Author(s): Morrison, Stewart C., Durward, Brian R., Watt, Gordon F., Donaldson, Malcolm D. C.
Article Title: Anthropometric Foot Structure of Peripubescent Children with Excessive versus Normal Body Mass
Year of publication: 2007
Citation: Morrison S.C. et al (2007) 'Anthropometric Foot Structure of Peripubescent Children with Excessive versus Normal Body Mass' Journal of the American Podiatric Medical Association, Sep-Oct; 97(5) 366-70
Link to published version:
http://www.japmaonline.org/cgi/reprint/97/5/366
DOI: (not stated)

Publisher statement:
http://www.japmaonline.org/misc/ifora.shtml

Anthropometric Foot Structure of Peripubescent Children with Excessive *versus* Normal Body Mass

A Cross-sectional Study

Stewart C. Morrison, PhD*
Brian R. Durward, PhD†
Gordon F. Watt, DPM†
Malcolm D. C. Donaldson, MD‡

Background: A variety of musculoskeletal problems have been associated with excessive body mass in children, including structural foot problems.

Methods: Two hundred children aged 9 to 12 years were recruited to evaluate the effect of body mass on foot structure. Three reliable anthropometric measures were recorded: foot length, forefoot width, and navicular height.

Results: Following independent sample *t* test analysis of the data, significant differences were found for the three anthropometric variables when children with normal body mass were compared with those with excessive body mass. The research indicates that foot length and width increase with body mass, whereas navicular height drops.

Conclusions: Excessive body mass affects the discrete anthropometric structure of the peripubescent foot. With the growing concern about childhood obesity, further research is essential to develop a comprehensive understanding of the issues identified and to quantify the findings presented here. (J Am Podiatr Med Assoc 97(5): 366-370, 2007)

The prevalence of obesity in children is now an international concern and one that is referred to by the International Obesity Taskforce as a "pan-European epidemic."[1] According to the International Obesity Taskforce, obesity in children is an acute public health crisis with numerous long-term consequences, including cardiovascular disease, type 2 diabetes, and psychosocial problems.[1] Evidence is also emerging that excessive body mass can cause deformity of the musculoskeletal system.[2] It has been proposed that obesity leads to structural deformity of the foot, in particular pes planus.[2-4] These structural changes have been reported to result in further complications of pain and discomfort, which in turn can reduce mobility and limit the child's ability to participate in physical activities.[3, 4] The potential for damage to delicate, immature bone is highlighted by Dananberg,[5] who reported that the magnitude of power required to propel the body forward during gait multiplied by the number of footsteps taken has the potential to create cyclical forces capable of causing bone and joint deformity. It has been reported that the foot is particularly susceptible to deformity owing to its distal location, flexibility, and late ossification.[6]

The current study was undertaken to evaluate the impact of excessive body mass on the anthropometric structure of the peripubescent foot. Anthropometric measures of foot length, forefoot width, and navicular height are reported in the literature as appropriate for identifying foot characteristics in the developing child.[7]

Materials and Methods

Before data collection, the Glasgow City Council granted approval to conduct this investigation in primary schools in the Glasgow postal area. The Glasgow Cale-

*School of Health and Bioscience, University of East London, Stratford, London, England.

†School of Health and Social Care, Glasgow Caledonian University, Glasgow, Scotland.

‡Division of Developmental Medicine, University of Glasgow, Royal Hospital for Sick Children, Glasgow, Scotland.

Corresponding author: Stewart C. Morrison, PhD, Stratford Campus, University of East London, Romford Rd, Stratford, London E15 4LZ, England.

donian University ethics committee also granted approval for the proposed research. Further permission was obtained from the eight primary schools that participated in the study. Data collection was conducted between September 1, 2004, and March 31, 2005.

A pilot study was initially conducted to establish the intrarater reliability of the lead researcher.[8] It was necessary to establish levels of consistency of repeated measurements of the three selected variables. Using type (2,1) intraclass correlation coefficient analysis, the lead researcher was shown to be highly reliable in making three repeated measurements of the foot variables. Intraclass correlation coefficient values of 0.98 to 0.99 were reported.

Anthropometric Measurements

To classify body mass status, height and weight were recorded. Before data collection, participants were asked to remove their shoes and socks. Height was measured with a portable stadiometer (Leicester Height Measure; Seca Ltd, Birmingham, England) in accordance with the protocol advocated by the National Center for Chronic Disease Prevention and Health Promotion.[9] Each child was asked to stand erect with his or her feet together and shoulders level. The four contact points (head, back, buttocks, and heels) were maintained against the spine of the stadiometer during measurement. The head was positioned in the Frankfurt plane, and the sliding bar was then lowered onto the crown of the head. Height was measured to the nearest millimeter and recorded by the researcher. A pair of manual calibrated Seca scales was used to measure body mass in kilograms. The participants were fully dressed in the typical school uniform.

Foot Variables

Foot length was recorded to the nearest millimeter as the distance from the posterior aspect of the heel to the most distal aspect of the longest toe. Foot length was measured with subjects standing upright using a foot board, a plastic device with calibrated lineation (in centimeters and millimeters).

Forefoot width was measured as the widest horizontal distance of the forefoot—from the most medial aspect of the first metatarsal head to the most lateral aspect of the fifth metatarsal head. With subjects standing, forefoot width was measured with a calibrated caliper, and the values were recorded in centimeters and millimeters.

The navicular tuberosity was palpated by the lead researcher (S.C.M.) and with each subject in a standing position; the vertical distance between the ground and the bony medial tubercular protuberance of the navicular was measured using a ruler.

Weight Classification

Participants were classified according to their body mass index SD score.[10] Body mass index was calculated as the weight in kilograms divided by the square of the height in meters. To allow for the effect of age and sex on body mass index, the values were transformed to SD scores. The body mass index SD score (BMI SDS) was derived using the following formula:

$$\text{BMI SDS} = \frac{BMI(of\ child) - Mean\ BMI(for\ child\text{'}s\ age)}{1\ SD\ of\ BMI(for\ age)}$$

The principle of this formula is that body mass index is expressed in relation to normative data (using the population data from the 1990 British Growth Reference[11]) so that information from children of both sexes and of different ages can be pooled. The software used for this BMI SDS conversion was the LMS transformation program (LMS, Louvain, Belgium).[12] This method summarized the height and weight of the recruited participant's data using three age-specific curves: L (lambda), M (mu), and S (sigma). These curves are based on national age-referenced databases for height and weight and, therefore, enable the classification of body mass according to national standards. In the absence of an agreed-on criterion for the classification of severe obesity in children, clinical guidance was sought; for this study it was determined that an SDS of 2.64 or greater would be adopted to classify severely obese subjects. The following SDS criteria were used: –1.64 or less, underweight; greater than –1.64 to 1.04, normal weight; greater than 1.04 (above the 85th percentile), overweight; greater than 1.64 (above the 95th percentile), obese; and greater than 2.64, severely obese.

Results

Sample demographics of the 200 children aged 9 to 12 years recruited for the study are given in Tables 1 and 2. Descriptive information pertaining to the effect of body mass on the anthropometric foot structure is presented in Figures 1 to 3. To identify the differences in anthropometric foot structure between children with excessive body mass and normal-weight subjects, t tests were conducted. The independent samples t test was used to determine whether differences in foot variables existed between the mean scores of the excessive body mass group and those of the normal-weight children (Table 3).

Table 1. Sample Demographics

	Subjects (No.)	Age, Mean (±1 SD) (years)	Height, Mean (±1 SD) (cm)	Body Mass, Mean (±1 SD) (kg)
Female	110	10.1 (0.8)	142.9 (9.2)	40.1 (10.4)
Male	90	10.4 (0.9)	142.8 (8.3)	40.1 (10.1)

Table 2. Weight Classification Distribution

	Females (No.)	Males (No.)
Normal weight	67	50
Overweight	17	13
Obese	24	23
Severely obese	2	4

Significant differences were evident in the variables between normal-weight children and those with excessive body mass. Mean foot length in normal-weight subjects was recorded as 21.7 to 22.0 cm, and this value increased in overweight subjects (22.6 cm), obese subjects (22.8–23.2 cm), and severely obese subjects (23.3–23.5 cm). Mean forefoot width was recorded in normal-weight subjects as 8.1 to 8.4 cm, and this value increased in overweight subjects (8.5–8.6 cm), obese subjects (8.6–8.8 cm), and severely obese subjects (9.3–9.6 cm). Differences in navicular height are less evident, and mean values were 3.8 to 4.0 cm in normal-weight subjects, 4.0 to 4.1 cm in overweight subjects, 4.0 cm in obese subjects, and 3.7 to 4.0 cm in severely obese subjects.

Discussion

This study was conducted to establish the effect of excessive body mass on foot structure in peripubescent children aged 9 to 12 years. The results indicate that differences in foot length, forefoot width, and navicular height were present in children of excessive body mass compared with those of normal body mass. It was observed that children with severe obesity had the longest feet (Fig. 1). These findings are consistent with those of Mauch et al,[13] who reported an increase in foot length and foot width with body mass index.

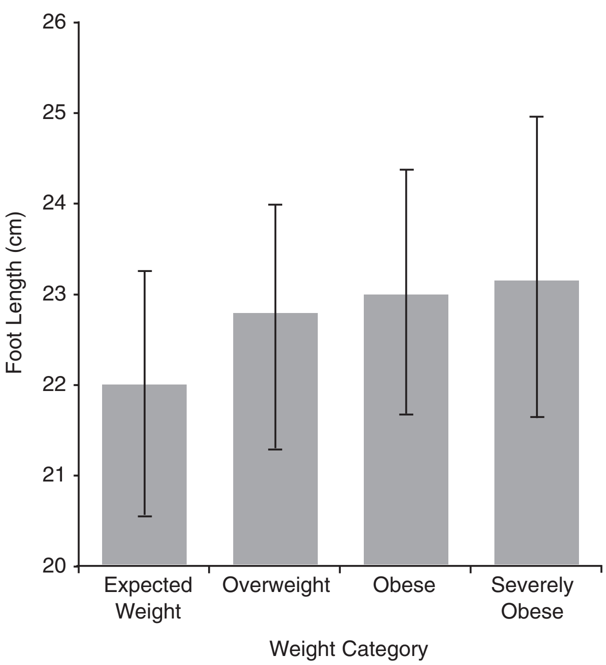

Figure 1. Mean foot length for each weight category used in this study. Foot length increases with body mass. Vertical lines represent ±1 SD.

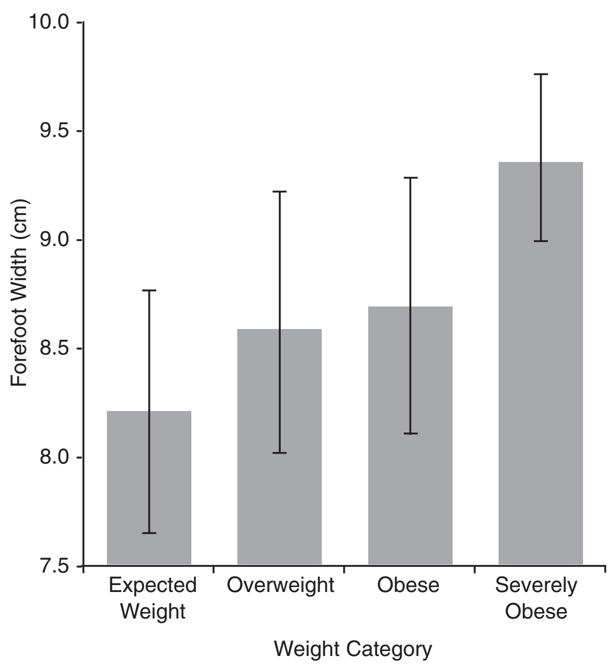

Figure 2. Mean forefoot width for each weight category. Forefoot width increases with body mass. Vertical lines represent ±1 SD.

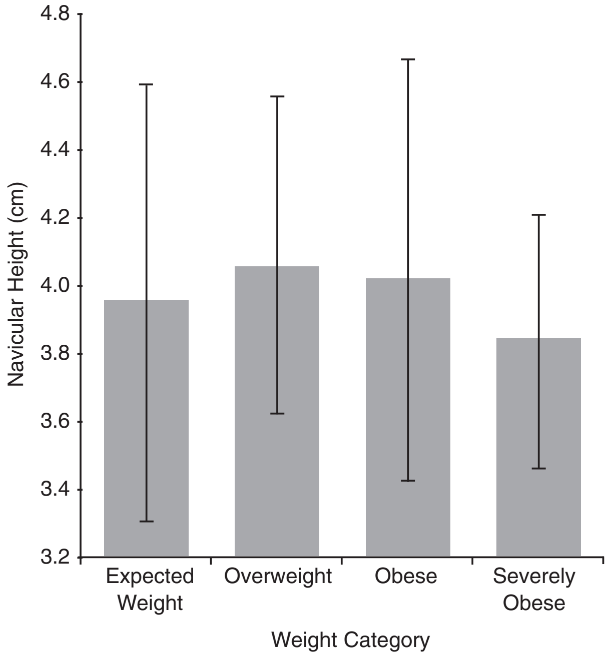

Figure 3. Mean navicular height for each weight category. There is no obvious change with body mass. Vertical lines represent ±1 SD.

An increase in forefoot width was also observed (Fig. 2). There was no evident increase or decrease in navicular height with differences in body mass (Fig. 3). It was expected that increased body mass would be associated with decreased navicular height due to changes in foot structure. This relationship was not apparent; this may be related to the small sample sizes for the different weight categories. Further investigation is warranted.

Independent *t* tests were calculated to compare mean values in normal-weight children with those in children of excessive body mass. This analysis indicated that there was a significant difference between the two weight groups for the variables measured ($P \leq .05$) (Table 3). Thus body mass is apparently associated with anthropometric foot structure.

It is difficult to postulate why there may be observable differences in foot length and forefoot width in subjects with excessive body mass compared with normal-weight children and whether excessive body mass causes such changes. The findings from this study are in agreement with those from Dowling et al,[2] Riddiford-Harland et al,[3] and Mauch et al.[13] The results are also similar to those of Hills et al,[14] who reported increased forefoot width with increased body mass. Hall et al[7] proposed that increased forefoot width in adults with excessive body mass was caused by decreased ligamentous strength. A potential reason for this may be ligamentous creep. The term *ligamentous creep* refers to stretching and decreased strength in ligaments caused by continuous stresses on them, which in turn causes instability of the forefoot during weightbearing.[15] Numerous reasons for such structural foot changes can be postulated: 1) biomechanical deformity (pes planus), 2) a hormonal cause of excessive mass (eg, increased height seen in subjects with excessive body mass), 3) an excess of adipose tissue, 4) increased bone formation and subperiosteal expansion resulting from increased plantar forces and pressures experienced during gait, and 5) a combination of these factors.

Table 3. Independent Samples *t* Tests for Foot Variables

Foot Variable	Mean Difference: Normal Weight *versus* Excessive Body Mass	95% Confidence Interval of Difference
Foot length (L)	0.8	0.4 to 1.2
Foot length (R)	0.9	0.5 to 1.3
Foot width (L)	0.4	0.3 to 0.6
Foot width (R)	0.4	0.2 to 0.6
Navicular height (L)	0.1	–0.0006 to 0.3
Navicular height (R)	0.1	0.018 to 0.2

Abbreviations: L, left; R, right.
Note: $P \leq .05$ for all.

Further research is required to identify the specific causative factors associated with obesity and structural foot changes. Particular attention should be given to establishing the relationship between excessive body mass and the development of pes planus. This study evaluated the effect of body mass on discrete parameters of the anthropometric foot structure. The results of the study cannot support or refute the theory that excessive body mass leads to the development of pes planus. It would be beneficial for future research to extend the anthropometric evaluation of the foot to include biomechanical evaluation of foot structure.

The findings from this research contribute to the understanding of the effect of body mass on the structural development of the pediatric foot and musculoskeletal system. Excessive body mass seems to lead to increased foot length and width. It is postulated that biomechanical changes in the behavior of forces and the configuration of the complex joint interactions in the foot may result in disruption to foot alignment and function. Further research is required to support these results.

Conclusion

The results of this study indicate that children with excessive body mass have longer and wider feet compared with children of normal body mass. This work focused on discrete anthropometric features of the peripubescent foot. Additional research is needed to examine other aspects of foot structure—in particular, factors causing pes planus. The findings reported support previous research indicating that excessive body mass may have a detrimental effect on the structure of the pediatric foot.

Financial Disclosures: Dr. Morrison, the lead researcher, was supported by a PhD grant from the Royal Hospital for Sick Children, Glasgow.
Conflict of Interest: None reported.

References

1. International Obesity Taskforce and European Association for the Study of Obesity: *Obesity in Europe: The Case for Action*, International Obesity Taskforce, London, 2002.
2. Dowling A, Steele J, Baur L: How does obesity and gender affect foot shape and structure in children? Available at: http://www.isb2005.org/proceedings/ISB05. Accessed October 5, 2005.
3. Riddiford-Harland DL, Steele JR, Storlien LH: Does obesity influence foot structure in prepubescent children? Int J Obes Relat Metab Disord **24:** 541, 2000.
4. Dowling AM, Steele JR, Baur LA: Does obesity influence foot structure and plantar pressure patterns in prepubescent children? Int J Obes Relat Metab Disord **25:** 845, 2001.
5. Dananberg HJ: Sagittal plane biomechanics. JAPMA **90:** 47, 2000.
6. LeVeau BF, Bernhardt DB: Developmental biomechanics. Phys Ther **64:** 1874, 1984.
7. Hall JG, Froster-Iskenius UG, Allanson JE: *Handbook of Normal Physical Measurements*, Oxford University Press, Oxford, England, 1989.
8. Morrison SC, Durward BR, Watt GF, et al: The intra-rater reliability of select measures conducted on the paediatric foot. The Foot **15:** 180, 2005.
9. National Center for Chronic Disease Prevention and Health Promotion: Anthropometry procedures manual. Available at: http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/BM.pdf. Accessed August 20, 2007.
10. Flodmark CE, Lissau I, Moreno LA, et al: New insights into the field of children and adolescents' obesity: the European perspective. Int J Obes Relat Metab Disord **28:** 1189, 2004.
11. Freeman JV, Cole TJ, Chinn S, et al: Cross-sectional stature and weight reference curves for the UK, 1990. Arch Dis Child **73:** 17, 1995.
12. *The British 1990 Growth Reference*, Child Growth Foundation, London, 2001.
13. Mauch M, Grau S, Krauss I, et al: Influence of age, gender and body-mass-index on 3-D foot shape in children. Gait Posture **20:** s91, 2004.
14. Hills AP, Hennig EM, Byrne NM, et al: The biomechanics of adiposity: structural and functional limitations of obesity and implications for movement. Obes Rev **3:** 35, 2002.
15. Tiberio D: Pathomechanics of structural foot deformities. Phys Ther **68:** 1840, 1988.