Effect of Excessive Body Weight on Foot Arch Changes in Preschoolers

A 2-Year Follow-up Study

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Background: A stable standing posture, and effective and aesthetic gait, depend heavily on correct anatomical construction of the feet, thanks to which they can play their important role. The shape and height of the foot arches are already formed in the preschool and early school years; therefore, abnormalities and disorders in children's feet, and correlations between foot formation and somatic build, are still crucial and interesting issues for orthopedists, pediatricians, physiotherapists, and podiatrists. This study deals with changes in the height of the longitudinal and transverse arches of the foot in 4- to 6-year-old children.

Methods: A total of 102 boys and 105 girls took part in a 24-month study in which their body weight, height, body mass index, and Clarke's and gamma angles were measured. The analysis also focused on correlations among sex, nutritional status, and changes in foot arch height.

Results: It was discovered that sex did not considerably affect Clarke's and gamma angle values. However, it was found that between ages 4 and 6 years, the proportion of overweight and obese boys and girls increased, and the medial longitudinal arch of the foot had a tendency to collapse in those with excessive body weight. The effect of nutritional status on the transverse arch of the foot is rather dubious.

Conclusions: In light of these findings, therapeutic programs for preventing foot deformities in children should also focus on body weight control. (J Am Podiatr Med Assoc 105(4): 313-319, 2015)

The preschool age is an extremely dynamic developmental period. The central nervous system evolves and motor skills improve greatly. The child undergoes intensive somatic and intellectual growth. Those changes also affect body posture and the shape of the feet. Harmonious coexistence of those processes creates favorable conditions for optimal functioning of the body. Any somatic development abnormalities or deviations from good posture should be diagnosed and corrected as early as possible, and that is why regular screening and education on proper nutrition and the role of exercise should be performed as early as the preschool years.

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Obesity and bad posture (including foot defects) are among the most common health problems at pediatric ages.[1-4] However, there are still disputes about correlations between the previously mentioned phenomena.[5-7] The purpose of this study was to determine correlations between nutritional status and foot arch height and to draw the attention of clinicians to the need for implementing a complex approach to foot problems.

A study was conducted with preschool children in Tarnow, Poland, between September 1, 2010, and September 1, 2012. The study presented herein is part of that project, and it deals with changes in foot arches in 4- to 6-year-old children, focusing also on the status of their nutrition. Basic somatic traits and the longitudinal and transverse arches of the foot were assessed. We also compared the 2010 and 2012 measurements of body weight and height, body mass index (BMI [calculated as weight in kilograms divided by height in meters squared]), and Clarke's

and gamma angles for the right and left feet between boys and girls and within the same sex.

Participants and Methods

Observations and measurements were conducted in ten randomly selected kindergartens in Tarnow. Before the study, we obtained written permission from kindergarten headmasters to conduct it and the informed consent of the minors' parents or legal guardians. The child's calendar age of 3.5 to 4.49 years on the day of the first measurements (September 2010) were the main criteria for study participation. Children who did not want to participate, who had disability certificates, or who were being treated for chronic diseases were excluded from the project. Finally, the results of measurements from 207 children, including 102 boys (49.3%) and 105 girls (50.7%), were analyzed.

The study was conducted in a playroom between 8 AM and 2 PM in the presence of a teacher who all of the children knew well. The participants were measured undressed to their underwear, the same equipment was used each time, and the measurements met high ethical standards. Body height was measured within 1 mm with a Martin anthropometer (Alumet; Warsaw, Poland), and body weight within 0.1 kg with a Tanita scale (Tanita Corporation of America Inc, Arlington Heights, Illinois). Then, BMI was calculated, and participants were assigned to appropriate nutritional groups, ie, normal weight, overweight, or obese, according to the definitions of Cole et al.[8] Foot arch height was assessed on a computer-aided podoscope (CQ Elektronik System, Wiśniowa, Poland)[9] using Clarke's (for the longitudinal arch) and gamma (for the transverse arch) angular values (Fig. 1). The participants were asked to stand still on the podoscope platform. Digital camera images of their soles were transferred from the podoscope to the monitor of the computer, and Clarke's angular values were calculated as an angle between two lines. One line was the tangent to the medial edge of the foot, and the other was routed through the most medial point of the metatarsal and the point of greatest concavity in the footprint. The gamma angle was calculated as the angle between the tangent and the medial and lateral edges of the foot.[10,11] The electronic footprint analysis was found to be useful in a screening study because it is cheap, noninvasive, and simple to perform.[12-16]

Clarke's angle decreases with a lowered medial longitudinal arch of the foot and is less than 42° when the foot is flat. In children with hollow foot, Clarke's angle is greater than 54°. The correct

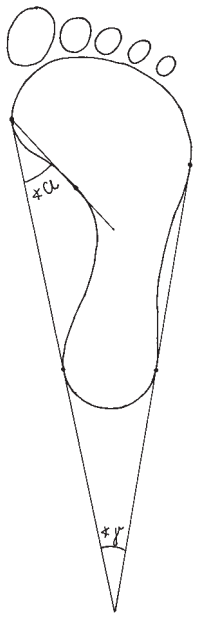


Figure 1. Clarke's angle (Cl) and gamma angle (γ).

gamma angle is 14° to 18°, and an angle exceeding 18° denotes a reduction of the transverse foot arching.[17]

The height and weight measurements of all of the children in tests 1 and 2 were performed by one physiotherapist, and another physiotherapist (A.J.-S.) with long-standing experience in the study of body posture handled the podoscope.

Statistical analysis was performed with Statistica version 10 software (StatSoft Inc, Tulsa, Oklahoma) by means of basic descriptive statistics, ie, mean and standard deviation, the Shapiro-Wilk test for normality, the t test for independent and dependent samples, the Wilcoxon test, and the Mann-Whitney U test. Differences were considered significant at $P < .05$.

Results

At 4 years old, girls had similar body weight, height, and BMI as their male peers. The longitudinal arches of the right and left feet in boys were slightly lower than those in girls (smaller Clarke's angle), whereas the transverse arch of the right foot was slightly higher in boys (smaller gamma angle), and in the case of the left foot it was higher in girls. However, those differences were not statistically significant (Table 1).

After 24 months, girls were still lighter than boys. The body weight difference increased from 0.28 to 1.03 kg, and body height from 0.36 to 2.25 cm, and they became statistically significant. The BMI in

Table 1. Comparison of Variables Between Boys and Girls

Time of Measurements and Group	Body Weight (kg)	Body Height (cm)	BMI	Clarke's Angle (°)		Gamma Angle (°)	
				Left Foot	Right Foot	Left Foot	Right Foot
2010							
Girls	17.78 ± 3.01	106.54 ± 5.64	15.58 ± 1.69	34.29 ± 12.77	36.12 ± 11.38	15.39 ± 2.09	15.08 ± 1.94
Boys	18.06 ± 2.79	106.9 ± 5.98	15.75 ± 1.51	33.63 ± 14.75	33.78 ± 14.49	15.57 ± 2.7	14.99 ± 3.11
P value	.320	.786	.287	.602	.241	.078	.625
2012							
Girls	22.25 ± 3.41	116.5 ± 5.27	16.37 ± 2.07	37.06 ± 12.96	37.31 ± 11.74	15.58 ± 2.01	15.2 ± 2.17
Boys	23.28 ± 4.58	118.75 ± 5.36	16.42 ± 2.4	35.03 ± 14.71	36.63 ± 13.09	15.04 ± 2.22	14.74 ± 2.28
P value	.251	.001[a]	.902	.277	.746	.097	.136

Note: Data are given as mean ± SD.
Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).
[a]Statistically significant.

boys was still higher than in girls, but the difference decreased from 0.17 to 0.05. At age 6, boys still boasted a slightly lower longitudinal arch of the foot, whereas the transverse arch, expressed by the gamma angle, increased in height and was slightly higher than in girls (Table 1).

Over 24 months, between tests 1 and 2, the boys' and girls' body weight and height, as well as their BMI, increased statistically significantly. Girls became approximately 10 cm taller and almost 4.5 kg heavier, and their BMI increased by 0.79. Boys were 11.85 cm taller and approximately 5 kg heavier, and their BMI increased by 0.67. The longitudinal arch also slightly increased in height. The Clarke's angle in the right foot increased by 1.19° in girls and by 2.85° in boys, and the increase in the left foot was 2.77° in girls and 1.4° in boys. The height of the transverse arch slightly increased in boys (the gamma angle decreased by 0.53° in the left and by 0.25° in the right foot). Girls showed a slight decrease in the height of the transverse arch of the foot (the gamma angle increased by 0.19° in the left foot and by 0.12° in the right foot) (Table 2).

On the day of the first measurement, almost 88% of girls and 91% of boys boasted a good weight to height ratio. Overweight or obesity was discovered in 12.37% of girls and in 8.76% of boys, and over 24 months, those proportions increased. At age 6 years, 27.56% of girls and 21.56% of boys were much too heavy (including 6.7% of girls and 9.8% of boys who were obese) (Table 3).

Observations of changes in the shape of foot arches in preschoolers divided into three nutritional groups revealed that they had a tendency to lower the longitudinal arch (Clarke's angle decreased) when they gained weight. Clarke's angle increased by approximately 4° in children with normal weight between ages 4 and 6 years, and that change was statistically significant. In overweight children, the height of the longitudinal arch was lowered; Clarke's angular value was smaller in these children by almost 3.5° in the left and right foot and by 7° in the left and more than 9° in the right foot (statistically significant change) in obese children. The transverse arch slightly increased in height (gamma angle was smaller) in children with normal weight and in overweight children, but it showed a tendency to lower in obese participants (Table 4).

Differences in Clarke's angular values in the right foot between 6-year-old children with normal weight versus overweight ($P = .029$) and between 6-year-old participants with normal weight versus obesity ($P = .00039$) were significant.

Discussion

A good level of physical fitness improving the quality of everyday functioning is conditioned by proper development of the nervous and musculoskeletal systems. It is reflected in the human body posture in which positioning of the spine and lower extremities is of key importance. Feet play an extremely important role; they support the whole body, enable bipedal movement, and stabilize the body in a standing position and in motion.[18] The functional fitness of the foot to a great extent depends on the muscular tone of the muscles maintaining its longitudinal and transverse arches.[19-23] They can perform these functions because of their specific and characteristic structure of a system of longitudinal and transverse arches, which most intensively develop in the preschool years.[24] It

Table 2. Comparison of Variables at Measurements 1 and 2

Group and Time of Measurements	Body Weight (kg)	Body Height (cm)	BMI	Clarke's Angle (°)		Gamma Angle (°)	
				Left Foot	Right Foot	Left Foot	Right Foot
Girls							
2010	17.78 ± 3.01	106.54 ± 5.64	15.58 ± 1.69	34.29 ± 12.77	36.12 ± 11.38	15.39 ± 2.09	15.08 ± 1.94
2012	22.25 ± 3.41	116.5 ± 5.27	16.37 ± 2.07	37.06 ± 12.96	37.31 ± 11.74	15.58 ± 2.01	15.2 ± 2.17
P value	.0000001[a]	.0000001[a]	.001[a]	.128	.326	.443	.759
Boys							
2010	18.06 ± 2.79	106.9 ± 5.98	15.75 ± 1.51	33.63 ± 14.75	33.78 ± 14.49	15.57 ± 2.7	14.99 ± 3.11
2012	23.28 ± 4.58	118.75 ± 5.36	16.42 ± 2.4	35.03 ± 14.71	36.63 ± 13.09	15.04 ± 2.22	14.74 ± 2.28
P value	.0000001[a]	.0000001[a]	.039[a]	.559	.179	.094	.250

Note: Data are given as mean ± SD.
Abbreviation: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).
[a]Statistically significant.

is then when foot deformities involved in lowering the height of the longitudinal arch are most frequently diagnosed.[25]

The prevalence of foot deformities in children has been the topic of numerous studies[26,27]; however, there still remains a lot of doubt. There are no explicit data confirming or negating correlations among sex, nutritional status, and flat feet. There is not even consensus of opinion on whether flat feet in children should be corrected,[28] but we know that changes in foot shape affect the gait pattern[29] and may be a cause of pain.[30] In elderly people, painful feet considerably worsen the quality of their functioning,[31] so it seems that studies on the epidemiology of foot deformities, their influence on stable posture and efficient ambulation, and the possibilities of correcting flat feet should be continued.

The longitudinal arches of the right and left feet in boys were slightly lower than those in girls, and that tendency did not change in 24 months of observation. A higher longitudinal arch of the foot in girls compared with boys was also found in preschool children by Pfeiffer et al[32] and in 7- to 9-year-old children by Drzał-Grabiec.[7] Mickle et al[33] justified the prevalence of flat feet in boys by greater medial midfoot plantar fat pad thickness compared with girls at the same age. They suggested that the longitudinal arch of the foot in boys developed later and that flat feet were apparent but did not have to be corrected. However, the study by Shibuya et al,[34] which found a correlation between flat feet and male sex in adults, contradicted the previous finding.

Table 3. Participants' Nutritional Status

Group and Time of Measurements	Participants (No. [%])		
	Normal Weight	Overweight	Obese
Girls			
2010	92 (87.61)	9 (8.57)	4 (3.8)
2012	76 (72.38)	22 (20.9)	7 (6.66)
Boys			
2010	93 (91.17)	7 (6.8)	2 (1.96)
2012	80 (78.4)	12 (11.76)	10 (9.8)

More collapsed foot arches in overweight people could be caused by the presence of a thicker layer of fatty tissue. Observations made in a group of 8-year-old children confirmed the presence of a thicker layer of fatty tissue on the medial midfoot plantar section and at the same time indicated a lower height of the longitudinal arch of the foot.[35] Other studies[36] proved a correlation between being overweight and the incidence of flat feet in 4-year-old children. At the same time, no significant difference in medial midfoot plantar fat pad thickness was found between children with normal weight and obesity. A negative effect of excessive body weight on flat feet was confirmed by Villarroya et al[37] and Nieto et al.[38] The analysis of annual changes in foot arches in preschoolers showed that the height of the longitudinal arch had a tendency to increase. However, those changes took place more slowly in obese children.[39] Our research also discovered a negative impact of excessive body weight on the longitudinal arch of the foot in preschoolers. Moreover, it was found that children with normal weight developed higher foot arches between ages 4 and 6 years, but obese children had lowered arches. However, the results of other

Table 4. Changes in Foot Arch Height Depending on Nutritional Status

Group and Time of Measurements	Clarke's Angle (°)		Gamma Angle (°)	
	Left Foot	Right Foot	Left Foot	Right Foot
Normal weight (n = 156)				
2010	33.04 ± 13.69	34.35 ± 13.14	15.35 ± 2.37	14.99 ± 2.63
2012	37.37 ± 13.91	38.76 ± 12.29	15.26 ± 2.03	14.86 ± 2.12
P value	.010[a]	.001[a]	.704	.475
Overweight (n = 34)				
2010	36.44 ± 15.18	36.79 ± 13.5	16.05 ± 2.5	15.46 ± 2.36
2012	32.86 ± 12.75	33.32 ± 11.57	15.06 ± 2.5	15.11 ± 2.47
P value	.369	.270	.095	.858
Obesity (n = 17)				
2010	37.47 ± 10.46	36.98 ± 10.98	15.52 ± 2.54	14.65 ± 2.53
2012	27.86 ± 9.62	30.45 ± 13.74	15.68 ± 2.74	16.35 ± 2.12
P value	.135	0.031[a]	.181	.554

Note: Data are given as mean ± SD.
[a]Statistically significant.

studies[40] did not unambiguously reveal such dependency. Chen et al[41] proved that a correlation between flat feet and male sex and obesity existed when lowered arches developed in both feet. Those correlations did not occur in children who had a lowered arch in one foot. It seems that the transverse arch of the foot to a considerably smaller degree depends on sex and nutritional status.

Many papers have already been written about the negative impact of excessive body weight on mental and physical fitness.[42] It is a well-known fact that the number of overweight people is increasing and that the increase is connected to a sedentary lifestyle.[43] This problem increasingly often also concerns the youngest generation.[44] The physical activity level of preschoolers is not sufficient. They are not encouraged to be active during their free time, especially in families in which one parent is obese.[45] Girls and boys sit in front of the television longer and longer, which—together with bad eating habits—contributes to excessive body weight.[46] In the United States, almost 14% of children aged 2 to 5 years are obese.[47] In Germany, approximately 13% of boys and almost 16% of girls are overweight or obese.[48] Similar observations concern 6-year-old Polish children.[49] The findings from our study show that excessive body weight makes foot arches collapse, which may lead to discomfort or pain and may deepen aversion to physical activity.[50] This, in turn, will cause further weight gain.

The incidence of asymptomatic flat feet in children is often ignored and left without implementing any therapeutic measures, but when it persists into adulthood it can be a cause of foot pain[51,52] and can increase the risk of aponeurositis[53-56] and osteoarthritis of the first metatarsophalangeal joint.[57] Low foot arching is also associated with knee pain and knee injuries in runners and older adults.[58,59] Long-term observations of changes in the arches of the foot in children with proper and excessive weight allowed us to better understand the process of shaping of the feet. The results of our study show that weight gain and obesity affected the lowering of foot arches. However, traditional flatfoot correction does not take into account reduction of excessive body weight as a vital constituent of therapeutic measures. In light of the present findings, it seems that the previously mentioned attitude should be altered. Overweight and obese children, and those with diagnosed flat feet, should especially be provided with a therapeutic program of exercises that help prevent foot disorders, and they should be encouraged to reduce their body weight.

The numerical strength of the group of participants was too small to allow us to generalize the results to the whole population of preschool children. It is indispensable to continue long-term observations of changes in the shape of the arches of the foot in children with proper and excessive weight who come from different environments. The research should be supplemented with the assessment of other constituents that shape the lower extremities, such as the position of the heel bones and knees.

Conclusions

1. The body weight, height, and BMI of preschool children are slightly different in boys than in girls, but the height of the foot arches does not unambiguously depend on sex.
2. The proportion of overweight and obese children increases between ages 4 and 6 years.
3. The longitudinal arch of the foot significantly increases in height in preschoolers with normal weight, whereas in overweight and obese boys and girls, a tendency to lower the longitudinal arch of the foot appears.
4. There is no correlation between BMI and height of the transverse arch of the foot in preschoolers.
5. Control of nutritional status and reduction of excessive body weight should be required elements of prevention of foot deformities in children.

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