ISSN 1413-3555
Rev. bras. fisioter., São Carlos, v. 11, n. 6, p. 495-501, nov./dec. 2007

EFFECTS OF OBESITY ON PLANTAR PRESSURE DISTRIBUTION IN CHILDREN

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Received: 04/04/2007 - Revised: 09/07/2007 - Accepted: 12/09/2007

ABSTRACT

Objective: The aim of this study was to determine whether there were differences in static and dynamic plantar pressure distribution between obese and non-obese children. Method: Twenty children aged from nine to eleven years were assessed and divided into two groups (obese and non-obese groups). The assessments included measurements of plantar pressure variables while standing and walking, by means of the Pedar System (Novel GMbH). Results: The obese children presented greater contact area, peak pressure, maximum mean pressure and pressure-time integral, in comparison with the non-obese children, with significant differences particularly in the midfoot and forefoot areas. Conclusion: The differences observed between the groups indicated that obese children may present significant modifications to their feet because of the excessive and repetitive loads that they are exposed to, which increases the risk of developing foot injuries and pathologies. It is suggested that there is a need to implement intervention programs with the aim of interfering with the progression of obesity-related problems from a structural and functional perspective.

Key words: plantar pressure; standing; walking; children; obesity.

RESUMO

Efeitos da obesidade na distribuição de pressão plantar em crianças

objetivo: O estudo teve como objetivo determinar se há diferenças na distribuição de pressão plantar estática e dinâmica entre crianças obesas e eutróficas. Método: Foram avaliadas vinte crianças, divididas em dois grupos (grupo de obesos e grupo de eutróficos), com idades entre nove e onze anos. As avaliações incluíram medidas das variáveis de pressão plantar na postura ereta e na marcha por meio do sistema Pedar (Novel GMbH). Resultados: Constatou-se que as crianças obesas apresentaram maiores áreas de contato, picos de pressão, pressões médias máximas e integrais pressão-tempo, quando comparadas às eutróficas, com diferenças significativas, principalmente nas regiões do médio-pé e antepé. Conclusões: As diferenças observadas entre os grupos indicam que crianças obesas podem apresentar modificações importantes nos pés em função da sobrecarga excessiva e repetitiva à qual estão expostas, aumentando o risco para o desenvolvimento de lesões e patologias nos pés. Portanto, é necessário que programas de intervenção sejam implantados a fim de interferir também na progressão de problemas de natureza estrutural e funcional relacionados à obesidade.

Palavras-chave: pressão plantar; postura ereta; marcha; crianças; obesidade.

INTRODUCTION

Knowledge concerning the stance and gait of obese individuals generally begins with subjective clinical assessments, based on the detection of their serious difficulty in performing activities of daily life, especially locomotion. Therefore, urgent attention must be given to the physical consequences of repetitive overload, mainly in the lower limbs, in order to provide support in the areas of prevention, treatment, and obesity control[1]. The assessment of plantar pressure distribution represents an important clinical tool for understanding the structural and functional implications of obesity.

Important studies on plantar pressure distribution have been conducted with children, focusing mainly on eutrophic children of different age groups[2-4]. Studies with obese children have also been conducted, showing time-space parameters, as well as kinematic, electromyographic[5,6], and plantar pressure distribution parameters[7-10]. The plantar pressure distribution studies assessed plantar pressure peaks during stance and gait and found higher values in the entire plantar area for obese children when compared to eutrophic ones; however, the most significant differences are in the midfoot and forefoot areas, probably due to the structural and functional modifications of obese children's feet. This behavior also occurs in obese adults when compared to eutrophic adults, both in static and in dynamic conditions[11-13].

Although the abovementioned studies have already assessed obese children in regard to plantar pressure distribution, the pressure data show great variability and, when collected with different equipment, hinder the comparison and standardization of values. In addition to that, the influence of body mass on the plantar pressure variables is not yet clear. Therefore, it becomes necessary to comprehend the main effects of obesity on the biomechanical characteristics of stance and gait, as well as on the movement of the feet, which can contribute to understanding how obesity influences weight-support activities. Hence, the objective of this study was to determine if there are differences in static and dynamic plantar pressure distribution between obese and eutrophic children and, specifically, where the pressure is located on the foot and in what proportion it correlates to body mass.

MATERIAL AND METHODS

Subjects

Twenty children of both genders participated in the study and were divided into two groups. The obese group (OG) consisted of 10 children with a mean age of 10.1 (± 1.0) years, body mass of 59.0 (±10.9) kg and height of 1.48 (± 0.82) m. The non-obese group (NOG) consisted of 10 children with a mean age of 9.6 (± 0.7) years, body mass of 32.1 (± 6.6) kg, and height of 1.42 (± 0.78) m. None of the children displayed any apparent musculoskeletal or neurological alteration in the lower limbs. Obesity was defined as ≥ 95th percentile of body mass index (BMI), according to international standardization proposed by the National Center for Health Statistics (NCHS)[14]. The project was approved by the Committee for Ethics in Research on Human Beings of Universidade Federal de São Carlos (Approval no. 259/2005). The parents or guardians signed a written informed consent, agreeing with their children's participation in the study.

Instruments and procedures

Body mass and height were initially measured in order to calculate the BMI using a digital scale (Filizola *Personal*) with 0.1 kg precision, and a wall stadiometer (Tonelli e Gomes) with precision in millimeters. Next, the children were submitted to the plantar pressure assessments during stance and gait through the Pedar system (Novel GMbH) that measures plantar pressure distribution in specific areas of the feet. This equipment consists of insoles with 99 capacitive sensors and its spatial resolution depends on the size of the insole (approximately 1 sensor/cm^2). The children performed the test on bare feet, having the insoles attached to each foot with tape and non-slip socks[15]. The sampling frequency was 50 Hz.

To record pressures during stance, the children were instructed to stand still for 10 seconds, keeping their feet slightly apart, with the weight evenly distributed between the feet, with arms to the side and their gaze fixed at eye level. For the dynamic measurement, the children were instructed to maintain gait speed, look ahead, and not pay attention to the feet while walking along a 10m catwalk. Because it interferes with pressure standards, speed was controlled, varying from 1.08 to 1.28 m/s (10% variation), according to the pilot study. Before the start of collection, children were instructed to practice a few times because only the attempts in which speed was within the established limit would be recorded. In each condition, three valid attempts were collected for each foot.

In order to analyze the data, the foot was divided into six anatomical areas as shown in Figure 1. The analyzed variables in each selected area during stance were contact area (CA), peak pressure (PP), and maximum mean pressure (MMP). For gait, in addition to these variables, the pressure-time integral (PTI) was also analyzed. The contact area is determined by the sum of the area of all overloaded sensors within an area; peak pressure describes the highest pressure registered within each area of the foot; maximum mean pressure indicates the maximum value among the mean pressure behaviors recorded in all sensors during the entire support phase; the pressure-time integral is the product of mean pressure and time during which pressure was applied, and it also provides an indicator of the duration of load application over a specific area. The pressure variables and their derivates are given in kPa units (100 kPa = 10N/cm^2).

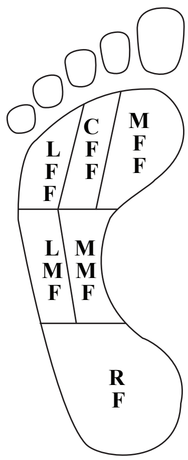

Figure 1. Representation of foot division into six anatomical areas. RF – rearfoot, MMF – medial midfoot, LMF – lateral midfoot, MFF – medial forefoot, CFF – central forefoot, LFF – lateral forefoot.

Data analysis

For statistical data analysis, we calculated the mean of all attempts, considering both the right and the left foot, i.e. twenty feet from each group. After calculating descriptive statistics (mean [$\bar{x}$], standard deviation [sd], and variation coefficient [VC]), the data were analyzed using Statistica software version 7.0. VC is defined as the standard deviation-mean ratio (VC = sd/$\bar{x}$). The Kolmogorov-Smirnov test was used to test the normality of the data. The independent t-test was applied to confirm the significant difference in BMI values between the groups and to compare the variables of pressure distribution between the groups in each anatomical area of the foot. The Mann-Whitney test was applied when necessary. Finally, Pearson's correlation coefficient was used to relate plantar pressure to body mass. For all tests, a 5% level of significance ($p \leq 0.05$) was considered.

RESULTS

The BMI value obtained for obese children (26.6 ± 2.7 kg/m^2) was significantly higher ($p \leq 0.01$) than that of eutrophic children (15.8 ± 1.9 kg/m^2). Therefore, these groups truly represented the selected population.

During stance, the OG showed greater contact areas in all areas of the foot and total contact area ($p \leq 0.01$), when compared to the NOG. Peak pressure was also greater for the OG; however, there were only significant differences between the groups in the medial and lateral midfoot and in the lateral forefoot ($p \leq 0.01$). Maximum mean pressure was also greater for obese children, with significant differences in the medial and lateral midfoot and in the central forefoot ($p \leq 0.05$). Figure 2 illustrates the behavior of pressure variables during stance for both groups.

During gait, the OG showed greater contact areas than the NOG with significant differences in all

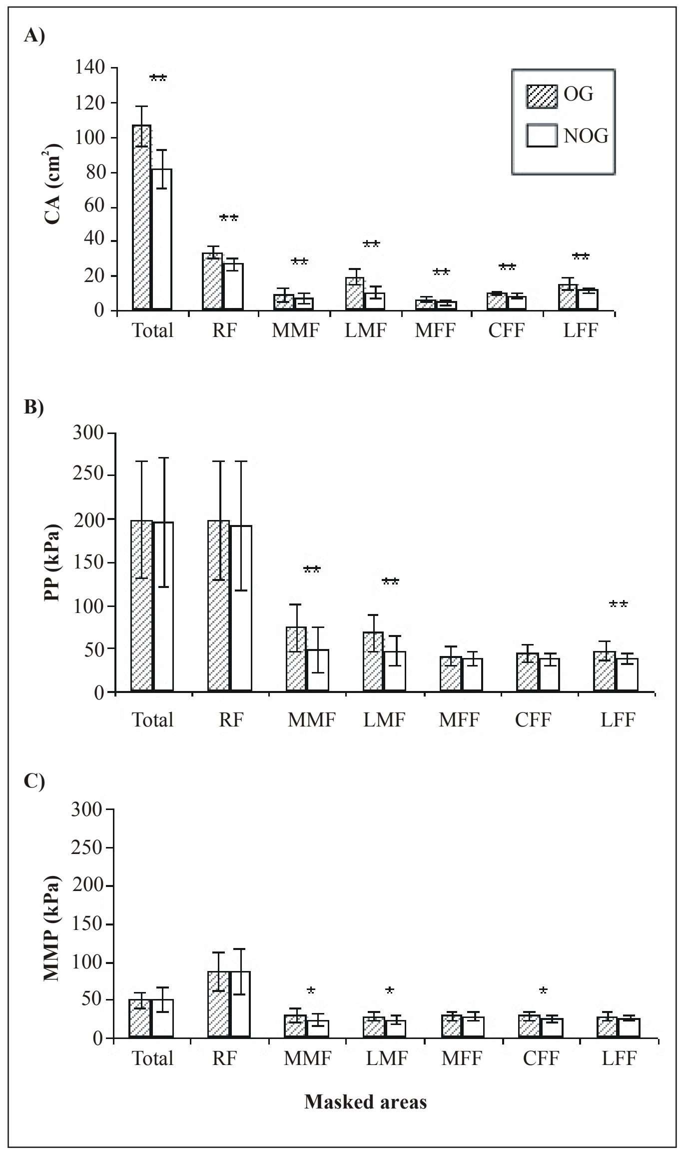

Figure 2. Mean (±s.d.) of the A) contact area (CA), B) peak pressure (PP) and C) maximum mean pressure (MMP) during stance for OG – obese group (n=20) and NOG – non obese group (n=20). The foot areas are defined in Figure 1 (*$p \leq 0.05$; ** $p \leq 0.01$).

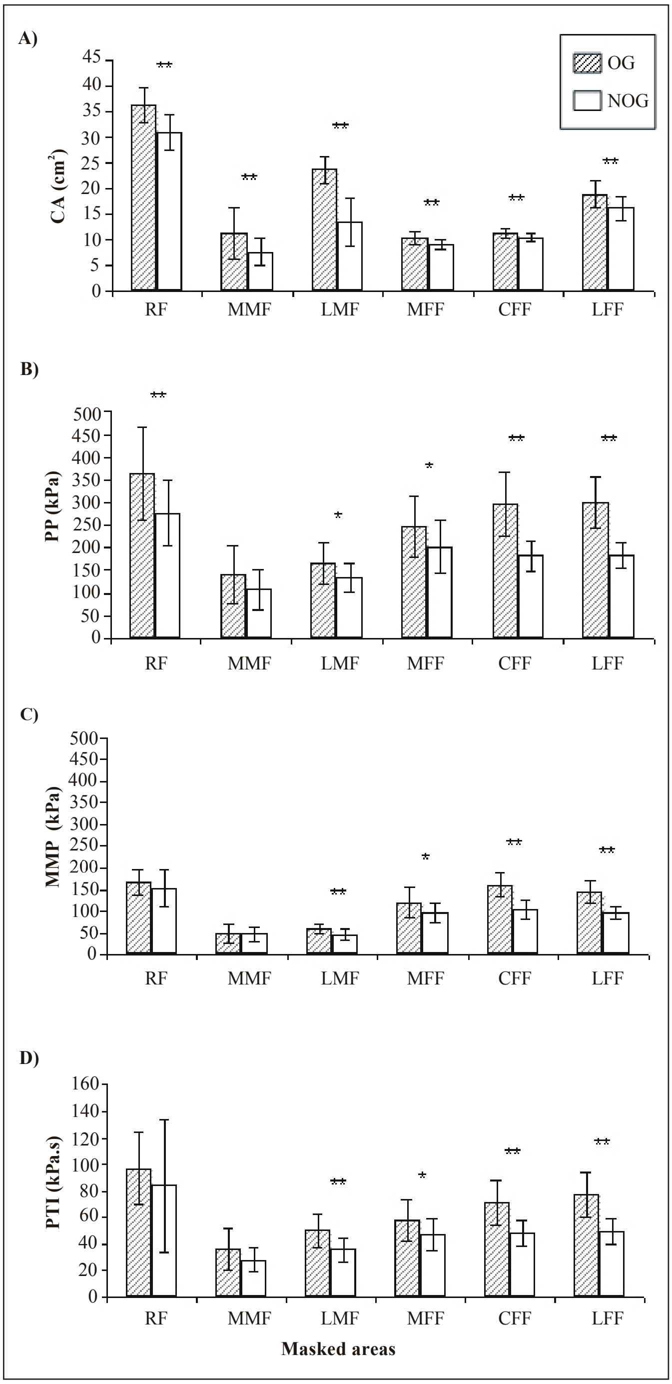

Figure 3. Mean (±standard deviation) of contact area (CA), peak pressure (PP), maximum mean pressure (MMP) and pressure-time integral (PTI) during gait for both groups.

areas of the foot ($p \leq 0.01$), as it did during stance. As for peak pressure, the OG showed greater values, being statistically different from the NOG in all areas of the foot ($p \leq 0.01$ and $p \leq 0.05$), except for the medial midfoot ($p \geq 0.05$). For maximum mean pressure, there were differences in the lateral midfoot ($p \leq 0.01$) and medial ($p \leq 0.05$), central, and lateral ($p \leq 0.01$) forefoot areas, also with greater values for the OG. The pressure-time integral followed the pattern of the previous variable, displaying statistically significant differences between the groups in the same areas of the foot. Figure 3 represents the comparison between the two groups during gait.

Variation coefficients were calculated for peak pressure and maximum mean pressure during gait because there is great concern for the variability of these measures. The values varied from 17 to 45% for the OG and from 16 to 41% for the NOG, considering the two variables.

The maximum mean pressures during stance and gait were correlated to body mass (Table 1).

Table 1. Correlation coefficients (r) between body mass (BM) and maximum mean pressure (MMP) during stance and gait

Masked areas	Stance		Gait	
	OG (n=20)	NOG (n=20)	OG (n=20)	NOG (n=20)
RF	-0.2	-0.2	0.0	0.2
MMF	0.4	0.7 *	0.0	-0.1
LMF	0.1	0.6 *	-0.2	-0.4
MFF	0.7 *	0.0	0.3	-0.2
CFF	0.5 *	-0.3	0.3	0.7 *
LFF	0.2	-0.3	0.2	0.6 *

BM (kg), MMP (kPa). OG – obese group, NOG – non obese group. The foot areas are defined in Figure 1. * $p \leq 0.05$

During stance, both groups displayed positive correlations between variables. For the OG, these correlations occurred in the medial and central forefoot areas, and for the NOG, in the lateral and medial midfoot areas. During gait, the OG did not show correlation between the variables, whereas the NOG showed positive correlations in the lateral and central forefoot areas.

DISCUSSION

In all areas of the foot, the OG had greater contact areas than the NOG, both during stance and during gait, the biggest differences being in the midfoot area. However, the manner of contact of the foot was similar in both groups during stance and gait, with greater support on the posterior (hindfoot) and lateral (lateral midfoot and forefoot) areas. These results are supported by studies that compared obese children[7,8,10] and adults to eutrophic[11-13] ones.

Considering that the OG had the greatest contact areas and that the greatest difference between the groups occurred in the midfoot area during both stance and gait, it is acceptable to assume that the obese children displayed flattening of the medial longitudinal arch. However, it is not yet clear why this flattening and, consequently, the rise in contact area in the midfoot area occur. It is known that obesity modifies the plantar surfaces of both sexes[13] and that the medial longitudinal arch seems to be affected by adaptation mechanisms to long term overload[11], unlike temporary load conditions in which the foot seems to maintain the arch structure by means of compensatory mechanisms both in obese and eutrophic[7] individuals.

As for peak pressure, the obese children generally displayed greater values than the eutrophic ones, with the greatest differences between the groups found in the midfoot area during stance, and in the forefoot, followed by the midfoot during gait. During stance, overload was greater in the hindfoot and midfoot areas. During gait, however, the hindfoot and forefoot areas suffered greater pressure, and the midfoot area had the lowest peak pressure. This distribution of peak pressure throughout the foot during stance and gait, both in obese and eutrophic children, is supported by literature[2,3,8,12,16].

The fact that the obese children present greater peak pressure in all areas of the foot when compared to the eutrophic ones is in line with studies conducted with both obese children[8,9] and adults[12,13] during stance and gait. This means that the excess fat tissue that obese children have to carry makes their lower limbs and especially their feet suffer greater overload, increasing the risk of injury.

The greatest differences between the groups were found mostly in the midfoot area, as well as the forefoot area during gait. These results are in accordance with literature[8,9,11,17], and this pattern is similar to that of the contact area, probably due to the well-known changes in the feet of obese children, mainly in the midfoot area, such as flattening of the plantar arch and wide contact area, as seen in a previous study[18].

For maximum mean pressure, there is a lack of references in literature because this variable has only recently been included in studies on plantar pressure distribution. Maximum mean pressure magnitude is smaller when compared to pressure peaks because it better represents the pressure distribution within a specific area of the foot. The OG generally showed greater values for this variable when compared to the NOG. The greatest differences between the obese and the eutrophic children occurred in the midfoot area during stance, and in the forefoot area during gait. Both groups showed greater overload in the hindfoot area during stance, and in the hindfoot and forefoot during gait. Therefore, the maximum mean pressure variable showed a similar pattern to that of peak pressure in the comparison between obese and eutrophic children, reflecting the same problems linked to obesity.

The high foot pressure values for obese children are a cause for concern because they can increase the risk of developing pain, discomfort, and foot pathologies, especially considering children's developing feet[8,13]. Dowling et al.[7] point out that, in the forefoot, the risks are greater given that this is an area of small bones and reduced ability to dissipate forces associated with dynamic weight support tasks; in this case excessive overload may cause stress fractures, ulcerations, and other pathologies. The structural and functional changes associated with the symptomatology may discourage children from participating in physical activities, which in turn can perpetuate the obesity cycle.

The variation coefficient values for peak pressure and maximum mean pressure for both groups showed smaller amplitudes when compared to those of Cavanagh et al.[16], who found variations of up to 100% in eutrophic individuals. Mean values for the plantar pressure variables indicate general behavior patterns; however, the variability obtained makes it difficult to establish the overload limits in the plantar tissues in normal and pathological conditions.

With regard to the pressure-time integral variable, the most overloaded areas over time were the hindfoot, followed by the forefoot, regardless of the group, confirming once more the posterior overload on the foot during gait. Higher values were found for the obese groups, in accordance with other studies that assessed this variable[8,9]. This increase in the pressure-time integral of obese children may indicate damage to the soft tissue of the foot, especially in the forefoot area which, as previously mentioned, has the smallest bone structures and is therefore the most vulnerable to injury. It is important to remember that both the pressure magnitude and the duration of its application affect the foot's movement. Low pressure over a long period of time or high pressure in a very short period of time can damage the structure and activity of the foot[19], increasing the risk of injury, especially in obese children.

Body mass generally displayed a low correlation to maximum mean pressure. That is to say that this measure does not shed much light on the variations in plantar pressure for obese and eutrophic children. Literature is inconsistent when it comes to the influence of factors like body mass (BM) on plantar pressure data. Some studies point out that there is little or no correlation between BM and peak pressure during both stance and gait[2,16]. These authors attribute the lack of correlation between these variables to the increase in the contact area of the foot, which would cause a redistribution of plantar overload. On the other hand, some authors state that there is a direct correlation between these factors[12,13] with regard to obese individuals, and the influence of BM on plantar pressures can bring structural consequences to feet and lower limbs as a whole[13].

In the present study, BM showed low correlation to maximum mean pressure in most of the anatomical areas of the feet of obese children, especially in the midfoot, which is the area that differs most from that of eutrophic children. However, it is widely known that obesity is associated with increase in plantar pressure. Thus, it may be that other factors are influencing the behavior of this variable. Cavanagh et al.[16] point out that what influences the magnitude of the pressure may not be BM per se, but skeletal structure, variation in bone anatomy, support movement patterns, and the composition and location of plantar soft tissue, which tends to distribute the pressure. In addition to that, other components of body composition, such as fat mass, can contribute to this pattern[20].

In short, obese children have a greater risk of foot injury and pathologies due to the excessive and repetitive overload caused by BM increase. However, BM is not the only contributor to the rise of the pressure variables, since it has proved to be poorly related to maximum mean pressure. The changes seen especially in the midfoot area of obese children indicate that this excessive overload can cause serious alterations in the foot and, thus, damage its functions.

FINAL CONSIDERATIONS

The differences in plantar pressure patterns between obese and eutrophic children are a cause for concern. Therefore, intervention programs should also include specific work for the feet during the activities, focusing on structure and function, so as to redistribute the forces and pressures on them. This is necessary because it can be an intervention in the appearance and evolution of obesity-related issues, preventing obese children from becoming obese adults at risk of developing greater complications, and improving their self-esteem and quality of life. The implementation of lower body strengthening and stretching exercises, posture correction, maintenance of skin integrity, as well as physical therapy treatment for pain can reduce the implications of obesity on activities of daily life. Furthermore, the intervention of a multidisciplinary team may help with cardiovascular and respiratory issues that are common in this population. The peculiar characteristics observed in the feet of obese individuals must be taken into account in their choice of footwear in order to minimize pain and discomfort. The use of insoles is also recommended for that purpose.

Acknowledgements

To the parents and the children who participated in this study, to CAPES for the financial support, and to the Movement and Posture Biomechanics Laboratory of Universidade de São Paulo (USP).

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