT, utilizando una investigación analítica observacional transversal del tipo comparativa, con 32 niños entre seis y once años, pareadas por sexo y edad y distribuidas en el grupo estudio (GE) y el grupo control (GC). La distribución plantar fue evaluada por medio del sistema de baropodometría electrónica Footwork y el tipo de pie clasificado por el índice de Chippaux-Smirak. El GE obtuvo la descarga de peso más grande en el sentido anterior y menor en el sentido posterior (p=0,02), además de menores valores de las presiones medianas de los pies derecho (p=0,00) e izquierdo (p=0,01) en relación al GC. La gran parte de los niños presentó el mismo tipo de pie bilateralmente, con prevalencia de pies planos en el GE y cavos en el GC. Los niños con PC espástica, que presentaron el desempeño locomotor preservado o con alguna disfunción, revelaron antepulsión corporal, menores presiones plantares medianas y prevalencia del pie plano, en comparación a los niños con DT.

Palabras clave | Deformidades del Pie; Pie; Parálisis Cerebral; Evaluación.

INTRODUCTION

Cerebral Palsy (CP) is characterized as movement and posture disorders, consequential of non-progressive afflictions in the developing encephalon, which causes performance limitations in activities easily performed by children with typical development (TD)[1,2].

Abnormalities in muscle tone and, consequently, in posture, are common in children with CP, spasticity being the most[2] predominant. For this reason, the primary change on CP is the motor impairment, which leads to postural adjustments, with alterations on body biomechanics and possible bone deformities[3].

The constant action of distinct forces on the plantar surface may compromise foot functionality, leading to changes in load distribution. These changes interfere with the alignment of ankle and foot and can lead to the emergence of plantar diseases and deformities[3,4].

This distribution analysis is relevant to the prevention of postural disorders[5,6] and can be performed with electronic baropodometry[7], which gives an indication of foot function and helps the investigation of abnormal patterns in static position and gait, thus contributing to the disorders' understanding[4]. Studies[8-10] demonstrate the effectiveness of this system to plantar pressure distribution evaluation, although the comparison of baropodometry and foot morphology between children with CP and TD is still little explored[10].

Consequent CP alterations can lead to differences in those children's plantar pressure distribution and foot type, when compared with TD. Therefore, our study aimed to compare the plantar pressure distribution and foot morphology between children with cerebral palsy and typical development.

METHODOLOGY

To achieve the goal proposed, an observational, cross-sectional, and analytical research, of comparative type, was used. The sample calculation, based on the study by Nakaya et al. [11], was of 16 children with TD in the control group (CG), and 16 children diagnosed with spastic CP in the study group (SG), chosen according to gender and age. We divulged the study in a university hospital and in public schools, in such a way that the sample happened for convenience. Inclusion criteria for SG were: children aged from 6 to 11 years, able to understand simple verbal instructions and with independent gait, classified in level I, in which the children walk without limitations, or in level II, in which they present limitations to walk long distances or in balance, according to the Gross Motor Function Classification System (GMFCS)[12]. As exclusion criteria, the children could not have performed orthopedic surgery in the lower limbs and/or application of botulinum toxin in the last six months, and could not present diagnosed associated disorders (mental deficiency and sensory problems) that would make the evaluation unfeasible.

The measurement of plantar pressure distribution variables was conducted with a Footwork electronic baropodometric system, which had an active surface of 400x400mm, dimensions 575x450x25mm, with 2704 capacitive sensors calibrated at a frequency of 150Hz,

maximum pressure by a capacitor of 100N/cm^2 and a 16-bit analog converter. The capacitor measurements were 7.62x7.62mm, weight of 3kg and a thickness of 4mm/5mm, with rubber. Child's shoe size, height, and weight, measured at the time of evaluation with a Líder brand scale, LD 1050, were used for calibration of the device.

The normality patterns considered were 57% to 60% of body weight for back foot, 40% to 43% for front foot, 50% to right lower limb and 50% for the left[13], characterizing antepulsion or retropulsion postures and right or left body laterality when the values exceeded these limits.

Chippaux-Smirak Index (CSI) was used to classify foot morphology. For the calculation, two straight lines were drawn in the right and left plantar prints: one tangent to the medial points in the first metatarsal head region and to the calcaneus, and another one tangent to the most lateral point of fifth metatarsal head to the calcaneus. In sequence, linking the most medial and the most lateral points in the metatarsal heads region, the greater width in the impression of the region was delimited (segment a). At the same time, the smallest foot width was marked in the longitudinal plantar arch or midfoot region (segment b). Both segments were measured (a and b), and we divided the latter by the former, obtaining a percentage. Five categories are described for medial longitudinal arch classification according to this index: 0% – high arch foot (cavus); 0.1%-29.9% – morphologically normal arch foot; 30%-39.9% – intermediate foot (flat degree I); 40%-44.9% – low arch foot (flat degree II); 45% or higher – flat foot (flat degree III)[14]. The morphology analysis of the 64 feet was held separately, the 32 SG feet and the 32 CG feet, since it can present itself bilaterally different, both in children with CP and with TD.

During the evaluation with the baropodometry system, the children were oriented to keep a standing position on the platform, adopting a spontaneous and comfortable posture, supported in both feet, barefoot, parallel feet, aligned heels, and loose arms along the body. Each child conducted the test three times, with eyes open and staring at a point marked one meter away, at the height of the children glabellar point, for 10 seconds. This time was established because children with CP have difficulties to remain in static posture for a long time[1]. The mean results were used for the analysis.

As a benefit, the children obtained relevant information about their plantar pressure distribution and foot type. During the assessments, if necessary, those responsible for the children were oriented to seek specialized treatment, being made available the images acquired through the equipment.

Data normality was verified using the Shapiro-Wilk test, and the comparison between groups was performed with the Mann-Whitney U test and the Fisher exact test. The analyses were conducted using the Windows Statistical Package for the Social Sciences, version 17.0.

The study was approved by the Research Ethics Committee of the Universidade Federal de Santa Maria under Protocol No. 1,218,985, respecting the ethical precepts contained in CNS Resolution No. 466/2012, with reading, analysis and signature of the informed consent form by the responsible, and Term of Consent by the participant.

RESULTS

The sample was composed of 32 children, paired by sex and age, and the characterization of study and control groups are described in Table 1.

Table 1. Groups characteristics

Characteristics	SG	CG
Age (mean±standard deviation)	8.68±1.77	8.68±1.77
Sex (male:female)	10:6	10:6
Body mass index (mean±standard deviation)	18.82±3.17	17.99±2.63
Shoe size (mean±standard deviation)	32.06±3.43	33.25±2.81
Topography (bilateral:unilateral)	9:7	NA
GMFCS I:II	10:6.	NA

GMFCS, Gross Motor Function Classification System; GE, Study Group; GC, control group; NA, non-applicable

The ages ranged from 6 to 11 years, no child used an insole or bracing, and all showed BMI within the normal range. Regarding the topography of children with CP, the bilateral (56.25%) predominated, and according to the GMFCS, there was a prevalence of children from level I (62.5%).

Table 2 presents the comparison of plantar pressure variables between the groups.

The groups showed significant statistical differences regarding weight-bearing in anterior and posterior direction, with SG in body antepulsion, and CG with values closer to normality, in mild body retropulsion. In addition, the values of feet average pressure also showed

a statistical difference, with SG presenting lower pressures when compared with CG.

The morphology comparison of the 32 feet in SG and the 32 in CG is presented in Table 3.

Table 2. Comparison of plantar pressure distribution variables between the groups

Variables	SG Mean±SD	CG Mean±SD	p-value *
DP_A	46.89±11.80	37.66±11.83	0.02*
DP_P	53.10±11.80	62.33±11.83	0.02*
DP_D	46.60±10.49	48.68±9.22	0.67
DP_E	53.39±10.49	51.31±9.22	0.67
AP_D	60.86±15.53	57.99±12.46	0.45
AP_E	58.04±14.05	57.14±12.55	0.86
PM_D	25.70±7.76	39.85±10.90	0.01*
PM_E	31.87±14.01	43.83±15.29	0.01*
PMa_D	110.7±45.86	149.96±62.14	0.08
PMa_E	110.70±45.86	149.96±62.14	0.08

*Mann-Whitney U Test; DP_A, anterior plantar distribution; DP_P, posterior plantar distribution; DP_D, right plantar distribution; DP_E, left plantar distribution; AP_D, area of the right foot; AP_E, area of the left foot; PM_D, average pressure of the right foot; PM_E, average pressure of the left foot; PMa_D, maximum pressure on the right foot; PMa_E, maximum pressure on the left foot; SG, study group; CG, control group

Table 3. Foot morphology

Variables		SG	CG	p-value *
R foot	Normal	2	6	0.12
	Not normal	14	10	
L foot	Normal	3	7	0.15
	Not normal	13	9	

*Fischer exact test, R foot – right foot, L foot – left foot; SG – study group; CG – control group

Of the 32 feet in SG, 5 were normal, as well as 13 of the 32 feet in CG. Besides, Table 4 presents the morphological changes of the 27 feet that were not considered normal in the SG and the 19 not-normal feet in CG.

Table 4. Foot morphological alterations

Variables		SG	CG	p-value *
R foot	Cavus	5	6	0.40
	Flat	9	4	
L foot	Cavus	5	6	0.23
	Flat	8	3	

*Fischer exact test, R foot – right foot, L foot – left foot; SG – study group; CG – control group

Regarding foot morphology, no statistically significant differences were found between the groups, the flat foot being prevalent in the SG and the cavus in the CG. In the SG, 12 children presented the same foot morphology bilaterally, 8 of which with flat feet, 3 with cavus feet, and 1 with normal feet. In the CG, the feet were symmetrical in 11 children, being 2 with flat feet, 5 with cavus feet, and 4 with normal feet.

DISCUSSION

When comparing the plantar pressure distribution and the foot morphology of children with Cerebral Palsy and typical development, our study identified that children with CP present antepulsion posture. This study is in concordance with Galli et al.[10], in which significantly increased plantar pressures were found on the front foot and midfoot in hemiplegic and diplegic children with CP, and decreased in the back foot.

Children with spastic CP present greater ankle joint stiffness compared with children TD, in addition to shortening of medial gastrocnemius, which reduces the movement response ability[15]. For this reason, the adoption of a different biomechanical alignment, such as the antepulsion posture, and the use of hip strategy, which needs less effort than the ankle strategy used by children with TD, compensate for the abnormal capacity of children with CP to stay in static position[16-19]. However, such adaptations demand a considerable effort of posterior antigravity muscles to avoid the fall[20], which can lead to an overload on the posterior muscular chain.

Besides these compensatory strategies, recent studies indicate that, although children with CP can produce anticipatory postural adjustment activities for movements, this activation is delayed, mainly in lower limb muscles, and their magnitude is smaller when compared with children with TD[21,22].

During the baropodometric evaluation, the pressures of right and left foot are registered, which allows the determination of weight percentage supported by each foot[8]. In both studied groups, the laterolateral weight distribution showed values close to normality, a fact that may be associated with the foot symmetry presented by most children.

There was a prevalence of the flat foot among children with CP, in concordance with the results by Galli et al.[10] and Costa et al.[1], in which all the studied CP topographies registered the predominance of flat

foot. Such a finding can be justified by the increase of anterior weight-bearing presented by the children evaluated in this study. By adopting antepulsion posture and using hip strategy, which leads to knee flexion, these children are predisposed to increased contact area in the medial foot region[10,23].

Changes in foot morphology are known to be associated with differences in the plantar pressure distribution[24]. In our study, children with CP presented smaller mean pressure in the foot, probably due to the flat foot, because the larger the contact area, the smaller the mean pressure on the foot, being better distributed in all foot areas[25]. In the CG, otherwise, most children presented cavus feet and, consequently, greater plantar pressure.

The formation of the longitudinal arch occurs around the first 6 years of life because growth influences ligament laxity, the musculature becomes more competent and the plantar face fat decreases[26]. Tong and Kong[27] observed, from a longitudinal study, that from 7 to 9 years, the longitudinal arch remains unchanged after formation. They concluded that in process of longitudinal arch formation, some factors, such as the type of footwear used, influence the children's foot type. These factors, not evaluated in our study, might justify the cavus foot predominance in the CG.

Studies[16,17,20] point out that hemiplegia, characterized by motor impairment and unilateral spasticity in the contralateral upper and lower limb to the affected brain hemisphere, leads the child to use the normal half-body, hindering the weight transfer on the side affected. Diplegic children, on the other hand, with bilateral spasticity, predominant in the lower limbs, present greater difficulties in posture control mechanisms.

As study limitation, we highlight the inclusion on the SG of children with unilateral and bilateral CP, considering that the plantar pressure distribution tends to appear differently in children with distinct CP topographies.

The results obtained in our study contribute to a better understanding of CP consequences and the adaptations these children need to perform to maintain the static position when compared with TD. From the clinical point of view, we point out the importance of foot type classification in CP, performed in this study through the CSI due to the frequent presence of deformities, which lead to an abnormal distribution of plantar pressures. The measurement of this variables enables the choice and modeling of corrective and protective devices for the prevention of postural disorders.

CONCLUSION

Children with CP, who feature preserved locomotor performance or with some dysfunction, revealed antepulsion posture, smaller mean plantar pressures, and flat foot prevalence when compared with children with TD.

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