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Association Between Foot Arch Index and Other Morphometric Indices

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The foot morphology is crucial for the normal functioning of the locomotor system. Footprints of randomly selected 150 Bulgarians aged 18 to 60 years were collected. We examined the morphological features of each foot by measuring the arch index, the Clarke angle and the Chippaux-Smirak index. Our results showed a greater incidence of high arched foot versus low arched foot. The study of the arch index once again confirmed the association of the Morton's toe foot with a high medial arch. In the group with high arched foot, BMI was lower than that in the other groups. Further investigation of the relations between BMI and arch index found no significant correlation between them. We found a particularly well-expressed correlation between the arch index and Chippaux-Smirak index. Our findings gave us reason to assume that the measurement of Chippaux-Smirak index can successfully replace the measurement of arch index.

Key words: foot, foot indices, arch index

Introduction

The human foot is characterized by unique features. These features have evolved over time to allow humans to stand upright and walk bipedally [10]. In the different phases of this gait, the foot changes its biomechanics and turns from a flexible structure that adapts to the surface into a rigid lever. This is possible because of the arches of the foot. They not only redistribute the weight of the body, but also ensure the different mobility of the individual parts of the foot [2].

The importance of the two longitudinal arches and the transverse arch is well known and generally recognized. The study of these arches has led to the identification of three main types of human foot – normal, high-arched and low-arched foot. The assessment of foot morphology most often relies on clinical observation and

different measurement methods. The classic method for studying foot morphology is through footprints (plantograms) and the measurement of various morphometric indices. This methodology is the basis of the development of digital methods, such as the podoscope, as well as the basis of dynamic studies of the foot and its 3D reconstructions [5].

Materials and Methods

Footprints (plantograms) of randomly selected 150 Bulgarian men and women, without malformations, surgery or traumas of the foot, aged 18 to 60 years were collected after their written consent. The female participants were 86, and the male ones – 64. The study was approved by the Research Ethics Committee at the Medical University "Prof. Dr. P. Stoyanov" with protocol No 140/01.07.2021. All participants filled out a survey in which they also noted their height and weight. The body Mass Index (BMI) was calculated based on these data. BMI between 22-25 was considered as normal, below 22 – as low and above 25 – as high. Each plantogram was studied using different measurements – Clarke angle, the Chippaux-Smirak index and the arch index.

Clarke's angle is the angle between the tangent line joining the medial edges of the first metatarsal head and the heel, and the second line that connects the first metatarsal head and the innermost point of the medial longitudinal arch concavity. If the Clarke's angle value is between 42° and 54° the foot is normal. High-arched foot presents with Clarke's angle more than 54° and the low-arched one with Clarke's angle value less than 41° (**Fig. 1A**).

Chippaux-Smirak index was measured as follows: 1) the distance between the outermost point of the first metatarsal in the medial and the outermost point of the fifth metatarsal was measured (maximum metatarsal foot width); 2) at the narrowest point of the foot arch the width was measured using a line parallel to the first one; 3) Chippaux-Smirak index was defined as a ratio between these two lines. In the cases with Chippaux-Smirak index between 25% and 45% the foot was considered as normal. If the Chippaux-Smirak index was more than 45% the foot was described as flat or low-arched foot (pes planus) and when the index was less than 25% - as high arched foot (**Fig. 1B**).

The arch index is the ratio of the area of the middle third of the foot to the whole footprint area with toes excluded. This was calculated as follows: 1) a line was drawn between the heel center and the base of the second toe; 2) the footprint was divided into three equal parts via lines perpendicular to the first one; 3) the area of the middle part and the area of the entire footprint were measured with ImageJ software; 4) the arch index was calculated (**Fig. 1C)**. The normal foot was defined by arch index scores between 0,21 and 0,28. The high-arched foot had arch index value less than 0,21, and the low-arched foot – more than 0,28 [6].

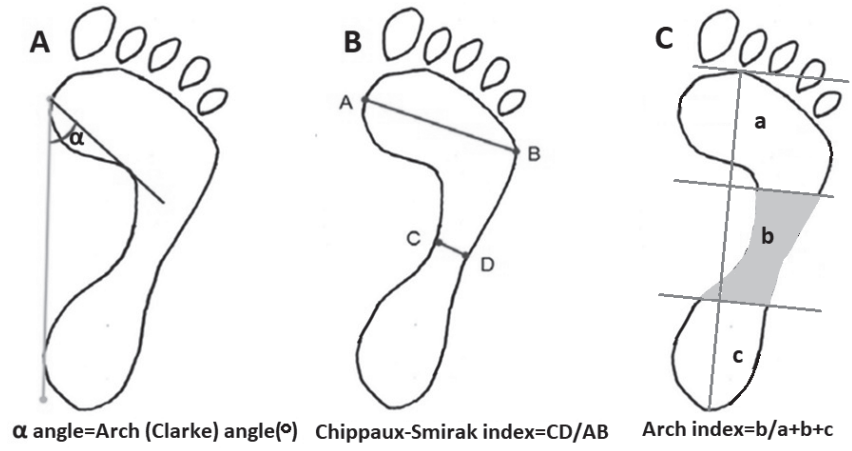

Fig. 1. A. Clarke's (arch) angle; **B**. Chippaux-Smirak index = CD/AB; **C.** Arch index=b/a+b+c

Results

According to the arch index values, the plantograms of 90 of the participants fell into the group with normal foot. Other 17 of them were classified as flat and 43 – with high-arched foot. The percentage distribution among the three groups was as follows: 60% were with normal; 11% – with flat; 29% with high-arched foot (**Fig. 2A**). We compared the BMI values of the participants distributed in the groups that were formed (**Fig. 2B**). The data analysis showed a statistically significant difference between the BMI values of people with high- and those with low-arched foot (**Fig. 2C**). When we compared the arch index values in the groups with low, with normal and with high BMI, there were no significant difference (data not shown).

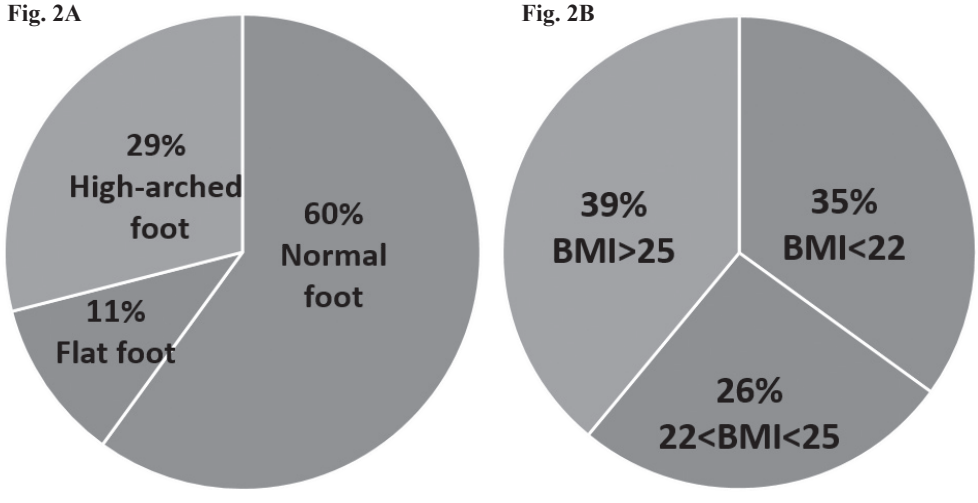

Fig. 2. A. Incidence of the foot types according to arch index values; **B.** Distribution of participants according to BMI;

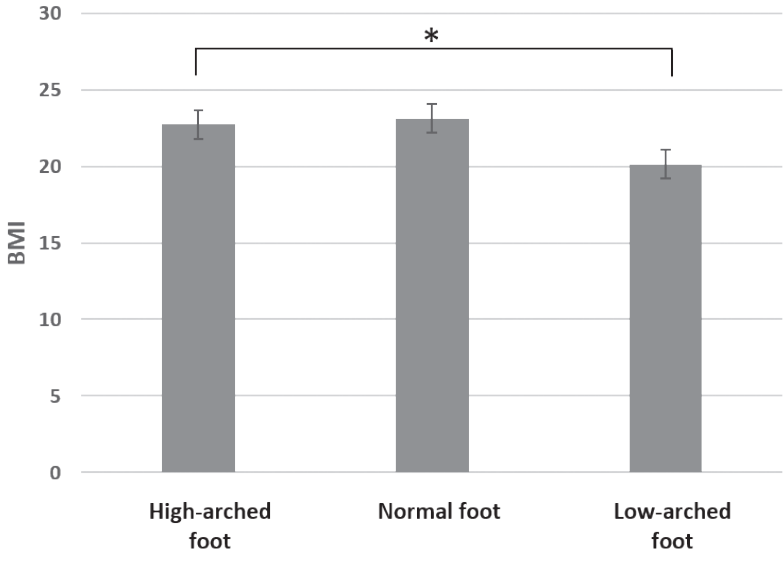

Fig. 2. C. BMI values in participants with different foot types. * - p≤0.05, BMI – body mass index

We analyzed the results obtained from arch index calculations in people with Morton's toe and those without it. The participants with longer second toe (Morton's toe) were 40 % of all, or 59 people out of 150. The arch index values in the group with Morton's toe were significantly lower with mean value 0,209. The mean value in the other group was 0,235 (**Fig. 3A**). The t-test confirmed this difference with p< 0,05.

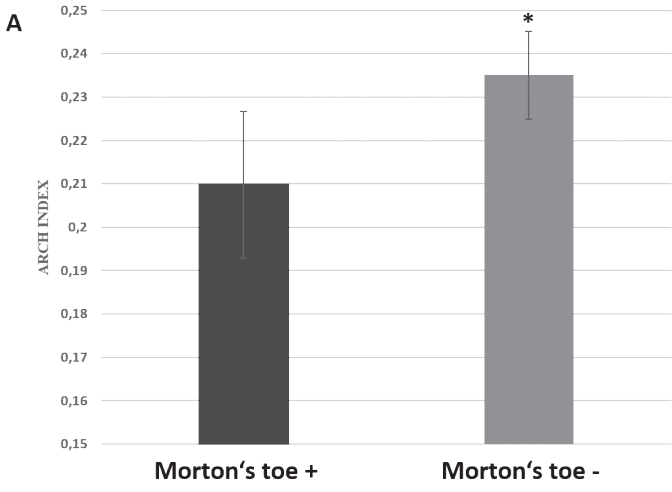

Fig.3. A. Arch index values in Morton's toe positive group and Morton's toe negative group

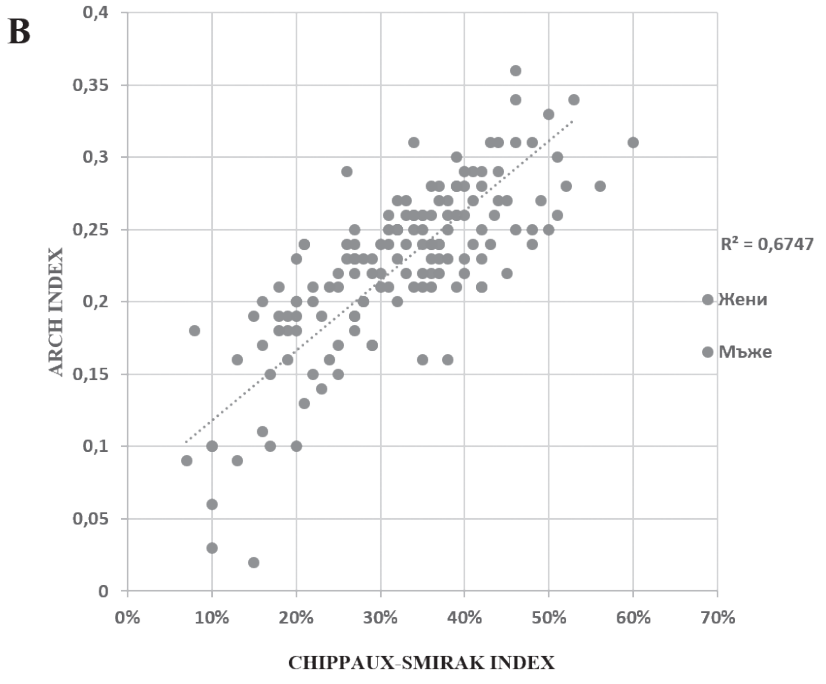

Fig.3. B. Correlation between arch index and Chippaux-Smirak index

We investigated the correlation between the arch index, Clarke's angle and Chippaux-Smirak index. Statistical analysis showed no correlation between Clarke's angle and Chippaux-Smirak index (r = -0,528), and no correlation between Clarke's angle and arch index (r = -0,399). We found very high, positive correlation between arch index and Chippaux-Smirak index with r = 0,777 (**Fig. 3B**).

Discussion

The type of foot is associated with various features of the biomechanics of the entire lower limb and body. A low-arched foot and a high-arched foot redistribute the weight of the body differently. This leads to uneven stress on different structures, which could lead to different manifestations of problems such as calluses, ulcerations, muscle-tendon strains and even stress fractures [1, 9]. That's why the type of foot should be evaluated in the medical practice of a wide range of specialists. The use of footprints is a simple, available, inexpensive and reliable method that does not require any equipment. Measuring more than one morphometric index increases reliability many times [8]. Arch index is both generally accepted as particularly reliable and relatively time consuming to use as it requires more calculations. The correlation between it and Chippaux-Smirak index allows its replacement by the easier-to-perform morphometric analysis.

Morton‘s toe is a condition that disrupts the biomechanics of the foot [7]. It is associated and accepted as a risk factor for the development of hallux valgus, plantar fasciitis, flat feet, stress fractures of the 2nd and 3rd metatarsal bones [3]. Literature data show that complications of Morton‘s toe occur and increase with advancing age [4, 7]. Our results for the co-existence of Morton‘s toe and high-arched foot can be interpreted in relation to the younger age of the participants, as a compensatory mechanism to overcome the instability of the first ray of the foot and as an additional risk for foot instability.

The obtained data show that BMI does not influence the arch index values. Lower BMI in people with a high-arched foot are most likely a result of constitutional features. At the same time, an even distribution of foot types is observed in the groups with different BMI.

Conclusions

1. The arch index values are not affected by BMI.
2. The measurement of Chippaux-Smirak index can replace the study of arch index in the assessment of foot type.

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