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Age and Gender-Related Differences in Anthropometric Foot Indices within the Bulgarian Population

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The human foot is designed for multi-functional performance, providing essential stability while standing, seamless adaptability to varied terrain, and the mechanical leverage necessary for movement. Foot characteristics show significant regional and ethnic differences. The characteristics of the foot change throughout the ontogenetic development. This determines the different frequency of high and low arch cases in different age groups. Within the Bulgarian population, the prevalence of low-arched feet (pes planus) is significantly higher in individuals under the age of 40 compared to those over 40. Furthermore, the incidence of the Greek foot (Morton's toe) is lower in the cohort under 40 years of age. Our study shows that foot morphology in Bulgaria is changing over time. This shift is most evident in men, where younger generations are more likely to have low arches, significantly changing the balance between high-arched and low-arched foot types in the population.

Key words: foot, plantograms, foot arch

Introduction

The human foot is designed for multi-functional performance, providing essential stability while standing, seamless adaptability to varied terrain, and the mechanical leverage necessary for movement. There is a broad consensus that morphological variations in anatomical structures directly impact biomechanical function, thereby predisposing individuals to an increased risk of musculoskeletal pathologies and injury [14, 17].

Plantograms or foot prints, obtained by inking the plantar surface of the foot or by using digital plantogrphs, reflect the shape and orientation of this surface of the lower limb during standing or locomotion. Measurements of various distances, angles, and

areas on plantograms are considered a simple and objective method for foot typing.

Because foot characteristics are heavily influenced by regional and ethnic factors, using external population data for local clinical assessments can be problematic [9, 12]. Our study addresses this gap by characterizing the Bulgarian population, where we observed distinct morphological trends - specifically, a high frequency of the 'Greek foot' variant and a relatively high incidence of high arch foot [2, 6].

The Greek foot, or Morton's toe, is a morphological variation where the second digit surpasses the hallux in length. This condition - described by American surgeon Dudley Morton—is primarily attributed to an abnormally short first metatarsal (brachymetatarsia) [8].

The characteristics of the foot change throughout the ontogenetic development. This determines the different frequency of high and low arch cases in different age groups [13, 15], and such differences have been reported in many populations. Using these literature data, we also examined the distribution of foot types in different age groups in Bulgarian population.

Material and Methods

Footprints (plantograms) of randomly selected 210 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 115, and the male ones – 95. According to their age the participants under 40-years were 125, and these over 40-years age were 85. The study was approved by the Research Ethics Committee at the Medical University "Prof. Dr. P. Stoyanov" with protocol №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 this data. Each plantogram was studied using different measurements - Clarke angle (CA), the Chippaux-Smirak Index (CSI) and the Arch Index (AI).

CA is the angle between the tangent line connecting the most medial points of the forefoot (1st metatarsal head) and the hindfoot (heel), and the line connecting that same forefoot point to the deepest part of the arch curve. If the CA value is between 42° and 54° the foot is normal. High-arched foot presents with CA more than 54° and the low-arched one with CA value less than 41°.

CSI is calculated as the ratio between the minimum midfoot width and the maximum forefoot width. First, a line is drawn across the widest part of the metatarsals. A second, parallel line is then measured at the narrowest point of the arch. The index is defined as the ratio of the arch width to the metatarsal width. In the cases with CSI between 25% and 45% the foot was considered as normal. If the CSI 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.

AI represents the ratio of the middle third of the footprint to the total footprint area (excluding the toes). To determine this, a longitudinal axis is drawn from the center of the heel to the base of the second toe. The footprint is then segmented into three equal

sections by lines perpendicular to this axis. The area of the middle part and the area of the entire footprint were measure with ImageJ software and AI was calculated The normal foot was defined by AI scores between 0,21 and 0,28. The high-arched foot had AI value less than 0,21, and the low-arched foot – more than 0,28.

Cases with a longer second toe and a difference of at least 2 mm with the first toe on the plantogram were defined as Greek foot or Morton's toe.

The study participants were first divided by age into two groups: under and over the age of 40. The average age of each group was respectively 26,5 and 48,8 years. Each of these groups was subdivided by gender into women and men. The t-test and chi-square test were used to analyze the data.

Results

We compared the frequency of Greek foot in people under and over 40 years of age, and we found a significant difference. In the group under 40 years the incidence of Morton's toe was 37.7% but in the group over 40 years it was 49.4%. Statistical significance was confirmed by chi-square test ($p<0.0001$).

When analyzing the prevalence of the Greek foot (Morton's toe) across both age and gender, our data revealed a significant higher frequency among older cohorts. Specifically, women over 40 demonstrated a higher prevalence of Morton's toe compared to those under 40 ($p < 0.001$). A similar age-related trend was confirmed in men, with the Greek foot being significantly more common in the over-40 demographic ($p < 0.001$). While no gender-based differences were observed in participants under 40, a notable disparity emerged in the older group: the frequency of Greek foot in women over 40 was significantly higher than in their male counterparts—exceeding 50% compared to 32%, respectively ($p < 0.001$) (**Fig. 1**).

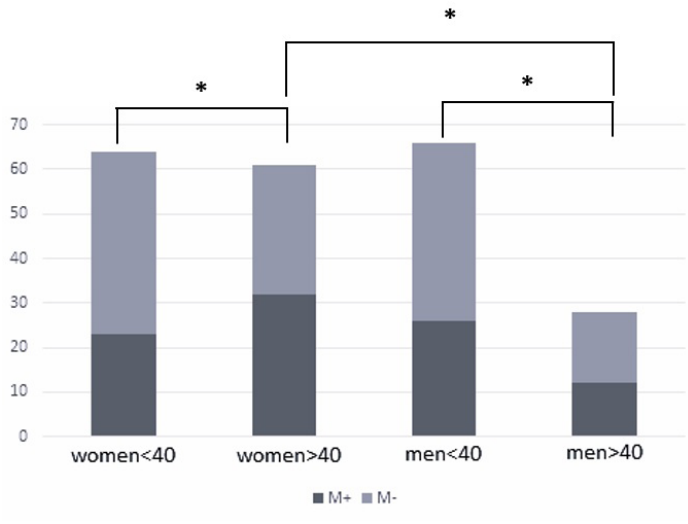

Fig. 1. Number of participants by gender and age group, with (M+) and without (M-) Morton's toe. <40 – under 40 years of age; >40 - over 40 years of age. * - statistically confirmed difference

We analized the values of CA, CSI and AI in both described age groups. According to the values of each

of the anthropometric indices, the plantograms were divided into three groups: 1) with normal values, 2) with high foot arch 3) with low foot arch. Statistical analysis confirmed the difference in the distribution of foot types in the two groups with $p< 0.001$ in both the t-test and the chi-square test. We found a different ratio of cases of high and low arch in the two age groups. In the group under 40 years of age, more cases of flatfoot are observed, and this difference is reported in all three indices (CA, CSI and AI) with $p<0.001$ (**Fig. 2**).

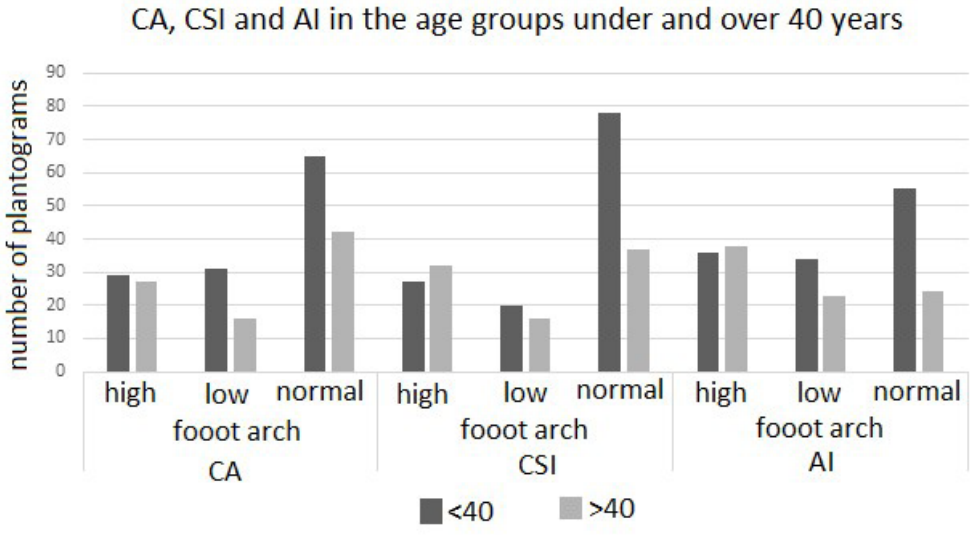

Fig. 2. Number of participants with different foot types (high-arched foot, normal-arched foot, low-arched foot) in the groups under and over 40 years of age according to used anthropometric indices (CA, CSI, AI)

We studied the distribution of foot types according to the values of each anthropometric index by gender in both age groups. Statistical analysis using the chi-square test confirmed significant differences in the distribution of foot types across age groups for both sexes. While this age-related variation was evident in both cohorts, it was more pronounced in men ($p < 0.001$) than in women ($p < 0.01$) (**Fig. 3**).

We analyzed the constitutional characteristics of the participants using height, weight, and BMI data. Independent t-tests revealed no statistically significant differences ($p > 0.5$) between the male and female cohorts across these metrics.

Discussion

Our data show that the anthropometric indicators characterizing the foot in the Bulgarian population are not static. The shifting distribution of foot types across different age groups highlights a distinct morphological trend, particularly among men.

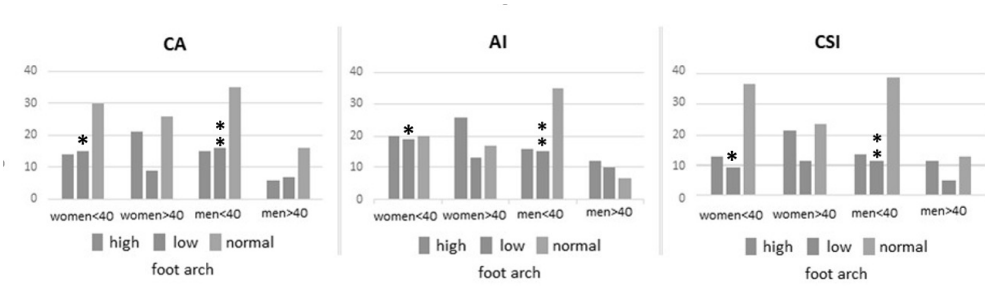

Fig. 3. Number of participants with different foot types according to used anthropometric indices (high-arched foot, normal-arched foot, low-arched foot), grouped by age and gender. * - statistically confirmed difference with p<0,01; ** - statistically confirmed difference with p<0,001.

Notably, younger male participants show a higher prevalence of low arches, resulting in a significant shift in the ratio between high-arched and low-arched individuals compared to older cohorts. The data should also be interpreted with the knowledge that in general the arches of the foot decrease with age within the framework of individual lifespan. This decrease according to literature data is particularly pronounced in the female gender, where it is associated with pregnancy and hormonal changes during the woman‘s life, as well as with socio-economic factors, such as the type of shoes [7, 10 11]. However, in the Bulgarian women population over 40 years of age, the frequency of flat feet is not higher compared to the group under 40 years of age.

The formation of the arches of the feet occurs during the first years of life, and is completed around 9-10 years of the age (slightly later for boys) [15]. A number of studies have attempted to answer the question of which factors have the greatest influence. Most of them assume that barefoot walking is essential in this early childhood [3]. Furthermore, research comparing orthopedic and regular shoes has reported no significant impact of either footwear type on the eventual height of the foot‘s arch [16].

Undoubtedly, socio-economic factors, such as living in the city or in the countryside, such as walking style and shoes worn in early childhood, such as the terrain on which one walks, have their importance in the formation of different foot types and the frequency of high and low arches in the population. These factors complement hereditary and genetic ones. The latter are unclear, and it is assumed that they act through a complex inheritance mechanism [5].

Our data clearly show that the hereditary factors act and modify the frequency of foot types in the Bulgarian population. If the cases of high and low arch are the result of a combination of external and internal factors, then the frequency of Greek foot depends only on genetic ones [1].

Data on the distribution of foot types in a population are important for sports medicine, physiotherapy, orthopedic practice and for industries such as footwear manufacturing [4]. Due to the complex set of social, economic and genetic factors that

determine the formation of the arches of the feet, significant regional, geographical, ethnic and racial characteristics are observed. This does not allow the free use of data obtained in the study of one population to characterize another and determines the need for local studies as ours.

Conclusions

1. Within the Bulgarian population, the prevalence of low-arched feet (pes planus) is significantly higher in individuals under the age of 40 compared to those over 40.
2. The incidence of the Greek foot (Morton's toe) is lower in the cohort under 40 years of age
3. Bulgarian males exhibit more pronounced shifts in anthropometric foot indices when comparing age groups under and over 40 years.

R e f e r e n c e s

1. Aigbogun, E. O., A. Alabi, B. Didia, K. Ordu. Morton's Toe: Prevalence and inheritance pattern among Nigerians. – *Int. J. Applied & Basic Med. Res.,* **9 (2),** 2019, 89.

2. Angelova, M., D. Marinova, V. Zhekova, St. Pavlov. Association between foot arch index and other morphometric indices. - *Acta Morphol. Anthropol.,* **30 (3-4),** 2023, 61-66.

3. Echarri, J. J. and Fr. Forriol. The development in footprint morphology in 1851 Congolese children from urban and rural areas, and the relationship between this and wearing shoes. – *J. Pediatric Orthopedics, Part B,* **12 (2)**, 2003, 141-46.

4. Fernández-Seguín, L. M., J. Mancha, R. S. Rodríguez, E. E. Martínez, B. G. Martín, J. R. Ortega. Comparison of plantar pressures and contact area between normal and cavus foot. - *Gait & Posture,* **39 (2)**, 2014, 789-792.

5. He, Y., M. Verleyen, B. Callewaert, A. Burssens, E. Audenaert. Unraveling the genetic landscape of foot arch morphology: A systematic review of single nucleotide polymorphisms. – *Clin. Genet.,* **107 (5)**, 2025, 485-494.

6. Marinova, D., M. Angelova, V. Zhekova. Morton's Toe frequency among the Bulgarian population and its association with high arched foot. - *Acta Morphol. Anthropol.,* **29,** 2022.

7. Matsumoto, Y., N. Ogihara, S. Kosuge, H. Hanawa, T. Kokubun, N. Kanemura. Sex differences in the kinematics and kinetics of the foot and plantar aponeurosis during drop-jump. – *Sci. Reports*, **13 (1)**, 2023, 12957.

8. Morton, D. J. Structural factors in static disorders of the foot. – *The Am. J. Surgery,* **9 (2),** 1930, 315-328.

9. Munro, B. J., and J. R. Steele. Foot-care awareness. A survey of persons aged 65 years and older. – *J. Am. Pediatric Med. Association* **88 (5),** 1998, 242-248.

10. Nozaki, S., K. Watanabe, T. Kamiya, M. Katayose, N. Ogihara. Sex- and age-related morphological variations in the talar articular surfaces of the calcaneus. – *Ann. Anatomy,* **229,** 2020, 151468.

11. Otsuka, R., H. Yatsuya, Y. Miura. Association of flatfoot with pain, fatigue and obesity in Japanese over sixties. – *Nihon Koshu Eisei Zasshi Japanese J.Public Health,* **50 (10),** 2003, 988-998.

12. **Pita-Fernandez, S., C. Gonzalez-Martin, F. Alonso-Tajes.** Flat foot in a random population and its impact on quality of life and functionality. – *J. Clin. Diagn. Res.,* **11 (4),** 2017, 22-27.
14. **Scott, G., H. B. Menz, L. Newcombe.** Age-related differences in foot structure and function. – *Gait & Posture,* **26 (1),** 2007, 68-75.
15. **Spörndly-Nees, S., B. Dåsberg, R. O. Nielsen, M. I. Boesen, H. Langberg**. The navicular position test - a reliable measure of the navicular bone position during rest and loading. – *Int. J. Sports Physical Therapy,* **6 (3),** 2011, 199-205.
16. **Stavlas, P., T. B. Grivas, C. Michas, E.Vasiliadis, V. Polyzois.** The evolution of foot morphology in children between 6 and 17 years of age: A cross-sectional study based on footprints in a Mediterranean population. – *The J. Foot & Ankle Surgery,* **44 (6),** 2005, 424-428.
17. **Vangara, S.V., P. Vv. Gopichand, M. Bedi, N. Puri**. Effect of barefoot walking on foot arch structure in tribal children. – *Asian J. Med. Sci.,* **7 (5),** 2016, 108-116.
18. **Williams, D. S., I. S. McClay, J. Hamill.** Arch structure and injury patterns in runners. – *Clin. Biomechanics (Bristol, Avon),* **16 (4),** 2001, 341-347.