Can Static Plantar Pressures of Prepubertal Children Be Predicted by Inked Footprints?

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A study was conducted to determine whether a pedograph could be used as a field-based screening tool to predict pressures generated on the plantar surfaces of the feet of prepubertal children during single-limb weightbearing stance. Plantar pressures were collected in 51 primary school–aged children using a pressure distribution measurement system. Statistically significant negative correlations were found between footprint angle and both peak force ($r = -0.453$) and peak area ($r = -0.539$), and statistically significant positive correlations were found between the Chippaux-Smirak Index and both peak force ($\rho = 0.285$) and peak area ($\rho = 0.559$). Although statistically significant, the weak relationships precluded foot structure variables from being used to predict the plantar pressures of children during static weightbearing. It is therefore recommended that an alternative field-based tool that directly measures plantar pressures be used to screen children in the public school system to identify those at risk of excessive plantar pressures. (J Am Podiatr Med Assoc 94(5): 429-433, 2004)

Childhood obesity is increasingly prevalent in industrialized societies and is associated with substantial health concerns. It was recently documented that obese children as young as 8 years old display foot structures, such as lowered arches, that may cause problematic symptoms in later life.[1] It has been shown that obese prepubertal children experience excessive pressures on the plantar surfaces of their forefeet during gait.[2, 3] It has been postulated that high plantar pressures may cause these children to experience foot discomfort during weightbearing activity and thus may deter them from participating in physical activity.[3]

As high plantar pressures during gait may be a deterrent to physical activity in obese children, a method for screening schoolchildren to predict pressures on the plantar surfaces of their feet is urgently required. If such at-risk children could be identified, appropriate intervention strategies could be implemented before the development of adverse effects.

Several tools are commercially available to assess the plantar surface of the foot, including pressure-sensitive mats or films,[4-6] pedobarography,[7] Musgrave Footprint mats (Musgrave Systems, Ltd, Llangollen, North Wales),[8] Harris and Beath mats,[6, 9, 10] and pedographs.[11-14] These systems require varying levels of expertise in terms of data collection and subsequent data analysis. Many of these systems are unsuitable as screening tools in the school system because they are too expensive, they require specialized expertise

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to use, or they are not appropriate for assessing large populations in a field-based situation.

One system, the pedograph, is recognized as a reliable and inexpensive tool that provides a noninvasive method to determine the external characteristics of the foot. It is also appropriate for screening large numbers of individuals in the field.[11] Whether such a system, which merely characterizes external footprint shape, can be used to predict the pressures exerted by children on the plantar surfaces of their feet during standing is unknown. For example, is there a relationship between the external structural characteristics of a child's footprint and the pressures generated during standing? The purpose of this study was to determine whether a pedograph can be used as a field-based tool to predict pressures generated on the plantar surfaces of the feet of primary school–aged children.

Methods

Participants

Fifty-one prepubertal children (29 girls and 22 boys; mean ± SD age, 8.4 ± 1.0 years; height, 1.32 ± 0.07 m; mass, 33.7 ± 9.9 kg) without musculoskeletal pathologies were recruited from local schools to participate in this study. The children represented a diverse range of body types (body mass index [the weight in kilograms divided by the square of the height in meters], 13.6 to 28.6; mean, 19.2 ± 4.6). Thirteen children (25%) were classified as overweight or obese according to the internationally accepted definition established by Cole et al[15] in 2000. Before commencement of the study, all procedures and methods were approved by the University of Wollongong Human Research Ethics Committee and the Ethics Committee of The Children's Hospital at Westmead.

Data-Collection Procedures

Foot Structure Assessment. Each child's feet were initially assessed by an experienced podiatric physician to identify and exclude any external factors that may have contributed to variations in plantar pressure distribution. A pedograph (Suavepie, SA, Capital Federal, Argentina), positioned on a level floor,[1] was then used to record each footprint. The undersurface of the membrane was inked before each testing session and subsequently after every five children or when deemed necessary. The pedograph paper, clearly identified with the participant code, was placed beneath the inked membrane, and the membrane was then lowered into place. Footprints were taken for 2 sec with the child supporting most of his or her mass on the test foot, resting only the hallux of the nontest foot on the ground if needed, and looking forward at a picture of a smiling face on the wall (Fig. 1). The child was assisted in lowering the test foot onto and lifting it off of the membrane. One clear footprint was recorded for the left and right feet of each participant.

From the footprints obtained using the pedograph, the footprint angle and the Chippaux-Smirak Index were calculated and classified following the protocol described by Forriol and Pascual (Fig. 2).[13] The reliability of these methods, as assessed in the present study, was confirmed before data collection by the chief investigator (A.M.D.) evaluating these variables for six participants on three separate occasions and calculating intraclass correlation coefficients using the method described by Vincent.[16] Intraclass correlation coefficients of $R_1 = 0.999$ for footprint angle and $R_1 = 0.999$ for Chippaux-Smirak Index confirmed that the data were highly reproducible. The purpose of the footprint analysis was to quantify the surface area of each child's foot that was in contact with the ground during static weightbearing.

Static Plantar Pressure Distribution Assessment. A pressure distribution measurement system (mini-EMED; Novel GmbH, Munich, Germany) was used to quantify the static pressures exerted on the plantar surfaces of each child's feet during standing. The mini-EMED platform was placed on a firm and level surface and then was surrounded by a custom-designed walkway of dense foam, which was flush with the pressure platform.

To assess static plantar pressure distribution, each child stood relaxed in the anatomical position in single-limb weightbearing stance on the mini-



Figure 1. Method used for footprint collection.

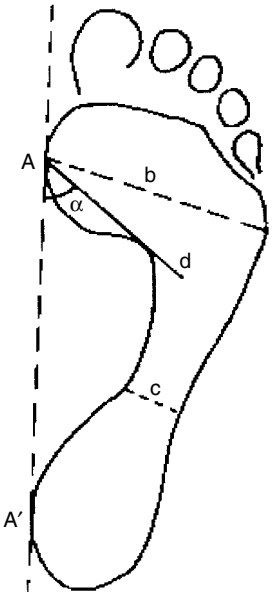

Figure 2. The footprint angle (α) and the Chippaux-Smirak Index (c/b) are calculated to represent the surface area of the foot in contact with the ground. To obtain the footprint angle, draw a straight line (A-A′) to connect the most medial points at the forefoot and heel. Then draw a line (A-d) from point A to the apex of the concavity of the medial longitudinal arch (d), whereby α represents the footprint angle. For the Chippaux-Smirak Index, draw a line from point A across the widest section of the forefoot (b). Then draw a second line (c) parallel to line b to identify the narrowest section of the medial longitudinal arch. Calculate the Chippaux-Smirak Index as c/b. (Adapted from Forriol and Pascual[13] and reprinted with permission from Dowling et al.[2])

EMED platform for 5 sec. Their attention was directed forward to the same picture of the smiling face on the wall. This was the same posture that was adopted when collecting the footprint data using the pedograph. Static footprints and plantar pressures are usually assessed with the individuals standing with their weight distributed evenly across their left and right feet. However, the threshold at which the mini-EMED plate was triggered to collect data (1 $N \cdot cm^{-2}$) was high relative to the mass of some of the smaller children. Therefore, single-limb weightbearing was adopted in the present study when using the pedograph and the pressure platform. Two static plantar pressure trials were recorded ($N \cdot cm^{-2}$) for each child's left and right feet at 16 Hz with three sensors per square centimeter. The pressure data were collected using the mini-33 program (Novel GmbH) and were transferred to a laptop computer (Armada 1530D; Compaq, New York, New York) and saved for later analysis.

From the footprints generated for each child by the mini-EMED system, the variables of peak force, peak area, and peak pressure for the whole foot were determined using plantar pressure analysis software (Novel-Win EMED-SF, Novel GmbH). Peak pressures were selected for analysis because they reveal information about the high pressures imposed on the foot at any stage during contact with the plate.[17] Peak area, peak force, and peak pressure values were averaged across the two trials recorded for each foot before further statistical analysis.

Statistical Analysis

Means and SDs were calculated for the total sample for footprint angle and Chippaux-Smirak Index derived from the pedograph and for the peak force, peak area, and peak pressure values obtained from the pressure platform. These data were then tested for normality using a Kolmogorov-Smirnov test and for equal variance using a Levene median test. If they were deemed normally distributed, Pearson product moment correlations were then calculated between the foot structure variable (footprint angle) and the static plantar pressure variables (peak force, peak area, and peak pressure) to determine the strength of the relationship between the two parameters. If the data were deemed not normally distributed, Spearman rank correlations were calculated between the foot structure variable (Chippaux-Smirak Index) and the static plantar pressure variables (peak force, peak area, and peak pressure) to determine the relationship between the two parameters.

Results

The footprint angle data (Table 1) were found to be significantly and negatively correlated with peak force ($r = –0.453$) (Fig. 3A) and peak area ($r = –0.539$) (Fig. 3B) ($P < .05$ for both). That is, decreases in footprint angle were associated with increases in peak force and peak area. Conversely, the Chippaux-Smirak Index data (Table 1) were significantly and positively correlated with peak force ($\rho = 0.285$) (Fig. 4A) and peak area ($\rho = 0.559$) (Fig. 4B) ($P < .05$ for both). However, there was no significant relationship between the foot structure variables of footprint angle ($r = –0.0420$; $P = .675$) and Chippaux-Smirak Index ($\rho = –0.0754$; $P = .450$) and peak pressure.

Discussion

The significant negative correlations between footprint angle and peak force and between footprint

Table 1. Descriptive Statistics for the Foot Structure Variables and the Static Plantar Pressure Variables

Variable	Mean	SD	SEM	Kurtosis	Skewness
Foot structure					
Footprint angle (°)	39.9	9.2	0.910	0.488	–0.794
Chippaux-Smirak Index (%)	23.0	22.4	2.222	–1.488	0.194
Static plantar pressure					
Peak force (N)	257.5	87.5	8.663	1.852	1.340
Peak area (cm^2)	55.7	15.0	1.489	0.910	0.983
Peak pressure (N/cm^2)	15.3	4.9	0.486	0.675	0.780

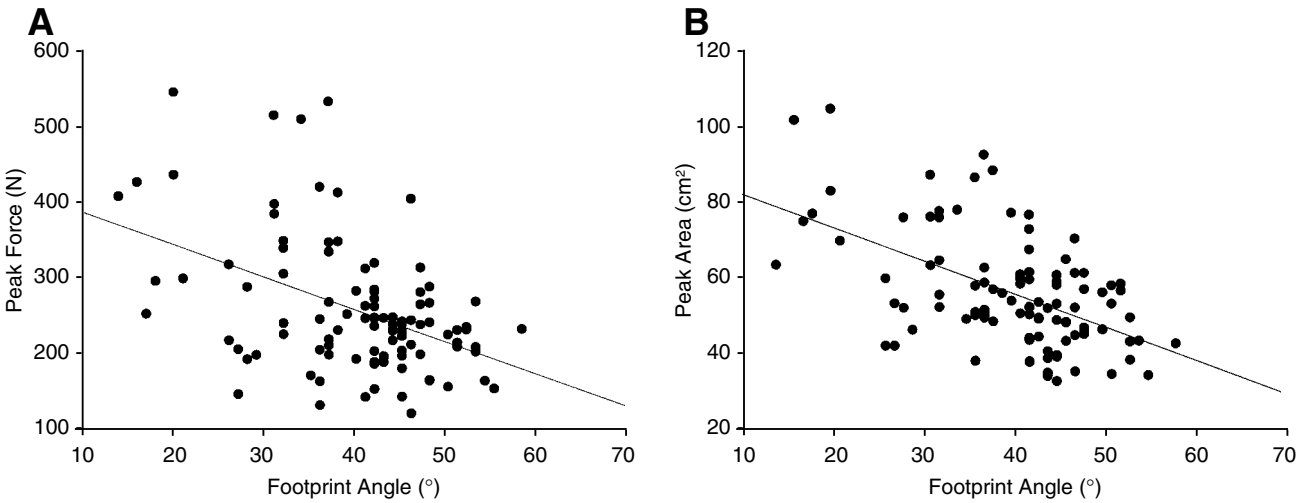

Figure 3. The relationship between footprint angle and peak force ($r = –0.453$; $P < .001$) (A) and between footprint angle and peak area ($r = –0.539$; $P < .001$) (B).

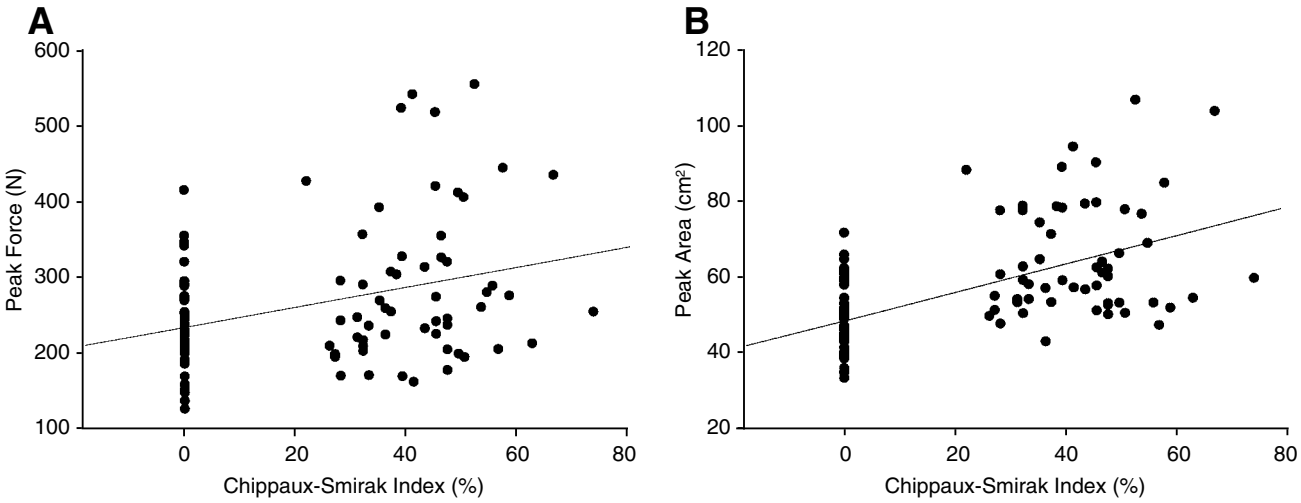

Figure 4. The relationship between the Chippaux-Smirak Index and peak force ($\rho = 0.285$; $P = .004$) (A) and between the Chippaux-Smirak Index and peak area ($\rho = 0.559$; $P < .001$) (B).

angle and peak area indicate that as more force was exerted on the foot and as a greater surface area of the foot was in contact with the mini-EMED system, there was an associated decrease in footprint angle (ie, an increased contact area of the plantar surface of the foot). Although significant, the correlations were low, so that only 20.5% and 29.1% of the variance in footprint angle could be explained by its relationship to static peak force and static peak area, respectively. The low correlation values precluded the footprint angle values obtained from the footprints from being used to predict either peak force or peak area for the children's feet derived from the pressure platform. Furthermore, as no significant relationship was found between footprint angle and peak pressure, this confirmed that the footprint angle obtained from footprints cannot be used to predict peak pressures generated by children during standing.

Unlike the footprint angle data, increases in the Chippaux-Smirak Index (indicative of an increased contact area of the plantar surface of the foot) were associated with increases in peak force and peak area. Furthermore, despite being significant, the low correlation values again precluded the Chippaux-Smirak Index values derived from the pedograph footprints from being used to predict the static plantar pressure variables. That is, only 8.1% and 31.3% of the variance in the Chippaux-Smirak Index data could be explained by its relationship to static peak force and static peak area, respectively. As no statistically significant relationship was found between the Chippaux-Smirak Index and peak pressure, the Chippaux-Smirak Index, like the footprint angle, cannot be used to predict peak pressures generated by children during standing. This result is not unexpected, as footprint angle and Chippaux-Smirak Index were developed specifically to characterize one aspect of foot structure. In contrast, plantar pressure measurement techniques were developed to characterize the effect of weightbearing on the pressures exerted on the anatomical structures of the foot.

Conclusion

On the basis of the low correlation values derived between the variables characterizing foot structure (footprint angle and Chippaux-Smirak Index) and static plantar pressure (peak force, peak area, and peak pressure), it was concluded that foot structure variables could not be used to predict the pressures exerted on the plantar surfaces of the feet by children during static weightbearing. It is therefore recommended that an alternative field-based tool that directly measures, rather than attempts to predict, plantar pressures be used to screen children in the public school system to identify those at risk of excessive plantar pressures.

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