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Does obesity influence foot structure in prepubescent children?

DL Riddiford-Harland*[1], JR Steele[1] and LH Storlien[1]

[1]*Department of Biomedical Science, University of Wollongong, NSW 2522, Australia*

OBJECTIVE: This study examines the relationship between obesity and foot structure in prepubescent children.
DESIGN: Field-based, experimental data on BMI (body mass index) and foot structure were collected for 431 consenting children from 18 randomly selected primary schools.
SUBJECTS: Of the 431 participants, 62 obese (BMI > 95th percentile) and 62 non-obese (10th percentile < BMI > 90th percentile) children (age = 8.5 ± 0.5 y) were selected.
MEASUREMENTS: Height and weight were measured to calculate BMI. Static weight-bearing footprints for the right and left foot of each subject were then taken using a pedograph to calculate the Footprint Angle and the Chippaux-Smirak Index as representative measures of the surface area of the foot in contact with the ground.
RESULTS: A significant difference was found between the Footprint Angle of the obese and non-obese subjects for both the left ($t = 3.663$; $P < 0.001$) and right ($t = 3.742$; $P < 0.001$) feet whereby obese subjects displayed a reduced angle. Chippaux–Smirak Index scores were also significantly different for both the left ($t = -6.362$; $P < 0.001$) and right ($t = -5.675$; $P < 0.001$) feet between the two subject groups where a greater score for the obese subjects was evident. A decreased footprint angle and an increased Chippaux–Smirak Index are characteristic of structural foot changes that have been associated with compromised foot function.
CONCLUSIONS: Excess body mass appears to have a significant effect on the foot structure of prepubescent children whereby young obese children display structural foot characteristics which may develop into problematic symptoms if excessive weight gain continues. Further investigation into possible consequences, particularly any effects on foot function, is warranted.
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Keywords: body mass index; foot structure; prepubescent children; obesity

Introduction

The proportion of overweight and obese children in the industrialised world has increased during the past two decades. For example, a study conducted by the National Health Statistics (Maryland, USA) indicated that from 1976–80 to 1988–94 the percentage of obese children (body mass index, BMI > 95th percentile) aged between 6 and 11 y had almost doubled from 7.6% to 13.7%.[1] These changes have been paralleled among Australian children (aged 5–11.9 y), where 13% of children have a BMI greater than the 95th percentile.[2] There are many long-term debilitating effects of obesity that may impair quality of life, including cardiovascular disease, diabetes mellitus and various musculoskeletal disorders. Of these musculoskeletal disorders, foot problems in obese adults are salient. This may be due to the increased stress placed on the feet by the need to bear excessive mass. However, there is relatively little research literature available examining the possible nexus between altered foot mechanics and obesity in a developmental context.

A common foot pathology is the flatfoot, medically termed pes planus. Flatfeet can cause varying degrees of discomfort and pain. Children, in the first few years of life, appear to walk with flatfeet. However, this is due to the development of a fat pad in the midfoot area, immature structures in the feet, and their gait pattern. As weight is gained with age, the tensile strength of the ligamentous and muscular structures of the child's foot increases. By about 5–6 y of age the child's foot has developed an adult type of longitudinal arch[3] and should therefore no longer display evidence of flatfeet. However, if laxity continues with weight gain, a lowered longitudinal arch or flatfoot may be maintained and lead to problematic adolescent or adult feet.[4–6] Whilst shape, structure and function of both the normal and pathological foot have been widely researched[4,7,8] there is a paucity of studies which have investigated the effect of excessive loading on the foot, especially structural aspects of the prepubescent foot. Therefore, the purpose of the present study was to investigate the relationship between obesity and foot structure in prepubescent children. As obesity in childhood is thought to lead to adult obesity and its associated health implications,[9–11] factors affecting the obese child warrant this investigation.

*Correspondence: DL Riddiford-Harland, Department of Biomedical Science, University of Wollongong, Northfields Ave, Wollongong NSW 2522, Australia.
E-mail: dianer@uow.edu.au
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Methods

Subjects
Four hundred and thirty two Grade 3 students who returned written parent/guardian consent forms participated in this study. The subjects were from 18 randomly selected consenting public primary schools from the 52 primary schools in the Wollongong Education District, New South Wales, Australia. From the 432 subjects, all children with a BMI greater than the 95th percentile ($n=62$) and an equal number of children (matched to the obese children for age and gender) from between the 10th and 90th percentile were selected to form the experimental and control sample (mean age $= 8.5 \pm 0.5$ y).[12] Ethical approval was obtained from both the University of Wollongong Human Research Ethics Committee and the NSW Department of School Education before commencing the study. All testing was conducted at school venues and according to the Statement of Human Experimentation.[13]

Body mass index
The height of each subject was measured to the nearest millimetre using a calibrated portable Hadlands Photonics stadiometer with a spirit level attached to the arm for greater accuracy. Body mass was measured to the nearest 0.05 kg using calibrated UC-300 Precision Medical Scales with subjects wearing minimal clothing (a T-shirt and shorts or skirt). One experienced researcher performed all measurements. Each subject's body mass index (BMI) was then calculated using the standard Quetelet Index protocol: body mass divided by height squared (kg/m^2). While the most precise measurement of obesity remains to be formulated, BMI is currently an internationally agreed measure for defining childhood obesity, particularly in field testing of large samples.[10,11,14] The subjects were then classified by their BMI score according to percentile range cut-off points. For children, special BMI-for-age-and-gender percentile charts were considered more appropriate than comparing child data to adult classifications due to the effects of developmental stages of maturation on body weight and height.[15]

Foot structure assessment
Static weight-bearing footprints were taken using a Productos Suavepie pedograph to assess foot structure. The pedograph was prepared following standard procedures[16] and positioned on a level surface. The underside of the membrane was inked before commencing each testing session and re-inked after every five subjects. A piece of pedograph paper, on which the school and subject code were clearly identified, was placed beneath the membrane and the membrane lowered into position. The foot to be imprinted was positioned parallel to and above the membrane. The subjects were assisted in lowering the foot onto the membrane before being instructed to stand motionless with weight centred over both feet and eyes focussed straight ahead for even weight distribution. Once in position for approximately 2 s, the foot was removed carefully and swiftly from the pedograph. Two outlines of each subject's left and right foot were recorded. The pedograph was used in the present study as it provided a distinct outline of each child's foot, was a non-invasive and reliable method to assess foot structure,[16] was a small unit to transport, and was an inexpensive and easy to administer procedure in the field to the large sample size.

One representative footprint per foot per subject was selected for analysis based on clarity and quality of the print. The Footprint Angle (FA) and Chippaux–Smirak Index (CSI) were then calculated from each of the footprints, following the protocol of Forriol and Pascual,[17] as representative measures of the surface area of the foot in contact with the ground (see Figure 1). To obtain the FA a straight line was

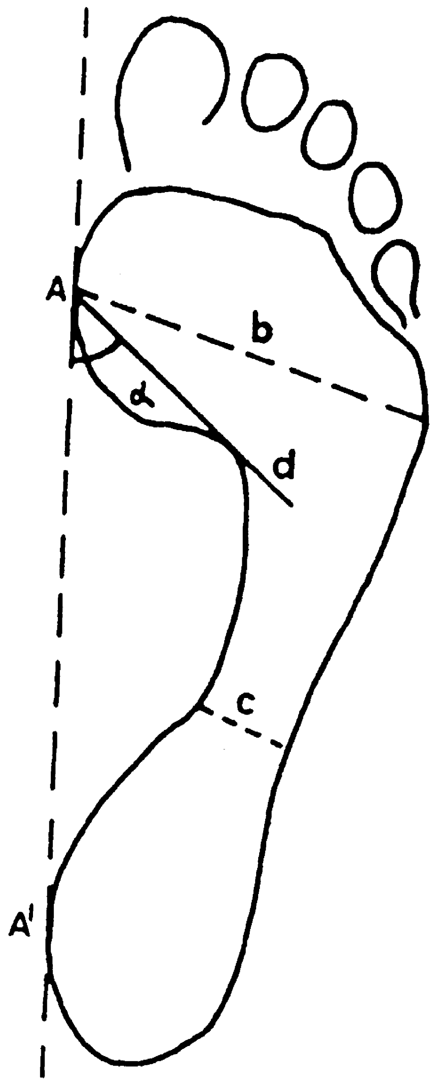

Figure 1 The Footprint Angle (α; degrees) and Chippaux–Smirak Index (c/b; %) calculated to represent the surface area of the foot in contact with the ground (adapted from Forriol and Pascual[17]).

drawn (A–A′) connecting the most medial points at the heel and at the forefoot. A second line (A–d) was then drawn from point A to the apex of the concavity of the medial arch (point d). The resultant angle at point A constituted the FA. Footprint Angles were then categorised into flat arch (0–29.9°), lowered arch (30–34.9°), intermediary arch (35–41.9°) and normal arch foot types (42° +).[17] To calculate the CSI, a line was extended from point A to the widest section of the forefoot (line b). A parallel line was then constructed (line c) to identify the narrowest area of the medial arch. The two lines where measured, line c divided by line b and the result expressed as a percentage. The minimum CSI value, 0%, indicated a high arch, 0.1–29.9% indicated a normal arch, 30–39.9% indicated an intermediary arch, 40–44.9% indicated a lowered arch and a percentage of 45% or above indicated a morphological flat arch foot.

Statistical analysis

Means and standard deviations for the dependent variables were calculated for the right and left feet of the subjects. The dependent variables were then analysed using independent *t*-tests to determine if any significant ($P < 0.001$) differences existed between the obese and non-obese children with respect to the dependent variables. Obesity was characterised by BMI whereas foot structure was characterised by FA and CSI. To decrease the chance of a type 1 error, the alpha level was adjusted using a modified Bonferroni test.[18]

Results

The mean BMI score calculated for the obese children (BMI = 23.3 kg/m^2 ± 2.4) was significantly greater than the mean calculated for the non-obese children (BMI = 16.1 kg/m^2 ± 0.9; $P < 0.001$) confirming two separate BMI categories. Although anticipated, this result confirmed that the two subject groups were significantly different with respect to obesity.

The FA derived for both the left and right feet of the obese children was significantly less ($P < 0.001$; Left FA = 38.14° ± 14.77; right FA = 37.63° ± 14.00) compared to the non-obese children (left FA = 46.90° ± 11.40, right FA = 46.07 ± 10.91; see Figure 2). In contrast, the CSI values were significantly greater ($P < 0.001$) for the obese children (left CSI = 36.30% ± 14.36; right CSI = 36.82% ± 13.97) compared to the non-obese children (left CSI = 20.62 ± 12.92; right 23.35 ± 12.42) for both the left and right feet (see Figure 3).

Discussion

Based on the FA and CSI data presented in Figures 2 and 3, obese children in the present study displayed a mean intermediary arch and intermediary foot-index according to the classifications of Forriol and Pascual[17] (FA between 35 and 41.9° and CSI between 30 and 39.9%) whereas non-obese subjects displayed a mean normal arch type and normal foot-index (FA > 42° and CSI between 0.1 and 29.9%). While the sample included a representative range of FA and CSI values, the mean arch heights for the non-obese group were consistent with studies on children of similar age.[17] The obese values however, indicated lower mean arch heights than previously recorded.

A significant difference was found between the subject groups for both FA and CSI, whereby obese children displayed a decreased FA and an increased CSI (see Figures 2 and 3). A decreased FA and an increased CSI have been associated with a lower longitudinal internal arch, a flatter cavity and a broader midfoot area of the footprint.[17,19] Lower arches have also been associated with a decrease in the integrity of the foot as a weight-bearing structure.

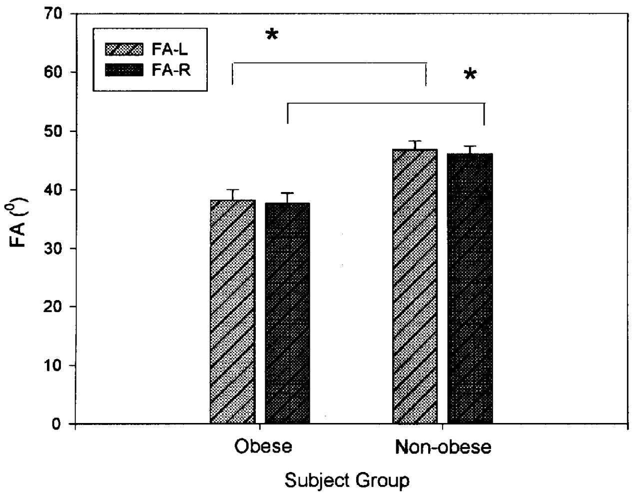

Figure 2 Footprint Angle (mean + s.e.m.) derived for the left and right feet of the obese and the non-obese children (*indicates a significant difference between the subject groups).

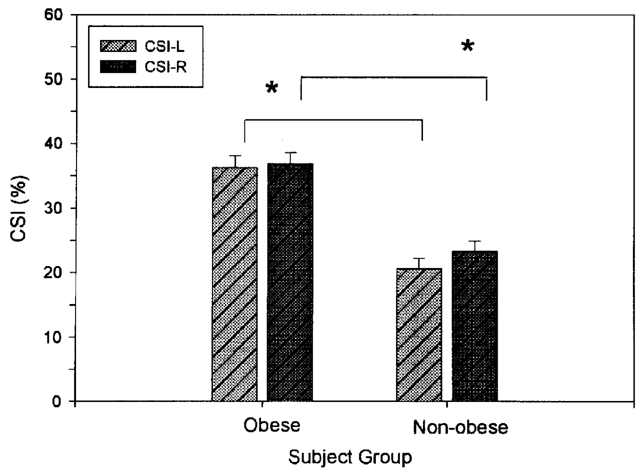

Figure 3 Chippaux–Smirak Index (mean + s.e.m.) derived for the left and right feet of the obese and the non-obese children (*indicates a significant difference between the subject groups).

Therefore, it is suggested that obese children as young as 8 y of age who display structural foot characteristics may be subject to problematic symptoms in later life, particularly if their excessive weight gain was to continue.

The structural changes in the foot associated with obesity may be a factor that hinders the participation of obese children in physical activity. For example, if structural foot changes associated with obese children's feet increase pressure within the foot or compromise foot function, this may lead to increased foot discomfort, particularly during weight-bearing activities. If so, declines in physical activity associated with foot discomfort may perpetuate the cycle of further increases in the obese child's body mass due to inactivity thereby increasing loads on the feet and, in turn, further exacerbating load bearing-associated foot problems.

Consistent with results in the present study, previous investigations have supported an association between foot structure and body mass. For example, in an analysis of footprints of children aged between 1 and 12 y, Welton[20] reported that the shape of the foot was influenced by body type, with broader footprints associated with a plump, obese or stocky build. While this study did not elaborate on any effect excess weight may have on foot development or efficiency, Welton[20] suggested that, although many footprints registered outside the normal range, they would not necessarily require intervention or treatment but rather monitoring for potential problems. However, Hennig *et al*[21] identified body weight as a major influence on the magnitude of the pressures under the feel of 125 children aged 6–10 y.

Can footprints be used to screen young children, particularly overweight and obese children, to identify those who may be at risk of developing foot pathologies associated with their excessive body mass? It is unknown if the greater prevalence of flatfootedness in the obese prepubescent child is due to the presence of a fat pad that remains or develops in the instep of the obese child, thereby causing a form of flatfeet that may have no pathological consequences. However, it is also unknown if there is some other structural dysfunction present, as a result of excessive weight-bearing, which has caused the longitudinal arch to collapse, thereby resulting in an increased foot contact area which will have pathological consequences. Further investigation is warranted to answer these questions.

Conclusions

It was concluded that excess body mass had a significant effect on the foot structure of prepubescent children. It is postulated that foot discomfort associated with these structural changes in the obese foot could hinder the participation of obese children in physical activity. Further research is therefore required to investigate the relationship between obesity and foot structure, particularly to determine if these structural changes influence plantar pressure distribution and/or foot discomfort. If a clear association can be established between assessment techniques suitable for use in the field, such as footprints, and plantar pressure distribution, screening can be implemented in schools to identify those children at risk of developing problematic feet characteristic of the obese adult.

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