The Influence of BMI Value and the Percentage of Fat Tissue on the Curvature of the Foot Longitudinal Arch among Students of University of Physical Education in Kraków

Wpływ wartości wskaźnika BMI oraz procentowej zawartości tkanki tłuszczowej na wysklepienie podłużne stóp wśród studentów AWF w Krakowie

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Streszczenie

Introduction: The foot is an essential element of the kinetic system. By performing the supporting function, it maintains the correct body posture, but above all it is used while walking. Feet are vulnerable to all the changes that occur in human environment. The civilisation changes are particularly harmful to the locomotor system.

Materials and methods: The research was conducted in the academic year 2014/2015 among the second year Physiotherapy and Physical Education students in the University of Physical Education in Kraków. The total of 93 students took part in the research (48 female and 45 male). The average age of the subjects was 21 years. In order to assess the curvature of the foot longitudinal arch a podoscope was used, whereas the Tanita BC-418 scales were applied to define the BMI value and calculate the percentage of body fat tissue.

Results: A vast majority of the subjects (70.9%) had a normal type of foot longitudinal arch. Higher longitudinal arch occurred more frequently among women than men, the normal type was less frequent. The BMI level was also within the norm among the majority of the students (79.6%). Overweight was more frequent among men than women. Both men and women with the correct BMI value in their majority had normal curvatures of both feet longitudinal arches. The highest percentage (75%) of the regular right foot longitudinal arch was recorded among women with low body fat deposition. In the case of the left foot the percentage was 68.8%. All the men with low fat deposition obtained normal values of the longitudinal arch curvature for both feet.

Conclusions: The subjects most frequently had a regular curvature of foot longitudinal arch. No significant influence of the percentage of fat tissue and BMI value on the Clarke's angle was recorded.

Keywords: foot arch, BMI, fat tissue, students

Introduction

The foot is an essential element of the kinetic system. By performing the supporting function, it maintains the correct body posture, but above all it is used while walking [1]. Feet are vulnerable to all the changes that occur in human environment. The civilisation changes are particularly harmful to the locomotor system. This mainly applies to the lower limbs. Any changes or deformations (defects) within the feet cause disturbance of motion abilities. According to Malina [2], one of the most common foot defects is flat feet. Obesity, which is considered the scourge of our times, has a direct impact on the biomechanics of the foot. As results from the research by Przysada et al., the values of the indicators characterising the structure of the feet in the case of overweight people significantly exceed the accepted norms in comparison with people with normal body weight [3].

The foot has a very complex anatomical structure, conditioned by its supporting and bearing function and functions as a shock absorber [2]. The passive element in the foot structure, which is the skeletal system, has a specific external and internal architecture. The external architecture is made of longitudinal and transverse arches, which are subject to stretching under pressure [2]. On the other hand, internal architecture includes a kind of

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scaffolding, which Gauthier called the dynamic triangle [4].

The efficiency of the internal foot stabilisation mechanism depends mainly on the content of connective tissue elements [5]. Basmajian and Stecko's research confirmed the above-mentioned thesis. The authors proved that people with normal foot structure, in standing position, active foot stabilisers, i.e. muscles, do not show electromyographic activity. The exceptions are the soleus and triceps surae muscles of the calf [6]. The muscles mainly control the so-called subtalar complex that allows movement in three planes. This role is mainly played by supinators and pronators [5]. A correctly constructed foot rests on the ground on three support points: heads No. I and V of the metatarsal bones and calcaneal tuber.

One of the most common foot defects is flat feet [2, 7]. In the course of this defect, three periods are usually distinguished, related to the nature of the changes taking place:

- muscular insufficiency, characterised by lowering of the arches of the foot only when it is weighted,
- ligament insufficiency, in which the changes are much more evident, even though when there is less weight, the foot can take the correct shape,
- fixed changes, characterised by permanent structural changes that are not susceptible to correction [8].

Sometimes the fourth period is marked by significant distortion of the feet [9].

At this point, it should be mentioned that the longitudinally flat foot is characterised by a lowered position of the longitudinal arches, a lopsided alignment of the calcaneus, and also significant pain [10]. The weakening of the spring ligament involves the slipping of the head of the talus, which also pulls the navicular. This results in abduction of the forefoot and leads to the flattening of the dynamic arc at the point of greatest weight [11].

The aim of the research was to determine the impact of the BMI value and body fat percentage on longitudinal arch of feet among students of the University of Physical Education in Kraków.

Empirical research was intended to provide answers to the following specific questions:

1. What was the most common type of longitudinal arch of the students participating in the research?
2. What was the level of the BMI values?
3. Did the BMI and body fat percentage affect the longitudinal arch of the subjects' feet?
4. To what extent were the variables studied varied by sex?

Materials and methods

The research was carried out in 2014. 93 students (including 48 female and 45 male) who are in their 2nd year of Physiotherapy and Physical Education studies at the University of Physical Education in Kraków were its participants. All students agreed to participate in the research. The average age of participants of the research was 21 years.

A podoscope was used to assess the longitudinal arch of the feet. This device is equipped with a 2D scanner with built-in sensors and a portable computer with specialised software analysing the image from the scanner. Each student was examined with a podoscope barefoot, in a standing position. Both feet were examined at the same time. This examination allowed the value of Clarke's angle in the case of both feet to be determined (Table 1).

The average body height of the examined men was 179.5 cm, and women 167.4 cm. The average body weight of students was 77.4 kg, and of students 60.1 kg (Table 2).

Table 1.

Norms for Clarke's angle

Angle values	Interpretation of results
x - 30°	Pathological arch of the foot requiring treatment
31° - 41°	Foot with lowered arch
42° - 54°	Foot with normal arch
55° - x	Hollowed out foot

The body height was measured using a Martin type anthropometer with an accuracy of 0.1 cm, and the Tanita *BC-418* scales was used to determine the BMI and to calculate the percentage of body fat. The scales were also used to measure student body weight with an accuracy up to 100 g. Students participated in the examination via Tanita scales in the morning, on an empty stomach, barefoot and in sports underwear.

The measurement of the body's percentage of fat was conducted with the use of an electrical signal that runs through the whole body from one foot to the other. Muscles largely consist of water while fat does not contain it. Thus, the difference in the time the electric impulse flows through the tissues determines the degree of fat cover. The longer the pulse flow time, the greater the fat content (tanita.com).

Table 2.

Numerical data on average values of somatic features broken down by sex

Somatic features	Sex		In total
	F	M	
Body height (cm) - ($\overline{X}$)	167.4	179.5	173.3
Body weight (kg) - ($\overline{X}$)	60.1	77.4	68.5

The following statistical techniques were used in the research:

1. For statistical description of qualitative data: tables of numbers and percentages.
2. For statistical description of qualitative data: *chi*-square statistical significance test. Statistically significant correlations: at level $p < 0.05$.

Results

A vast majority of the subjects (70.9%) had a normal type of right foot arch. Higher longitudinal arch occurred relatively more frequently among women than men, the normal type was less frequent (Table 3). In this case, sexual diversity was statistically significant.

correct arch was observed in as much as 83.3% of respondents (Table 7). In contrast, none of the subjects had a higher left foot arch. However, 16.7% of underweight women participating in the research had lowered left foot arch.

Most women with the correct BMI had arches of both feet normal (64.1% – on the right, 71.8% – on the left). In 28.2% of respondents, elevated Clarke's angle values were observed for the right foot, while for the left only in 15.4%.

On the other hand, overweight students found interesting relationships between the arch of the right and left foot. The right foot was normally arched in 66.7% of the subjects, and 33.3% in the lowered. Exactly the opposite interest was recorded in the case of the left foot, 33.3% and 66.7%, respectively.

Table 3.

Distribution of types of longitudinal arch of the right foot

Type of longitudinal arch	Sex				In total		Analysis of statistical significance
	F		M				
	N	%	N	%	N	%	
Flat	0	0.0	2	4.4	2	2.2	$chi^2(3) = 9.58$ $p = 0.023$
Lower arch	4	8.3	4	8.9	8	8.6	
Normal	30	62.5	36	80	66	70.9	
Higher arch	14	29.2	3	6.7	17	18.3	
In total	48	100	45	100	93	100	

Regarding the left foot, as above, the majority of subjects (72%) had a normal type of longitudinal arch. However, the differences between men and women were insignificant and statistically insignificant (Table 4).

The research results presented below showed that the vast majority of students (79.6%) examined had the BMI level within the norm (Table 5). Overweight was more common in men than women, whilst underweight – conversely. The correct BMI value was found in more women (81.3%) than men (77.8%). The differences in results between men and women turned out to be statistically significant.

The research has shown that 50% of underweight women had a right longitudinal arch of the right foot (Table 6). The remaining 50% had higher arch of such foot. In the case of the left foot,

Men with the BMI in the norm had mostly correct arch in their feet (right – 80%, left – 71.4%). It was noted that every fifth student examined had reduced values of Clarke's angle but only in the left foot. In the right, the percentages were much lower (8.6%). As much as 80% overweight respondents had both feet properly hollowed out. The relationship between the BMI and arching proved to be statistically insignificant (Tables 8 and 9).

The highest percentage (75%) of the regular right foot longitudinal arch was recorded among women with low body fat deposition (Table 10). In the case of the left foot the percentage was 68.8% (Table 11). Higher longitudinal arch of the right foot was found in 25% of participants from this group. Reduced arch in this fat deposition range was only in the left foot (18.8%). In the group of women with normal fat deposition, as much as

Table 4.

Distribution of types of longitudinal arch of the left foot

Type of longitudinal arch	Sex				In total		Analysis of statistical significance
	F		M				
	N	%	N	%	N	%	
Flat	1	2.1	0	0.0	1	1.1	$chi^2(3) = 1.39$ $p = 0.709$
Lower arch	7	14.6	8	17.8	15	16.1	
Normal	34	70.8	33	73.3	67	72	
Higher arch	6	12.5	4	8.9	10	10.8	
In total	48	100	45	100	93	100	

Table 5.

BMI level

BMI	Sex				In total		Analysis of statistical significance
	F		M				
	N	%	N	%	N	%	
Underweight	6	12.5	0	0.0	6	6.5	$chi^2(2) = 9.90$ $p = 0.007$
Norm	39	81.3	35	77.8	74	79.6	
Overweight	3	6.2	10	22.2	13	13.9	
In total	48	100	45	100	93	100	

Table 6.

BMI and longitudinal arch of the right foot in women

Type of longitudinal arch *(right foot)*	BMI						In total		Analysis of statistical significance
	Underweight		Norm		Overweight				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	0	0.0	0	0.0	0	0.0	$chi^2(4) = 4.72$ $p = 0.317$
Lower arch	0	0.0	3	7.7	1	33.3	4	8.3	
Normal	3	50	25	64.1	2	66.7	30	62.5	
Higher arch	3	50	11	28.2	0	0.0	14	29.2	
In total	6	100	39	100	3	100	48	100	

Table 7.

BMI and longitudinal arch of the left foot in women

Type of longitudinal arch *(left foot)*	BMI						In total		Analysis of statistical significance
	Underweight		Norm		Overweight				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	1	2.6	0	0.0	1	2.1	$chi^2(6) = 8.45$ $p = 0.207$
Lower arch	1	16.7	4	10.2	2	66.7	7	14.6	
Normal	5	83.3	28	71.8	1	33.3	34	70.8	
Higher arch	0	0.0	6	15.4	0	0.0	6	12.5	
In total	6	100	39	100	3	100	48	100	

72.4% had proper arch in the left foot (Table 11). For the right foot the percentage was lower and amounted to 55.2%. It should be noted that as many as 34.5% of the students participating in the research had higher right foot arch. Women with a high body fat percentage mostly had proper arch of both feet (66.7% each). In the case of other women (33.3%), reduced values of Clarke's angle were observed in both the right and left foot.

Table 8.

BMI and longitudinal arch of the right foot in men

Type of longitudinal arch *(right foot)*	BMI						In total		Analysis of statistical significance
	Underweight		Norm		Overweight				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	1	2.8	1	10	2	4.4	$chi^2(3) = 1.77$ $p = 0.622$
Lower arch	0	0.0	3	8.6	1	10	4	8.9	
Normal	0	0.0	28	80	8	80	36	80	
Higher arch	0	0.0	3	8.6	0	0.0	3	6.7	
In total	0	0.0	35	100	10	100	45	100	

Table 9.

BMI and longitudinal arch of the left foot in men

TType of longitudinal arch *(left foot)*	BMI						In total		Analysis of statistical significance
	Underweight		Norm		Overweight				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	0	0.0	0	0.0	0	0.0	$chi^2(2) = 0.53$ $p = 0.766$
Lower arch	0	0.0	7	20	1	10	8	17.8	
Normal	0	0.0	25	71.4	8	80	33	73.3	
Higher arch	0	0.0	3	8.6	1	10	4	8.9	
In total	0	0.0	35	100	10	100	45	100	

Table 10.

FAT% and longitudinal arch of the right foot in women

Type of longitudinal arch *(right foot)*	FAT %						In total		Analysis of statistical significance
	Low		Norm		High				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	0	0.0	0	0.0	0	0.0	$chi^2(4) = 5.63$ $p = 0.228$
Lower arch	0	0.0	3	10.3	1	33.3	4	8.3	
Normal	12	75	16	55.2	2	66.7	30	62.5	
Higher arch	4	25	10	34.5	0	0.00	14	29.2	
In total	16	100	29	100	3	100	48	100	

Table 11.

FAT% and longitudinal arch of the left foot in women

Typ wysklepienia podłużnego *(stopa lewa)*	FAT %						In total		Analysis of statistical significance
	Low		Norm		High				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	1	3.5	0	0.0	1	2.1	$chi^2(6) = 2.37$ $p = 0.883$
Lower arch	3	18.8	3	10.3	1	33.3	7	14.6	
Normal	11	68.7	21	72.4	2	66.7	34	70.8	
Higher arch	2	12.5	4	13.8	0	0.0	6	12.5	
In total	16	100	29	100	3	100	48	100	

All men with low body fat (100%) obtained the correct longitudinal arch of both feet (Tables 12 and 13). The feet of the students with normal percentage of fat had mostly correct longitudinal arch (right – 79.5%, left – 71.8%). Every fifth respondent had a lowered arch of the left foot. Men with a high body fat percentage, mostly (75%) had both feet properly arched. The re-

Table 12.

FAT% and longitudinal arch of the right foot in men

Type of longitudinal arch *(right foot)*	FAT %						In total		Analysis of statistical significance
	Low		Norm		High				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	2	5.1	0	0.0	2	4.4	$chi^2(6) = 2.29$ $p = 0.891$
Lower arch	0	0.0	3	7.7	1	25	4	8.9	
Normal	2	100	31	79.5	3	75	36	80	
Higher arch	0	0.0	3	7.7	0	0.0	3	6.7	
In total	2	100	39	100	4	100	45	100	

Table 13.

FAT% and longitudinal arch of the left foot in men

Type of longitudinal arch *(left foot)*	FAT %						In total		Analysis of statistical significance
	Low		Norm		High				
	N	%	N	%	N	%	N	%	
Flat	0	0.0	0	0.0	0	0.0	0	0.0	$chi^2(4) = 2.85$ $p = 0.584$
Lower arch	0	0.0	8	20.5	0	0.0	8	17.8	
Normal	2	100	28	71.8	3	75	33	73.3	
Higher arch	0	0.0	3	7.7	1	25	4	8.9	
In total	2	100	39	100	4	100	45	100	

maining 25% had lower right foot arch or higher left foot arch. The correlation between FAT% and longitudinal arch of the feet was statistically insignificant for both women and men.

Discussion

The foot, due to its complex structure, is the basic support element of the human locomotor system. Its shock-absorbing function enables a fully economical bipedal locomotion. However, due to their complex structure, the feet are exposed to various external factors that can lead to their deformation.

It is believed that flatfoot is one of the most common foot defects in the case of children and adolescents [7]. However, according to Puszczałowska-Lizis [12], this defect is not common at all among academic youth. The research performed by Walicka-Cupryś et al. [13] led to similar conclusions which indicate that flat foot occurred in every fifth participant of the experiment. In the research conducted by Przysada et al. on students of Physiotherapy at the University of Rzeszów, the results were very similar [3]. According to own research, the percentage of students of both sexes with lowered longitudinal arch of the feet did not exceed 1/5 of the subjects.

Research on the value of the BMI, determining the weight-growth ratio, was conducted with participation of many students by many authors. In the research by Wołos et al. [14], it was revealed that over one in ten students were found to be overweight or obese, much more often in the case of men. According to Zuzda et al. [15], every fifth student of the Białystok University of Technology and the Białystok School of Economics is overweight or obese. Among the female students participating in the study, only every twentieth was overweight or obese. However, women were more often underweight. In own research, the correct BMI values were noted in the majority of subjects. Overweight was more common in men, while underweight was more common in women. A similar trend was observed taking into account the percentage of body fat.

In the study of Jankowicz-Szymańska [16], it was shown that the longitudinal arch of the feet was lower in people with the higher BMI value. The research by Przysada et al. [3] led to similar conclusions, according to which flatfoot was observed in both people with normal body weight and those who are overweight. However, this defect is much more common in people with elevated BMI. The values of indicators characterising the structure of the feet of overweight people were far more than normal compared to students with normal weight. Mosór and Kromka-Szyder [17] suggest that a high body mass index can lead to the formation of a flat foot, but the norms of foot structure indexes should be adjusted to specific age ranges. This would allow for more accurate research. As a result of the above research, body weight significantly affects the structure of the feet.

The research conducted on populations from abroad also lead to similar conclusions. Shibuya et al. [18] believe that the BMI values have a significant impact on the formation of flat

feet among Americans. On the other hand, research conducted by Abdel-Fattah et al. [19] on a group of Saudi recruits prove that flat foot more than twice as often in people who are overweight or obese. The results of the research from other parts of the world are similar [20, 21].

An interesting experiment was conducted by Hills et al. [22], in which the effect of own weight load and added half of the real body weight on the indicators characterising the structure of the feet was examined. 70 adult men and women were examined. They were divided into two groups: the members of the first one were obese and the other had normal body weight. The conclusions were clear. In the group of people with obesity, foot building parameters were more abnormal than those in the control group. This was particularly evident from the lowering of the longitudinal arch of the feet. Convergent results were obtained two years later in the research of Tsung et al. [23].

However, many examples of the research show that there is no correlation between the weight-increase ratio, which the BMI is, and the values of the indicators characterising the structure of feet [24]. In the research conducted by Puszczałowska-Lizis [25], a significant relationship was observed only between body weight and longitudinal arch of the feet. The BMI did not significantly affect the parameters of the foot structure. In 2014, in an experiment carried out by the author cited above, an attempt was made to check whether the longitudinal arch of the feet depends on the slenderness index. However, also in this case, no significant correlation was found between these two indexes [26].

Based on our own research, carried out among the students of the University of Physical Education in Kraków, it can be stated that the BMI values do not affect the longitudinal arch of the feet, both in men and women. Also, no significant relationship was observed between FAT% and the values of Clarke's angle.

In order to more accurately verify the research concept implemented in this article, it would be advisable to carry out such research on a larger population and in different environments as well as age groups.

Conclusions

Based on the results obtained from the conducted research, the following conclusions were formulated:

1. The most frequently observed type of longitudinal arch of the examined students was the correct arch.
2. The percentage of body fat had no significant effect on the values of the Clarke's angular index in the subjects.
3. There was no relationship between the BMI and longitudinal arch of the feet in the group participating in the research.
4. There were slight differences in the results of the variables studied between men and women.

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Streszczenie

Wstęp: Stopa jest istotnym elementem układu kinetycznego. Pełniąc funkcję podporową utrzymuje prawidłową postawę ciała, lecz przede wszystkim wykorzystywana jest podczas chodu. Stopy narażone są na wszelkie zmiany, które zachodzą w środowisku człowieka. Szczególnie niekorzystnie na układ ruchu wpływają przemiany cywilizacyjne.

Materiał i metody: Badania przeprowadzono w roku akademickim 2014/2015 wśród studentów II roku fizjoterapii i wychowania fizycznego, Akademii Wychowania Fizycznego w Krakowie. Łącznie przebadano 93 osoby (w tym 48 kobiet i 45 mężczyzn). Średnia wieku badanych wyniosła 21 lat. Do oceny wysklepienia podłużnego stóp zastosowano podoskop, a do określenia wartości wskaźnika BMI oraz obliczenia procentowej zawartości tkanki tłuszczowej w organizmie zastosowano wagą Tanita *BC-418*.

Wyniki: Zdecydowana większość badanych (70,9%) charakteryzowała się normalnym typem wysklepienia stóp. U kobiet częściej niż u mężczyzn występowało podwyższone wysklepienie, a rzadziej typ normalny. Także poziom wskaźnika BMI u większości studentów (79,6%) mieścił się w normie. Nadwaga występowała częściej u mężczyzn niż kobiet. Zarówno mężczyźni jak i kobiety z prawidłową wartością wskaźnika BMI w większości mieli wysklepienie obu stóp w normie. Najwyższy odsetek (75%) prawidłowego podłużnego wysklepienia stopy prawej odnotowano u kobiet z niskim otłuszczeniem ciała. Dla stopy lewej odsetek ten wyniósł 68,8%. Wszyscy mężczyźni o niskim otłuszczeniu uzyskali prawidłowe wartości wysklepienia podłużnego dla obu stóp.

Wnioski: Wśród badanych najczęściej występowało prawidłowe wysklepienie stóp. Nie odnotowano istotnego wpływu procentowej zawartość tkanki tłuszczowej i wskaźnika BMI na wartości wskaźnika kątowego Clarke'a..

Słowa kluczowe: wysklepienie stóp, BMI, tkanka tłuszczowa, studenci