SECTION – EXERCISE SCIENCES

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CHARACTERISTICS OF FOOT ARCHES AND FOOT PRESSURE DISTRIBUTION IN 10-11-YEAR-OLD MALE SOCCER PLAYERS

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Authors' contribution:

A. Study design/planning
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D. Data interpretation
E. Preparation of manuscript
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Abstract

Aim. The aim of the study was to compare the longitudinal arch of the foot and foot pressure distribution (FPD) parameters in young male soccer players and controls.

Methods. A group of 50 soccer players and 50 non-training controls participated in the project. Their height and weight were measured, and body fat percentage (BFP) as well as BMI calculated. The height of foot arches and FPD were examined.

Results. Participants did not differ with age, height or BMI. However, soccer players were significantly lighter and had smaller BFP. The mean Arch Index (AI) was similar in both groups but more soccer players had very high foot arches whereas more controls, a low longitudinal arch of the foot. Normal arches prevailed in controls. The AI became greater with the increase of BMI, both in soccer players and in controls. FPD was greater in controls on the head of the first metatarsal bone, whereas in soccer players, on the head of the fifth metatarsal bone. A significantly greater FPD on the medial heel was found in both groups as compared to lateral heel pressure, which was greater in controls.

Conclusions. Regular soccer training changed FPD but affected the longitudinal arch of the foot less distinctly. Soccer training cannot be treated as an element supporting the process of proper foot formation in children.

Introduction

Bad posture is common in school children. According to some researchers, it is true in the case of more than 90% of the 6-12-year-olds [1]. Flat feet are considered to be the most frequently prevailing postural defects [2]. There has been discovered a significant correlation between greater body mass in children aged 6-9 and the prevalence of planovalgus feet [3]. Feet are also part of the musculoskeletal system in which children [4] most often experience pain. On the other hand, flat feet are connected with a more frequent prevalence of pain within the knee joint and the lower part of the spine [5].

Despite the fact that many research works and academic publications were devoted to foot deformities, there is still no single, commonly used definition of flat feet [6]. This results, to a great extent, from the complicated structure of the foot and its intricate functioning. As many as 28 out of 34 muscles of the foot, are short muscles (the origin and insertion within the foot), and 21 are deep muscles [7,8]. Their functions have not been recognised well enough so far [9]. However, it is known that difficult locomotor tasks, such as a one leg stand, increase the activity of the short muscles of the foot [10], and their fatigue results in backfoot pronation [11]. Wong [12] observed that short muscles were inefficient in people with adult-acquired flat feet.

In specialist studies, one can find analyses of foot posture and plantar pressure distribution in competitors of different sports. Klingele et al. [13] proved that flat feet more frequently prevailed in alpine skiers and runners. For example, runners had flatter feet after having run a half-marathon [14]. Distinctive patterns of plantar pressure distribution were observed in non-professional basketball players in whom the forefoot pressure and pressure in most areas of the foot were mostly revealed while taking measurements of movement patterns typical of that sport [15]. However, there is no research on the effect of training sports by children and adolescents - in whom the foot posture is not mature yet - on the height of foot arches and their functioning.

The study aimed to examine the hypothesis whether sports training and multiple repetitions of specific locomotor patterns would alter the FPD and the longitudinal arch of the foot in the period of time in which foot posture was still being formed. Boys training soccer were selected as a research group because soccer is the most popular team sport in the world and, moreover, it is connected with a great risk of micro- and macro-injuries to the musculoskeletal system [16,17].

Material and methods

The study group consisted of a total of 100 boys aged 10-11, including 50 students of a sports class - who had trained soccer in elite youth clubs for four years at least two times a week for two hours - and their 50 peers who did not do any sport (control group). The right foot was dominant for all participants. Tests were conducted before noon, prior to the training session, and the same conditions were maintained for all participants who were included in the study on the condition that they were male, regularly trained soccer for at least four years and had sustained no injuries to their musculoskeletal system within 12 months prior to the study. Those youngsters who had sustained injuries to their lower limbs within the 12 months preceding the study were excluded from the project. Participation in the study was voluntary. Participants' parents/legal guardians signed and dated informed consent documents, agreeing to the involvement of their children in the study. They were allowed to be present during the tests and were provided with the children's results. The approval of the Bioethics Committee at the local Medical Association was also obtained (No. 2/0177). The study was performed in accordance with the ethical standards of the Helsinki Declaration.

Participants' body height was taken, measuring the distance from the floor to the highest point on their heads in a standing position with their feet together, knees straightened and the eyes facing forward; the score was given within 0.1cm. Body height was measured by means of a calibrated anthropometer - ZPH Alumet (No. 010208, Warsaw, Poland). Participants' body mass, measured to the nearest 0.1 kg, and body fat percentage (BFP) were measured on the Tanita scales (bf-350 Tanita Corporation of America, Inc., Arlington Heights, Illinois, USA). The BMI was calculated dividing body mass (kg) by height squared (m), and based on the standards designed by Cole et al.[18], and body mass status was categorised as: normal body mass, overweight or obesity.

The longitudinal arch of the foot was measured by means of the Arch Index (AI - the ratio of the area of the middle third of the footprint to the entire footprint area) on a computerised baroresistive platform - BTS P-walk (BTS Bioengineering Corp., NY, USA) in a two-feet barefoot standing position. During the 30-second measurement test, participants stood on the platform in a habitual, relaxed position. The foot arch was normal if the AI was between 21% and 28%; its value below 21% denoted hollow foot, and above 28%, flat foot19. The same footprints were used to assess the mean pressure in selected anatomical regions of the left and right foot: MF – medial forefoot, LF – lateral forefoot, MH – medial heel, and LH – lateral heel.

Statistical Analysis

Analysis of the collected data was conducted by means of Statistica v10. Basic descriptive statistics, such as contingency tables, the Shapiro-Wilk test (for normal distribution of variables), the Mann-Whitney U test (for comparison between groups) and the Wilcoxon test (for comparison of dependable variables) were used. Correlations between the BMI, BFP and AI values were calculated by means of Spearman's signed rank correlation coefficient. The level of significance was accepted at $\alpha=0.05$.

Results

Participants did not differ with age or height (Table 1). Controls had greater body mass by 5.67 kg and greater BFP by approximately 5%. These were statistically significant differences. BMI was also higher in the controls (by approximately 1.8 kg/m^2), but that difference was not of statistical significance. Six out of all soccer players were overweight. The body mass of the remaining 44 players was normal. In controls, eight were overweight, while obesity was found in nine participants.

The mean values of the AI for the left and right foot in both groups were within the norm; however, they were smaller in soccer players (for the left foot that difference was of statistical significance). In the left foot, a very high arch was seen in 38% of soccer players and in 20%

of controls, a normal longitudinal arch in 54% and in 66%, and a lowered arch in 8% and in 14%, respectively. In the right foot, hollow foot was discovered in 44% of soccer players and in 26% of controls, a normal arch in 42% and in 64%, and a low arch in 14% and in 10%, respectively.

The assessment of correlations between variables revealed some dependencies between the BMI, BFP and the longitudinal arch of the foot expressed by the AI value (Table 2). In the case of BMI, that correlation was significant for the AI in both feet among all participants and controls, and also for the AI in the right foot in soccer players. In the case of BFP, that correlation was significant in the whole population in both sub-groups for the right foot. Taking into account the above observations, and in order to discover a more precise effect of BMI and BFP on the foot arches, it was calculated that the AI in participants with normal body mass was 21.00$\pm$5.75 for the left and 21.10$\pm$6.32 for the right foot. In overweight participants, those values were 24.75$\pm$3.20 and 24.29+6.61, and in obese ones, they were 25.84$\pm$3.43 and 25.90$\pm$2.06, respectively. Statistical significance was discovered only between the AI in the right foot in those with normal body mass and in obese participants (p=0.012; the Kruskal-Wallis test). The AI became greater with the increase of BMI, both in soccer players and in controls.

The intergroup comparison revealed greater medial forefoot pressure distribution in controls than in soccer players. For the right foot, those differences were of statistical significance. The lateral forefoot pressure distribution in both feet was significantly greater in soccer players (Table 3). The lateral and medial heel pressure distribution was similar in both groups.

The comparison of the symmetry of medial and lateral forefoot pressure distribution revealed significant asymmetries both in soccer players and in controls, but the lateral forefoot pressure distribution was greater in soccer players whereas the medial forefoot pressure distribution was larger in the controls (Table 4). Both groups unveiled asymmetric heel pressure distribution. A greater pressure was distributed to the medial heel.

Table 1. Basic traits of somatic build and the value of the Arch Index in the study groups (Mann-Whitney U test, α=0.05)

Variable	Group	Mean	Median	Std. Dev.	p
Age [years]	Soccer players	10.48	10.00	0.50	0.121
	Control group	10.66	11.00	0.47	
Body height [cm]	Soccer players	144.91	146.70	6.96	0.056
	Control group	147.58	149.00	6.38	
Body mass [kg]	Soccer players	37.14	37.50	6.18	0.042*
	Control group	42.81	39.30	12.41	
BMI [kg/m^2]	Soccer players	17.59	17.33	1.91	0.056
	Control group	19.37	18.30	4.32	
Fat tissue [%]	Soccer players	13.18	12.00	3.99	0.003*
	Control group	18.16	16.40	8.78	
Arch Index left foot [%]	Soccer players	20.06	22.30	6.46	0.005*
	Control group	23.87	23.58	3.63	
Arch Index right foot [%]	Soccer players	20.91	22.10	6.50	0.086
	Control group	23.08	23.24	5.93	

*statistically significant differences

Table 2. Correlations between BMI, BFP and AI in Participants (Spearman's signed rank correlation coefficient)

Correlated variables	All	Soccer players	Control group
BMI & Arch Index left foot	0.23*	0.19	0.27*
BMI & Arch Index right foot	0.28*	0.26*	0.30*
Fat tissue & Arch Index left foot	0.12	0,10	0.20
Fat tissue & Arch Index right foot	0.29*	0.28*	0.29*

Table 3. Plantar pressure distribution in the study groups (Mann-Whitney U test, $\alpha=0.05$)

Variable	Group	Mean	Median	Std. Dev.	p
MF pressure distribution - left foot [kPa]	Soccer players	14.98	15.00	2.77	0.098
	Control group	16.00	16.50	3.22	
LF pressure distribution - left foot [kPa]	Soccer players	16.02	16.00	4.20	0.029*
	Control group	14.48	13.50	3.73	
MH pressure distribution - left foot [kPa]	Soccer players	28.62	28.00	3.43	0.830
	Control group	28.76	29.00	2.86	
LH pressure distribution - left foot [kPa]	Soccer players	25.92	26.00	3.14	0.874
	Control group	26.08	26.00	2.50	
MF pressure distribution - right foot [kPa]	Soccer players	14.40	15.00	2.71	0.020*
	Control group	16.16	15.00	3.19	
LF pressure distribution -right foot [kPa]	Soccer players	17.62	17.00	4.83	0.007*
	Control group	15.16	14.50	4.60	
MH pressure distribution - right foot [kPa]	Soccer players	26.00	26.00	2.83	0.454
	Control group	26.68	27.00	3.58	
LH pressure distribution - right foot [kPa]	Soccer players	24.14	24.00	2.65	0.274
	Control group	24.60	24.00	3.80	

*statistically significant differences; MF – medial forefoot; LF – lateral forefoot; MH – medial heel; LH – lateral heel

Table 4. Comparison of plantar pressure distribution in MF and LF, and in MH and LH regions for the left and right foot in soccer players and in controls (Wilcoxon test, $\alpha=0.05$)

	Soccer players			Control group		
Left foot	MF pressure	LF pressure	p	MF pressure	LF pressure	p
	Me=15.0	Me=16.0	0.092	Me=16.5	Me=13.5	0.034*
	MH pressure	LH pressure	p	MH pressure	LH pressure	p
	Me=28.0	Me=26.0	0.0000001*	Me=29.0	Me=26.0	0.0000001*
Right foot	MF pressure	LF pressure	p	MF pressure	LF pressure	p
	Me=15.0	Me=17.0	0.0001*	Me=15.0	Me=14.5	0.289
	MH pressure	LH pressure	p	MH pressure	LH pressure	p
	Me=26.0	Me=24.0	0.0000001*	Me=27.0	Me=24.0	0.0000001*

*statistically significant differences; Me – Median; MF – medial forefoot; LF – lateral forefoot; MH – medial heel; LH – lateral heel

Discussion

Physiotherapists dealing with spinal problems and lower limb conditions in children are often asked by their clients' parents whether training certain sports will positively affect postural balance in their children. An honest answer to that question should be based on research results. Since foot disorders are one of the most frequently diagnosed irregularities in the process of forming the skeletal system and soccer is one of the most popular team games in the world, the authors of this paper decided to analyse the impact of soccer training on the foot arches and plantar pressure distribution in the 10-11-year-old boys. An unconfirmed, statistically significant trend to elevate the longitudinal arch of the foot and a significantly increased lateral forefoot pressure distribution were discovered in soccer players as compared to non-training controls.

The above observations were convergent with the research results obtained by Eils et al. [20] who found slightly higher foot arches in soccer players with 12-year-long training experience than in non-training controls. On the other hand, Grabary's [21] observations were totally different. She discovered lowering of the longitudinal and transverse arch of the foot in the 10-14–year-old soccer players as compared to their peers who did not do any sports. Also Wozniacka et al. [22] were of an opinion that a very high transverse arch of the foot prevailed in professional soccer players more frequently than in the general population. It was unveiled in our research that 14% of soccer players had flat feet. Long-term observations on the morphological structure of the feet in soccer players conducted in an older age group (14-16-year olds) showed a significantly frequent prevalence of flat feet [23]. Moreover, a high proportion of prevalence of that disorder in soccer players increased within the consecutive two years of conducting the research. On the other hand, after three-year-long observations, the researchers discovered a decrease in the size of prevalence of severe flat feet in favour of increasing the prevalence of mild flat feet. Despite the-above, they emphasized the need to monitor foot morphology and function, because alterations in the shape of foot arches are closely connected with a high risk of occurring injuries in junior soccer players. Many researchers also highlighted a significant correlation between flat feet and excessive body mass [24,25]. As a matter of fact, the group under study had only six overweight soccer players, while the controls included eight overweight and nine obese participants, and in both of the examined groups, the AI became greater with the increase in BMI.

In the authors' research, in the group of 10-11-year-old soccer players, a significantly greater overloading of the external part of the forefoot and heel was revealed in the right compared to the left lower limb. Increased pressure of the lateral forefront on the ground in 20-year-old soccer players was discovered by Sims et al. [26]. Their observations were connected with an increased number of stress fractures to the fifth metatarsal bone in that group of players. This was probably connected with multiple repetition of the eversion movement of the foot [27]. Various soccer-specific movements result in different plantar pressure distribution. Specific medial foot pressure distribution was observed in kicking [20]. The methods of measuring plantar pressure and foot arches with the use of footprints may considerably help clinicians in diagnosing injuries to lower limbs resulting from dynamic activities [28]. In tests conducted on junior soccer players, significant differences in the morphological structure of their feet were discovered, as compared to the controls. The footprints of soccer players revealed narrowing of the medial part of the midfoot and the lateral part of the forefoot [29]. In the authors' research, significantly greater static overload of lateral surfaces of the foot both in the left and in the right foot in soccer players were found in comparison to the controls. A greater tendency towards foot supination in adolescent soccer players was observed during gait and sports activities, expressed by a smaller contact surface of the feet and ground. The authors concluded that that type of support for the feet provided a lever and resulted in decreased energy expenditure needed for propulsion during running [30]. The conclusions of other researchers and the results of the authors' tests showed the need to incorporate exercises for muscles stabilizing the ankle joints and foot muscles responsible for shaping the architecture of foot arches in training protocols of junior sportspersons. Their musculoskeletal system is still in its developmental stage and, already at such a young age, some activities preventing injuries and eliminating musculoskeletal dysfunctions seem to be of considerable significance. Apart from the above, the soccer players under research had a greater proportion of the right foot with increased longitudinal arch than the non-training controls and significantly greater overloading of the right than the left limb. Chow et al. [31] discovered a significant correlation between high foot arch and increased plantar pressure in the forefoot and the patellofemoral pain syndrome in runners. In our study, one of the inclusion criteria concerned a lack of injuries to the lower limbs within the 12 months preceding the project, thus, we are not able to state that the differences in overloading the limb were caused by the musculoskeletal complaints. Taking asymmetric plantar pressure distribution between the left and the right foot in soccer players into account, it may be stated that it is typical for those training that sport. The movement patterns typical for soccer players, performed with one lower limb, such as kicking the ball, tackling, advancing with the ball and shooting towards the goal, may result in asymmetric muscle tension or affect muscle strength [32]. Marencakova et al. [23], in a long-term observation, also discovered significant asymmetry of body mass distribution in the lower limbs of junior soccer players which may have resulted from the domination of one limb over the other. The researchers explicitly emphasized the fact that asymmetric body mass distribution may significantly affect the prevalence of injuries.

The authors must admit that the research presented has been impeded by a small numerical strength of the population under study. Statistical analysis showed that with the current number of participants, the significance of group-related differences concerning body mass, body fat and the AI of the left foot could be confirmed by a high statistical power of the test. Confirming the significance of differences regarding overloading of individual areas of the feet at the 0.8 level would require doubling the number of participants. The studies presented were limited by the lack of long-term observations among soccer players and a lack of analysis of the lower limb alignment (knee and hip alignment). In their research on experienced adult soccer players, Mucha et al. [33] discovered that the height of foot arches affected the quality of deep knee bend performance and this was connected with the functioning of the whole kinematic chain. Yaniv et al. [34] assessed lower limb alignment in 10-21-year-old soccer and tennis players. They discovered that the 13-year-old and older soccer players had higher foot arches and an inclination to *varus* knees. Future studies should concentrate on discovering whether changing the alignment of the lower limb axis towards *varus* knees correlates with excessive lateral FPD and on examining the plantar pressure distribution of the foot during different activities, such as walking or running.

Taking the observations of the authors mentioned above and the results of the authors' research into account, it may be concluded that soccer training specifically changes foot pressure distribution parameters. Body posture, including foot alignment, should be regularly assessed in children training soccer.

Conclusions

Regular soccer training before the completion of the the foot arch formation process increased lateral forefoot pressure distribution and slightly affected the increase in the height of the longitudinal arch of the foot. The BMI values significantly affected the development of flat feet both in soccer players and in non-training controls. Correlations between specific patterns of the FPD and the alignment of the whole lower limb, as well as the frequency of the injury prevalence, still requires further research.

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