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The assessment of longitudinal and transverse arching and load distribution in young women's feet

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Abstract
Introduction. The human foot is an essential element of the musculoskeletal system. All foot shape irregularities may not only significantly impact the quality of life, but also cause serious afflictions and diseases in older ages. In addition, the lack of physical activity may adversely affect foot arching. Aim of Study. The objective of the study was to assess the extent of the foot arching and load distribution in sedentary female academic youth. Material and Methods. The study consisted of 20 physically inactive women aged 21 years. Foot arching was assessed with a CQ Electronic System podoscope, the analysis of the foot load was assessed with FDM-3 Zebris dynamographic platform. Results. The study shows that the female students had non-significant differences in longitudinal arching of the right and left foot. All women had the correct transverse feet arching. The percentage of load distribution on the right and left feet were within the scope of 50%. There were however significant statistical differences concerning a load placed on the forefoot and backfoot between the right and left foot. Conclusions. All analyzed students, according to Clarke's standards, had correct longitudinal and transverse arching of the foot, however, they showed differences in load distribution between the right and left foot and between forefoot and backfoot. The forefoot of the left foot and the backfoot of the right foot were more frequently loaded.

KEYWORDS: feet arching, load distribution, female.

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Introduction

The human foot constitutes an essential static-dynamic link of the musculoskeletal system. On the one hand, it is a supporting element that allows balancing the body in the standing position, and on the other hand, it plays an important part in the gait mechanics. It is responsible for shock absorption which protects the spine and cranium from microtraumas [32]. The foot has its own specific internal and external architecture. Foot efficiency and its correct operation depends on the morphological structure and, more importantly, on the correct shape of longitudinal and transverse arches [13, 27].

Correct arching and load distribution of the feet are the basis for correct body posture and subsequent physical activity. The foot constitutes one of the links in the proprioceptive kinematic chain, therefore any irregularities occurring in shapes and functions of its segments may result in dysfunctions of other locomotor organs [6, 8]. Such dysfunctions include scoliosis, asymmetry in body parts position, and neurological diseases [21, 34]. It turns out that all the above disorders may influence the quality of life and wellbeing [20].

Apart from genetic factors and diseases, numerous environmental factors can affect the feet' growth and development. Quality and type of used shoes (often connected to fashion) are responsible for the majority of foot deformities and problems among students [14, 33]. The weakness of the muscles, ligaments, or bony arch-supporting structures can lead to the collapse of the arch [41]. Pathological flat feet can cause changes in muscle balance, gait, and alignment of joint motion [16]. Other factors possibly influencing the students' feet arching are diseases of the circulatory system, inflammations, keeping prolonged standing position, lack of attention to the hygiene and protection of the legs, or pregnancy [4, 19, 33].

The condition of feet also largely depends on the load, duration, and intensity of effort during sports training, as well as on the surface on which the exercises take place [3, 19, 43]. Bibro et al. [6] showed that in young men lower limb strength training has caused changes both in the foot loading pattern and the height of the longitudinal arching. In athletes performing taekwondo, handball, volleyball, athletics, football, wrestling, weightlifting, gymnastics, and swimming the irregularities of the longitudinal and transverse foot arches were determined [3, 19, 22, 44]. However, there are also studies, like Yi-Liang and Shen-Feng [43], where no changes in arches of the foot were observed between the basketball players and the sedentary control group. Some authors claim that physical activity improves foot arching and body posture. However, they also emphasize that inappropriate training load or exercise methodology may negatively influence the correct functioning and structure of the feet [19, 45].

In adults, excessive weight − frequently connected with the lack of physical activity − was shown to negatively affect foot structure and its function. These structural changes appear to be associated with increased foot discomfort and/or foot pain, which are significantly more often reported by overweight people compared to their leaner counterparts [5, 35]. It is identified that increased foot pain could act as a deterrent for obese individuals to participate in physical activity and in turn, perpetuate the cycle of obesity, as the base of support during most weight-bearing activities is feet [37]. Przysada et al. [31] while examining the students, have observed that feet disorders occurred more frequently in overweight persons. Adamczyk et al. [1] have concluded that persons with higher BMI are at higher risk of developing transverse flatfoot.

Feet health problems concern 71 to 87% of the population aged 18-33 [34]. It is the period between childhood and adulthood when people start taking care of their health by themselves [42]. Most of the problems that occur in middle and older age influence the quality of life in the elderly. However, problems in foot arching may begin in young adults – the question is why? Students belong to one of the most exposed groups to the occurrence of foot irregularities, and often have specific foot health issues that differ from those of other age groups, such as ankle sprains, tinea pedis, onychomycosis, plantar warts, and ingrown toenails [12, 15, 17, 23, 29]. Students are also subjected to different kinds of general changes, such as greater autonomy, control over their lifestyle, control over physical activity, and development of attitudes and beliefs about health and financial problems [24]. Even at this age, untreated foot problems can lead to scoliosis, postural problems, slower walking speeds, uneven plantar pressure distribution, difficulty in carrying out daily activities, increased risk of falling, and the appearance of neurological diseases [21]. Rodríguez-Sanz et al. [34] while examining a group of students aged 22, stated that their quality of life in terms of the feet' health was low, regardless of sex. Nevertheless, feet should be properly cared for and their condition should be regularly controlled since it prevents the occurrence and development of diseases, disorders, or infections. Despite the multi causality and scope of the issue, studies in the student groups that analyze feet defects and their health consequences, are conducted occasionally. Therefore, the aim of the study was to assess the parameters of foot arching and their load distribution in physically inactive young women.

Material and Methods

The study has been conducted in March 2015. The study group consisted of 20 women aged about 21 (21.3 ± 0.93), physically inactive – they didn't do any additional physical activity beyond that of daily living. Detailed characteristics of the group are presented in Table 2. Before the study, all participants were informed about the procedures and methods of the research, which was followed by their written consent to participate in the observation. Before starting the research, the students declared that they did not take any recreational physical activity for a year. The study was conducted in compliance with the Ethical Principles for Medical Research of the Helsinki Declaration.

The study inclusion criteria were: female, age 20-25, physically inactive, written consent to participate in the study, and to use the results for scientific purposes. The study exclusion criteria were: physically active women (women practicing competitive sports or performing at least 30 minutes of physical activity every day), neurological or orthopedic disorders occurrence, no consent for participation in the study.

Body mass accurate to 0.1 kg and body height accurate to 0.5 cm were measured with a calibrated electronic scale with a stadiometer (RADWAG, Zyrardow, Poland). The data was used to calculate BMI [36].

Longitudinal foot arching was assessed with a CQ Electronic System podoscope (podoscope, CQ Electronic

System, Czernica Wr., Poland) [10]. The device registered the image of the planta surface, and after defining the points, it calculated the foot arching parameters. The person being examined was standing on the device barefoot in a natural position with an even load distribution onto both feet. Next, the device registered the reflection of the planta surface and the computer recorded all the parameters taken. Based on the plantogram outcomes, longitudinal feet arching was assessed according to Clarke's angle [9]. The studies have shown that it is a sensitive and practical assessment measure of the feet arching [28]. Clarke's angle standards are presented in Table 1.

Table 1. Clarke's angle reference values

Clarke's angle values	Value interpretation
< 30º	flat feet
31-41º	feet with lower longitudinal arch
42-54º	correct longitudinal feet arch
< 55º	hollow feet

Based on the plantogram outcomes, transverse feet arching was assessed as well, with the use of Wejsflog longitudinal-transverse index 'Ww'. It evaluates the ratio between foot length and width. In the case of correct longitudinal arching, the foot length-width ratio should be 3:1, values closer to '2' indicated a transverse flatfoot [39].
Additionally, the following angles were defined: α angle – hallux position, β angle – little toe position, γ angle – heel position. Values below 0º both in hallux and little toe positions indicated varus position, and values above 7º indicated valgoid position. The correct heel position should be 15-18° [39].
For the evaluation of feet load and the force of foot base reaction, an FDM-3 Zebris dynamographic platform was applied (FDM-3 dynamographic platform, Zebris Medical GmbH, Am Galgenbuhl, Germany) [7]. The student took a natural standing position on the platform. Next, the distribution of load onto the forefoot and backfoot was registered, as well as total foot load.
All measurements were always taken by the same researchers, two times.

Statistical analysis
All data was collected into the Microsoft Excel program. To characterize the collected study data, basic measures of descriptive statistics were applied: mean ($\bar{x}$), standard deviation (SD), minimal and maximal values (Min--Max), median (Me). The normality of the distribution of the analyzed features was assessed with the Shapiro–Wilk test, whereas the significance of differences between right and left foot was measured with the Student's t-test. The adopted significance level was $p < 0.05$. Statistical calculations were made using the Statistica 13.0 program (Tibco, Palo Alto, CA, USA).

Results
The analysis of the somatic parameters shows that seventeen students had the correct body mass, two were underweight, and one was overweight. Table 2 shows the arithmetic mean, standard deviation, minimal and maximal values, and the median of the studied data.

Table 2. The somatic characteristics of the studied women

Parameter	$\bar{x} \pm$ SD	Me	Min-Max
Age	21.3 ± 0.93	21.0	21.0-25.0
Body weight [kg]	58.2 ± 6.00	57.1	49.0-67.0
Body height [cm]	165.2 ± 4.92	165.5	156.0-174.0
BMI [kg/m^2]	21.2 ± 2.12	20.8	17.5-26.8

Note: BMI – body mass index, $\bar{x}$ – mean, SD – standard deviation, Min-Max – minimal and maximal values, Me – median

The students' feet arching data is presented in Table 3. Clarke's angle, which evaluates the foot arching, generally indicated the correct shape of the longitudinal arches; the differences were within 49.1º in the left foot and 51.9º in the right foot. It is worth to underline that one student had flat feet indicated by the average values, two students had hollow feet and the rest of the cases were within the applied standards. Seven students participating in the study had both feet correctly shaped. All the participating students had correctly arched both right and left feet.
The average values of the alpha angle determining the hallux position were 3.5º in the left foot and 3.9º in the right foot. Eight students had the correct hallux position, seven students were valgoid, and five varus. The average values of the beta angle determining the little toe position were within 12.8º in the left foot and 14.4º in the right foot. All the students had a valgoid position of the little toe. The average values of the gamma angle were 14.9º in the left foot and 15.5º in the right foot. The analyzed students had bilateral flatfoot (1 person), unilateral flatfoot (3 persons), correctly arched feet (7 persons), hollow feet (2 persons). Seven participants

had one hollow foot and the other one correctly arched. In each case there were no statistically significant differences between right and left foot in terms of longitudinal arching (p = 0.267), transverse arching (p = 0.273), and hallux position (p = 0.349). However, significant differences were observed between right and left foot in the case of the heel position (p = 0.05), and little toe position (p = 0.03) (Table 3).

The testing of whether the transverse and longitudinal arching influenced the position of respective foot structures resulted in finding significant changes between the transverse arching of the right foot (p = –0.534) and left foot (p = –0.516), and the heel position (gamma angle) of both feet. It is possible that in this group of students the heel position might have been influenced by the transverse feet arching.

Table 3. Average values of parameters characterizing students' feet arching

Parameter	Foot	$\bar{x} \pm SD$	Me	Min-Max	p
Clarke's angle	*right*	51.9 ± 4.98	52.1	43.8-61.5	0.267
	left	49.1 ± 8.07	49.1	34.9-69.5	
'Ww' index	*right*	2.7 ± 0.12	3.0	2.6-3.0	0.273
	left	2.7 ± 0.11	3.0	2.5-3.0	
α angle	*right*	3.9 ± 5.32	4.0	(–2.7)-17.4	0.349
	left	3.5 ± 6.45	4.4	(–7.6)-14.7	
β angle	*right*	14.4 ± 4.74	15.4	7.4-23.8	0.030
	left	12.8 ± 3.85	12.1	5.6-20.9	
γ angle	*right*	15.5 ± 1.41	15.3	13.6-17.9	0.050
	left	14.9 ± 1.49	14.8	11.6-17.8	

Note: The Student's t-test, statistical significance $p < 0.05$; 'Ww' index – Wejsflog longitudinal-transverse index, α angle – hallux position, β angle – little toe position, γ angle – heel position, $\bar{x}$ – mean, SD – standard deviation, Min-Max – minimal and maximal values, Me – median

Table 4 includes the data presenting the participants' foot loading. There were significant differences concerning the load of the forefoot (p = 0.03) and backfoot (p = 0.04) between the right and left foot in the group of researched students. The significance of the total foot loading was not calculated since it is a distribution of 100% body weight pressure onto both feet. The average pressure force of the right forefoot was 51 N/cm^2 and was higher than the left forefoot load. In addition, the load force of both feet indicated that the right foot was more frequently loaded than the left one.

More frequent loading (the median value) was observed in the forefoot of the left foot and the backfoot of the right foot. The analysis of the total load distribution onto the supporting surface shows that the right foot was more frequently loaded (60% of the participants) (Table 4).

Table 4. Average load distribution on the forefoot, backfoot, and whole supporting surface of the left and right feet

Parameter	Foot	$\bar{x} \pm SD$	Me	Min-Max	p
Forefoot	*right*	51.8 ± 15.64	51.5	17.0-74.0	0.03
	left	51.5 ± 18.68	56.5	19.0-78.0	
Backfoot	*right*	48.3 ± 15.68	48.5	26.0-83.0	0.04
	left	48.5 ± 18.68	43.5	22.0-81.0	
Total foot	*right*	52.8 ± 7.25	50.0	45.0-77.0	–
	left	47.2 ± 7.25	50.0	23.0-55.0	

Note: The Student's t-test, statistical significance $p < 0.05$; $\bar{x}$ – mean, SD – standard deviation, Min-Max – minimal and maximal values, Me – median

A detailed analysis of load distribution onto feet depending on the form of arching was conducted. As a criterion of the correct foot arching was Clarke's angle values within 42-54º.The correct longitudinal foot arching, both in the left and right feet, conditioned more frequent loading of the forefoot than the backfoot. The analysis of the whole right and left foot load shows that on average the load of both feet was correctly distributed.

In the group of participants with incorrect foot arching, there was a similarity of loading forefoot and backfoot of the right foot but in the left foot, the backfoot and forefoot were more frequently loaded. While comparing right and left foot loading, it has to be stated that in study participants with incorrect arching, the right foot was more frequently loaded.

Students with flatfeet, correctly arched feet, and hollow feet had the load distributed more onto the forefoot of both right and left feet. However, women with asymmetrical feet arching had the backfoot of both feet loaded more often than the forefoot. When it comes to the load distribution on the whole foot surface, students with flat feet and asymmetrically arched feet had the load distributed more onto the right foot whereas students with hollow feet had their left foot loaded more often. It is worth emphasizing that in the case of the correct longitudinal arching, the values of load distribution were the same for both feet.

Discussion

In our study, the differences were observed both in parameters typical for feet arching and loading. In each case, asymmetry was observed between the right and left foot. There were significant differences concerning a load placed on the forefoot and backfoot between the right and left foot. The alpha angle values were within the reference range, nonetheless, all students suffered from the little toe (beta angle) and heel valgus (gamma angle).

It was observed that Clarke's angle generally indicated the correct longitudinal arching of the feet. All women participating in the study had the correct transverse arching of both feet. Adamczyk et al. [1] reached the same conclusion. All the other participants had the correct longitudinal feet arching. Madejski et al. [23] found that among the group of 21-year-old students all had correct longitudinal feet arching. Puszczalowska-Lizis and Kwolek [30] conducted a study on 280 students aged 23 and observed that longitudinal flatfoot is not a commonly occurring defect in the academic youth. Yet, Przysada et al. [31] observed that the students had more frequently feet with lower arching and flat feet.

In our group of students, there were no statistically significant differences between right and left foot neither in terms of longitudinal arching and transverse arching nor in the hallux position. However, significant differences were observed between the feet in the heel position ($p = 0.05$) and the little toe ($p = 0.03$). More frequent loading was observed on the forefoot of the left foot and the backfoot of the right foot. The analysis of the load distribution on the whole supporting surface shows that the right foot was more frequently loaded. During the literature review, there was only one research found that differentiated the parameters of left and right foot arching in students. Mucha et al. [26] studying a group of 21-year-old students observed that the level of longitudinal feet arching was within the reference range for age and sex, whereas foot loading was not the same. It oscillated within 51.93-48.07% for the left against the right foot. The surface being loaded was smaller in the right foot, whereas the load distribution on the left and right backfoot was at a similar level [26].

The main area of interest for many researchers is the analysis of body weight and physical activity influence onto the feet arching and load distribution. The authors have shown that physical activity can cause changes both in the foot loading pattern and the longitudinal arching [3, 19, 22, 44]. Przysada et al. [31] and Adamczyk et al. [1] have proved that overweight and obese persons develop flat feet more often. All our study participants had correct body weight and, like 60% of the population, they didn't meet the minimum recommended daily physical effort [40], yet they had some differences in load distribution, which may affect their health in the future.

The limitation of the study was the small number of participants. It was a pilot study before implementing the observations to a larger student's youth group. Conducting the research in a bigger number of female students will probably minimize the error of statistical reasoning.

Future research recommendation may be the analysis of foot load performed not only in a static position but also in dynamic positions, such as walking, running, jumping. It could be worth verifying if and eventually how the measured parameters (typical for longitudinal arching and feet load) depend on the level of performed physical activity. The relation of "handedness" on the foot load distribution and foot arches is also worth future research.

Conclusions

Concluding, it seems essential to conduct research involving the factors causing changes in foot arching, diseases, and their structure's deformations. However, we analyzed young healthy students, who had correct longitudinal and transverse feet arching and hallux and heel position, they overloaded the forefoot of the left foot and the backfoot of the right foot and all suffered from the little toe valgus. These conditions, when untreated, will probably affect their feet' health in the future.

Conflicts of Interest

The authors declare no conflict of interest.

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