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Assessment of correctness of foot shape and correlations with anthropometric indicators and the centre of body gravity in preschool children

Ocena prawidłowości kształtu stóp i korelacji ze wskaźnikami antropometrycznymi i środkiem ciężkości ciała u dzieci w wieku przedszkolnym

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Abstract

Introduction and objective: Preschool and early school age plays an important role in shaping the foot and posture in children. The aims of the study were to assess the correctness of foot shape in preschool children and to determine possible correlations with age, gender, waist-to-height ratio (WHtR) and body mass index (BMI), and the centre of body gravity. **Materials and methods:** A study of feet and anthropometric parameters was carried out in children aged 4–6 years. Foot examination was performed using a podoscope and a strain gauge platform, while body weight was assessed using a Tanita device. Body weight, height, Clarke's angle, centre of gravity, and WHtR were analysed. **Results:** There were no statistically significant differences in the value of the Clarke's angle between the left and right feet in both girls and boys, regardless of the age group. The BMI did not correlate statistically with the results of the Clarke's angle measurements, both for all the subjects and taking into account their age. The BMI value was statistically significantly correlated with the centre of body gravity due to the correct WHtR. **Conclusions:** The study confirmed that the longitudinal arch of the foot shows no clear sexual dimorphism. The BMI and Clarke's angle were not dependent on each other in the study group. The study showed no changes in the centre of body gravity in relation to the children's body shape.

Keywords: children, body posture defects, Clarke's angle, anthropometric indicators, centre of body gravity

Streszczenie

Wprowadzenie i cel: Wiek przedszkolny i wczesnoszkolny odgrywa ważną rolę w kształtowaniu stopy i postawy u dzieci. Celem pracy była ocena prawidłowości kształtu stóp dzieci w wieku przedszkolnym oraz określenie możliwych korelacji z wiekiem, płcią, wskaźnikami talia–wzrost (*waist-to-height ratio*, WHtR) i masy ciała (*body mass index*, BMI) oraz środkiem ciężkości ciała. **Materiał i metody:** Badania stóp i parametrów antropometrycznych przeprowadzono u dzieci w wieku 4–6 lat. Wykonano badanie stóp za pomocą podoskopu i platformy tensometrycznej, a masę ciała oceniono za pomocą urządzenia Tanita. Analizowano masę ciała, wzrost, kąt Clarke'a, środek ciężkości i WhtR. **Wyniki:** Nie stwierdzono istotnych statystycznie różnic w wartości kąta Clarke'a pomiędzy stopą lewą i prawą u dziewcząt i chłopców w poszczególnych grupach wiekowych. Wskaźnik BMI nie korelował statystycznie z wynikami kąta Clarke'a, zarówno w odniesieniu do ogółu badanych, jak i z uwzględnieniem ich wieku. Wartość wskaźnika BMI była statystycznie istotnie skorelowana ze środkiem ciężkości ciała dzięki prawidłowemu wskaźnikowi WHtR. **Wnioski:** Badania potwierdziły, że wysklepienie podłużne stopy nie wykazuje wyraźnego dymorfizmu płciowego. BMI i kąt Clarke'a nie są od siebie zależne w badanej grupie. W badaniach nie wykazano zmian środka ciężkości ciała w stosunku do budowy ciała dziecka.

Słowa kluczowe: dzieci, wady postawy ciała, kąt Clarke'a, wskaźniki antropometryczne, środek ciężkości ciała

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INTRODUCTION

Flat foot and flat valgus foot are among the most commonly reported reasons for orthopaedic consultation, and can persist until the age of 8 in view of appropriate ligamentous laxity, increased fat tissue, and immature neuromuscular control[1]. Flat foot is a typical phenomenon in children's development although it is still a reason for medical consultations[2]. It is observed that with age the prevalence of flat feet is reduced[3].

Clinically, it is recognised that all normally developing children are born with flexible flat feet and in the first decade of life the medial longitudinal arch develops gradually. The maturation of the medial longitudinal arch continues after the age of six, with a slower rate until the age of 10[3].

Preschool and early school age is considered the most important period in foot development. Early intervention and therapy can help with better treatment effects and contributes to preventing pain because adults with flexible flat feet report significantly increased levels of back and lower limb pain[1,2]. Flat feet can cause pain in the lower limbs and reduce their normal functioning. According to the study by Hell et al., pain appears in less than 2% of paediatric patients[4].

Pain may cause aversion to physical activity and impair the quality of life[1].

Prevalence estimates of flat feet reported in the literature, whilst inconsistent, suggests that the condition is more frequently seen in younger children, males, and individuals who are overweight or obese[2].

In this study, we tried to evaluate the development of foot in preschool children. The aims of the study were to assess foot shape, and determine possible correlations with age, gender, waist-to-height ratio (WHtR), body mass index (BMI), and the centre of body gravity and body posture.

MATERIALS AND METHODS

The study of feet and anthropometric parameters was conducted in 2019 in preschool children (4–6 years old) attending a private kindergarten in Bydgoszcz. A total of 77 children (36 girls – 46.8%, 41 boys – 53.2%) participated in the study. The study group consisted of 22 four-year-old (28.6%), 29 five-year-old (37.7%), and 26 six-year-old children (33.8%). The children were recruited for the study after explaining the purpose of the study and obtaining the consent of parents and legal guardians. The consent of the kindergarten's headmaster was also obtained before the study started.

The criteria of study exclusion were the following: age not in the range of 4–6 years old, neurological diseases, and lack of child's consent to participate. Finally, the parents of the children received detailed results, a description, and recommendations.

The study was performed by using the podoscope Podologic Podoscan 2D FootCAD and the tensometric platform Platforma FreeMED BASE with the FreeSTEP software. The use of the podoscope enabled the assessment of the plantar surface of the foot and the degree of arch. The Clarke's angle was measured using the podoscope. The Clarke's angle was defined as the angle between the straight line parallel to the medial edge of the foot and the straight line largest recess. The statistic analysis with the use of the platform, which was connected to a computer, allowed testing the pressure of the feet on the ground, and observation of the movement of the body's centre of gravity and balance testing. The study was done when the children were in the standing position, motionless. Throughout the test, the atmosphere was calm and the children were not hurried.

In order to assess body weight, the children participating in the study were weighed using the Tanita MC-780 MA device with an integrated 4-electrode, 4-limb system. During the measurement, an electrical pulse of low intensity (90 μA) was flowing through the body. The test was performed three hours after a meal. During the analysis, the children in the study group were in their underwear. Body height [cm] and waist circumference [cm] were measured with the anthropometric tape Baseline 150 cm, with an accuracy of 0.5 cm.

To objectively assess the nutritional status of children, the BMI results were compared to age-appropriate percentile grids. The study used the percentile grids of children and adolescents from the national OLA and OLAF studies, and the percentile grids of the World Health Organization (WHO). The WHtR was calculated on the basis of the ratio of the waist circumference to the child's height.

The study was approved by the Bioethical Committee of the Nicolaus Copernicus University in Toruń, Ludwik Rydygier Collegium Medicum in Bydgoszcz (KB No. 402/2018).

The obtained research results were subjected to a statistical analysis in order to investigate the relationship between individual statistical variables. The study relied on the non-parametric *U* Mann–Whitney test, the non-parametric Wilcoxon test, and the non-parametric Kruskal–Wallis rank test. All calculations, figures and tables were made in Statistica 10.0 and Microsoft Excel using their standard functions. The statistically significant level was recognised as $p \leq 0.05$.

RESULTS

In the study, the largest group comprised children aged five years old (37.7%), and the least numerous group was that of four-year-olds (28.6%). Boys were more numerous (53.2%). Taking into account the children's age, in the groups of five- and six-year-olds boys predominated, while in the group of four-year-olds there were more girls than boys.

Somatics characteristics – body weight, height, and BMI

Girls had a higher body weight – 21.26 kg, while the average weight in the group of boys was 21.24 kg. The body weight was higher only in the group of four-year-olds boys. A higher body height was determined in boys – 116.15 cm, while the average height among girls was 113.72 cm. A higher

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Parameter				Body weight			Height			Body mass index		
Age	Gender	*n*	%	Average	*SD*	*p*	Average	*SD*	*p*	Average	*SD*	*p*
4 years old	Girls	13	59.1	18.47	2.87	0.611	106.27	5.49	0.170	16.28	1.50	0.738
	Boys	9	40.9	18.86	2.35		109.44	5.58		15.75	1.60	
5 years old	Girls	12	41.4	21.77	3.76	0.773	115.13	4.32	0.790	16.35	2.16	0.642
	Boys	17	58.6	21.02	3.11		115.26	4.71		15.76	1.52	
6 years old	Girls	11	42.3	24.00	4.28	0.815	121.00	6.43	0.958	16.33	1.94	0.406
	Boys	15	57.7	22.92	2.84		121.17	5.33		15.58	1.39	
Total	Girls	36	46.75	21.26	4.22	0.721	113.72	8.12	0.153	16.32	1.82	0.189
	Boys	41	53.25	21.24	3.19		116.15	6.70		15.69	1.46	
	Total	77	100	21.25	3.68		115.01	7.45		15.99	1.66	

Tab. 1. Body weight, height and BMI by age and gender

Gender		Girls			Boys			Total		*p*
Age	Interpretation of WHtR	Number	%	Mean Minimum Maximum Median	Number	%	Mean Minimum Maximum Median	Number	%	
4 years old	Correct	8	10.4	0.50 0.44	8	10.4	0.48 0.42	16	20.8	0.180
	Incorrect	5	6.5	0.56 0.50	1	1.3	0.52 0.49	6	7.8	
5 years old	Correct	9	11.7	0.50 0.45	15	19.5	0.47 0.43	24	31.2	0.181
	Incorrect	3	3.9	0.61 0.49	1	1.3	0.52 0.47	4	5.2	
6 years old	Correct	9	11.7	0.46 0.42	14	18.2	0.46 0.43	23	29.9	0.399
	Incorrect	2	2.6	0.53 0.47	1	1.3	0.51 0.45	3	3.9	
Total		36	46.8	0.49 0.42 0.56 0.49	40	51.9	0.47 0.42 0.52 0.48	76	98.7	0.020

Tab. 2. Interpretation of the WHtR

BMI was found in girls – 16.32, with the average of 15.69 in the group of boys. The differences in body weight, body height, and BMI were not statistically significant for all children and in the age groups (Tab. 1).

BMI analysis with the use of percentile grids from the OLA and OLAF studies and from the WHO studies is difficult. According to the interpretation of BMI results based on the WHO percentile grids, one child was underweight, 51 had normal weight, 18 were overweight, and seven had obesity. However, according to the interpretation performed with the OLA and OLAF percentile grids, six children were underweight, 56 children had normal weight, 14 were overweight and one child was obese.

WHtR

The majority of children had correct WHtR – 63 children (81.8%). The difference between girls and boys was statistically significant ($p = 0.020$), while the WHtR differences in the group of four-year-olds, five-year-olds, and six-year-olds were not statistically significant. A higher mean WHtR was recorded in the group of girls – 0.49, with an average of 0.47 in the group of boys. The difference was statistically significant ($p = 0.044$) (Tab. 2).

Clarke's angle

The differences between girls and boys in the group of four–six-year-olds in left foot analysis were not statistically significant. In the group of four–six-year-olds, the majority of children had normal left feet and the shortest children had hollow foot (Fig. 1).

The difference between girls and boys in right foot analysis was statistically significant only in the group of six-year-olds ($p = 0.041$). In the group of four- and six-year-olds, the majority had normal feet. In the group of five-year-olds, hollow foot predominated – 11 children (14.3%), while the remaining children had normal feet or flat feet – 9 children each (11.7% in all groups) (Fig. 2).

The longitudinal arch results were comparable. The difference in the mean value between the age groups among four-year-olds was 1°, and in the group of six-year-olds it was 1.4°. In the group of five-year-olds it was the highest – 8.6°. Tab. 3 shows the mean, median, minimal and maximal values of the Clarke's angle in the left and right feet.

No statistically significant differences were recorded between the left and right feet for girls and boys in different age groups according to the Wilcoxon test. In the left and right feet, there were no statistically significant differences

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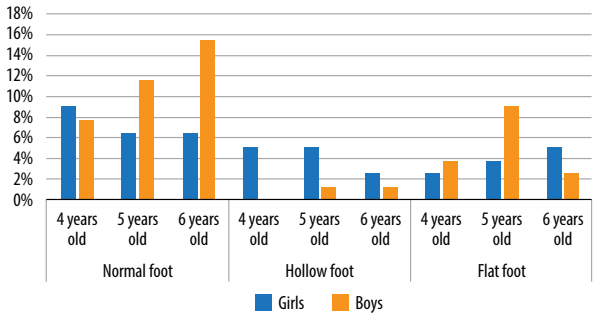

Fig. 1. Interpretation of the Clarke's angle in the left foot

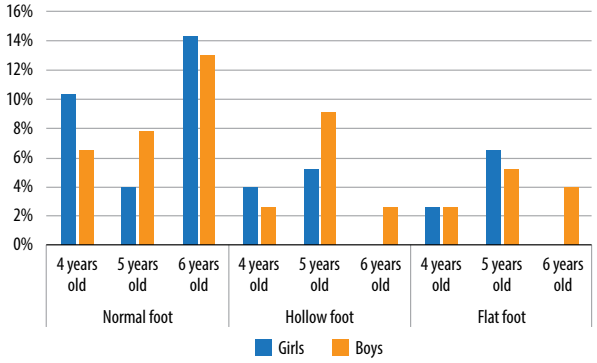

Fig. 2. Interpretation of the Clarke's angle in the right foot

between girls and boys in different age groups. According to the Mann–Whitney *U* test, there were no statistically significant differences between the age groups in the left and right feet. The same applied to the gender groups.

Correlation of BMI and Clarke's angle results in age and gender groups

The BMI values were not statistically significant in correlation with the results of the Clarke's angle in the left and right feet for all the subjects in the gender groups and in the age groups without looking at the interpretations from the OLA and OLAF studies or the WHO studies.

The results of the centre of body gravity

The analysis of BMI results with the use of OLA/OLAF percentile grids showed that they remained in a statistically significant low correlation ($p = 0.016$) with the results of the centre of gravity for the whole group and in mean correlation in the group of correct WHtR. BMI analysis with the WHO percentile girds showed that BMI did not statistically correlate with the results of measurements of the centre of gravity ($p = 0.173$).

In the group of correct WHtR, the centre of gravity tilted backward in 42.9% of children; this was especially visible in the group of the children with normal weight (the centre of gravity tilted forward in 14.3% or backward in 33.8%) and also in the group with excessive weight the centre of gravity tilted backward in 7.8%. The centre of gravity in children with incorrect WHtR generally tilted backwards.

Assessment of body posture

In the group of four–six-year-olds, the majority of children had good posture (59 children), while 18 children had abnormal posture. Analysing the correlation, there was no statistically significant relationship between good and abnormal posture and the centre of body gravity.

DISCUSSION

The analysis of the occurrence of foot defects in children of all ages is in the area of interest of many researchers, being a serious medical and social problem. The medial longitudinal arch develops gradually over the first decade of life. The development of a child's foot is dependent on age and it evolves over time. In is clinically recognised that children achieve adult foot posture between the ages of seven and 10[3].

The most popular and also the simplest method of assessing the condition of the longitudinal arch of the foot is to determine the Clarke's angle, which can be a prognostic

Age	Gender	Feet	Number	Mean	Standard deviation	Min	Max	Q25	Median	Q75
4 years old	Girls	Left	13	49.9	11.10	40.0	80.0	42.0	45.0	55.0
		Right	13	46.3	8.23	34.0	63.0	43.0	44.0	51.0
	Boys	Left	9	46.2	6.69	37.0	53.0	40.0	49.0	52.0
		Right	9	49.0	10.07	37.0	68.0	44.0	47.0	54.0
5 years old	Girls	Left	12	45.3	17.06	6.0	63.0	41.0	47.5	58.0
		Right	12	48.6	15.78	15.0	68.0	38.0	51.5	60.0
	Boys	Left	17	41.4	10.93	17.0	58.0	38.0	45.0	49.0
		Right	17	43.9	13.32	20.0	62.0	37.0	44.0	51.0
6 years old	Girls	Left	11	45.6	5.90	39.0	56.0	41.0	45.0	50.0
		Right	11	47.4	3.35	42.0	54.0	45.0	48.0	49.0
	Boys	Left	15	47.1	6.78	32.0	58.0	43.0	47.0	53.0
		Right	15	48.3	4.86	40.0	55.0	44.0	49.0	52.0

Tab. 3. Results of the Clarke's angle measurement in the left and right feet by age and gender

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factor in foot development. In our own study, the Clarke's angle was assessed, and the results were compared with the findings reported by other authors. In the study, the Clarke's angle was found to be correct in the boys of all age groups. Similarly, in the study by Klimczak et al., no significant statistical difference was observed when it comes to the Clarke's angle in four- and five-year-old boys. However, according to the study by Klimczak et al., based on the mean value of the Clarke's angle, the feet of four-year-old boys had reduced arching, which was not confirmed in our own study. The mean values of the Clarke's angle in five-year-old boys in the right and left feet (41.8° and 43.8°) were almost identical to in the values obtained in own study (41.4° and 43.9°). The value of the Clarke's angle in girls, both in our study and in the study by Klimczak et al., proves the correct formation of the longitudinal arch in girls[5].

In the study by Jankowicz-Szymańska and Pociecha, statistically significant differences were observed in the arch of the right foot in both sexes between the ages of four and six and in the case of the arch of the left foot – in five- and six-year-old boys. There were statistically significant differences in the longitudinal arch in the right foot in four-year-old boys and in the left foot between four-year-old boys and four-year-old girls. In our own study, no significant statistical differences were found among different age groups with respect to the left and right foot. A significant difference was observed only in the right feet between girls and boys in the group of six-year-olds[6].

The study by Hazzaa et al., conducted on a group of obese children, showed a significant positive correlation between the sex and the occurrence of flat feet but no correlation between the age and the development of flat feet[7]. In our own study, there were no significant statistical differences between the values of the Clarke's angle in children at the age of four and five, either boys or girls. There is no basis for assuming the hypothesis of gender differentiation due to this feature. The results are also confirmed by the study conducted by Serweta and Wójcik[8].

Our study found that girls were characterised by higher foot arches in comparison to boys, similarly to the study by Jankowicz-Szymańska and Pociecha[6].

In our study, the BMI was not in any significant statistical correlation with the Clarke's angle results. Similar findings were reported by Mikołajczyk and Jankowicz-Szymańska[9].

The correlation between body weight and the value of the longitudinal arch of the feet has been analysed by many authors. Mickle et al. showed a relationship between increased body weight and lower values of the plantar arch in comparison to children without overweight or obesity. A lower value of the plantar arch suggests that flatter feet occur commonly in children with abnormal body weight. It is postulated that overweight or obesity in a child causes structural changes in the foot that may affect the functional capacity of the medial longitudinal arch[10].

Šušnjević et al. showed that overweight children were 1.76 times more likely and obese children 1.88 times likely to have flat feet in comparison to children with normal body weight[11].

According to the study by Chen et al., the frequency of flat feet decreased with age: 54.5% of three-year-olds have flat feet, but only 21% of six-year-olds have two-sided flat feet. In the group of bilateral flat feet, the risk was found to decrease with age, increase with weight gain beyond the norm, and it was higher in boys than in girls[12].

The study by Pfeiffer et al. confirms that the frequency of flat foot decreases significantly with age. Boys were significantly more prone to flat feet than girls[13].

In our own study, the reduced frequency of flat feet with the children's age was not confirmed. The longitudinal arch of the feet of four–six-year-old children was comparable. The higher tendency can be caused by the small size of the study group; similar results were found in the study by Hazzaa et al.[7].

The study by Kojić et al., conducted on a smaller sample of respondents, confirms the dependence of the distribution of results on the size of the study group. In this study, 14.9% of children had a normal foot arch, while 44.6% had a high arch, and 20.3% had flat feet. The study also showed a difference between the arch of the left foot and the right foot[14]. In our study, 56% of children had normal feet, 23% had hollow feet, and 21% had flat feet. Similar results were obtained by Klimczak et al. However, it should be emphasised that the study group was older because it included children aged six to 10; however, the tendency to shape the rates in the Polish population is similar[5].

Changes in body posture may contribute to an uneven load on the lower limbs and as a result, a shift in the centre of gravity. The stability of body posture depends on active weight transfer and coordination of the pressure centre between the feet, which is the variable controlling human posture. Its development results from the active control of weight transfer from one foot to the other and the self-organising coordination of each foot separately[15]. A greater load on a given part of the foot causes the torso to tilt in the opposite direction to the created impulse[16]. Rusek et al. showed that a higher content of adipose tissue and a higher BMI in children resulted in a better balance. In the study, higher adipose tissue content correlated with a smaller surface area expressed by the body's centre of gravity and a lower deviation in the frontal plane[17].

Nevertheless, the results of studies showing the correlation between body mass composition, BMI, and balance parameters in children show significant differences. The available scientific literature includes articles on the relationships between body mass composition and BMI and balance parameters. The following studies present opposite results to the findings reported by Rusek et al.: McGraw et al., Pagnotti et al., Fink et al., Steinberg et al., Andreato et al., and Lara et al.[17–23]. McGraw et al. found that obese boys had greater sway and medial/lateral sway

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areas than non-obese boys[18]. Pagnotti et al. showed that people with clinical obesity exhibited greater instability than non-obese individuals[19], which might be a result of reduced proprioceptive abilities[20]. A relatively high percentage of overweight and obese children show imbalances and gait patterns, and increased foot pressure. Asa result, they have an increased susceptibility to injuries and a tendency to withdraw from physical activity[21]. The study by Lara et al. confirms that there is a relationship between excess body weight and values below the norm in certain equilibrium states[23]. Andreato et al. showed that decreased foot sensitivity was associated with poorer balance and/or postural stability[22]. In their research, Mickle et al. proved that age and gender influenced balance control. Boys showed more sway than girls under all studied conditions. Eight-year-old children showed significantly more swinging than older children during bipedal posture, while eight-year-old children did much worse in one limb than 10-year-old children[24]. The study by Kolic et al. showed that the ability to balance improved with age, with girls showing more mature balance strategies at an earlier age. Decreased BMI was associated with greater balance ability and postural control[25]. In the study by Plandowska et al., girls maintained a bipedal standing position with a slower rocking speed and less swing range than their male peers. Girls also showed better postural stability than boys[17,26].

In our study, based on the interpretation of BMI results with the use of percentile grids from the national OLA and OLAF studies, the BMI results were statistically significantly correlated with the results of the centre of gravity measurements for the whole group and in the correlation of the mean in the group of normal WHtR scores. When analysing the BMI results with the WHO percentile grids, no statistically significant correlation was found with the results of the centre of body gravity. In the interpretation of the above results, it should be emphasised that there are differences in group assignment (underweight, normal weight, overweight, obesity) depending on the percentile channel. Body height centiles in the Polish percentile grid defined in the OLA and OLAF studies have higher values compared to the WHO height standard. In our study, there was a difference in BMI assignment to the group, with 21 children (27.27%) showing different assignment to an appropriate group. The OLA and OLAF studies are more reliable because they included a representative sample of the Polish population of children and adolescents aged three to 18 years, while the WHO Growth Standards for children from birth to the age of five were compiled on the basis of anthropometric data from children from several countries[27].

Skin receptors play an important role in the control of balance and gait. According to Strzalkowski et al., skin receptors on the sole of the foot provide information about the interaction of the body with the environment as well as the body's position and orientation. The authors emphasise that stimulating the skin receptors of the foot affects body posture, balance, and gait control[16]. It has been shown that overweight or obesity is associated with lower plantar sensitivity, with obese subjects having reduced postural stability[22]. The influence of excess body weight on postural stability was confirmed by our own study, which showed that with increasing values of the BMI, a backward deflection of the body's centre of gravity is observed. In the study, the children with normal and excess body weight tended to put more stress on the hindfoot in relation to the forefoot. According to the study by García-Liñeira et al., boys rely more on somatoaesthetic information, while girls use more visual and vestibular information[28]. Sensory integration therapy in children has a positive effect on the stability of body posture, as demonstrated in the study by Maciaszek et al.[29].

CONCLUSIONS

With regard to the formation of the longitudinal arch of the feet in girls and boys, there were no significant differences in the study, which indicates the lack of clearly marked sexual dimorphism. Nevertheless, girls showed a higher longitudinal arch of the feet earlier than boys.

The study found no correlation between the values of the Clarke's angle and the age of the examined children. BMI and Clarke's angle were not dependent on gender or age category. BMI values were statistically significantly correlated with the results of the centre of body gravity measurements due to the correct WHtR, but only when interpreted based on the percentile grids from the national OLA and OLAF studies.

Along with an increase in BMI values, the centre of body gravity shifts more to the hindfoot.

The centre of gravity does not depend on the children's body posture (correct or incorrect).

Maintaining a healthy body weight is indicated for maintaining proprioception at an appropriate level and indirectly controlling body posture in space.

Conflict of interest

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Author contribution

Original concept of study: PS, AZP, DC. Collection, recording and/or compilation of data: PS, AZP, DC. Analysis and interpretation of data: PS, AZP, JS. Writing of manuscript: PS, AZP, DC, ML. Critical review of manuscript: PS, AZP, JS, DC, ML, AK. Final approval of manuscript: PS, AZP, JS, DC, ML, AK.

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