Assessment of Plantar Arch Index and the prevalence of foot deformity among athletes and non-athletes students at the University of Uyo, Nigeria

Ekanem, Akpan Udo, Ph.D., akpanuekanem@gmail.com
Edem, Gabriel Donatus, corresponding author, profgabe4sure@gmail.com
Okon, Kingsley Akaninyene , kingsleyokon510@gmail.com
Victor, Esther Queen, essymama386@gmail.com
Physical and Forensic Anthropology Unit, Department of Human Anatomy
Faculty of Basic Medical Sciences, University of Uyo, Nigeria

Abstract

The plantar arch index establishes a concrete relationship between the central and posterior parts of the footprint. The Cavanagh and Rodgers Arch Index (PAI) is a standard mathematical value used as an important determinant in the identification of foot physiology and potential pathology. Cavanagh and Rodgers Arch Index was developed by Cavanagh and Rodgers in 1987 representing the ratio of middle third of a footprint relative to the total area. Foot deformities are a category of acquired and congenital conditions that affect foot functions. Deformed feet can cause individuals to experience mobility problems resulting to weakness, obesity and cardiovascular conditions. Currently, there is no reported research on the prevalence of foot deformities among athletes and non-athletes at University of Uyo in Akwa Ibom State, Nigeria and this forms the rationale behind this study. This study aimed at determining the prevalence of foot deformities among University of Uyo students using simple random sampling method. Asum total of 800 students (including 500 males and 300 females) aged between 17-40 years. Both male and female athletes as well as non-athletes participated in this study. Endorsing ink, plain tile and white paper were used to obtain

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the footprints of each participant. The plantar arch index was determined and calculated using the Cavanagh and Rodgers Arch Index. GraphPad Prism software (version 8.0.2) was used to analyzed data obtained from the study. Results obtained from this study showed that athletic males had the plantar arch index of 0.20±0.001 when compared to non-athletic males. Similarly, athletic females had PAI of 0.20±0.003 and 0.19±0.002 for right and left foot respectively when compared to non- athletic females with PAI of 0.23±0.008 and 0.22±0.009 for right and left foot respectively. These values correspond with the Cavanagh and Rodgers arch index for high arch (pes cavus) which is one of the foot pathologies. Our study indicated the presence of pes cavus among athletic students for both male and female and standards of foot normality among non-athletic students (male and female) of the University of Uyo, Nigeria.

Keywords: plantar arch index, pes cavus, Cavanagh and Rodgers arch index, endorsing ink, University of Uyo

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Introduction

Foot Arch

The lower limb, especially the foot, is among the most distinctive features of human anatomy (Hernandez et al., 2007). There is a functional relationship between the structure of the arch of the foot and the biomechanics of the lower leg. The arch provides an elastic, springy connection between forefoot and the hind foot. The association entails that majority of the forces incurred during weight bearing of the foot can be dissipated before the force reaches the long bones of the legs and thigh. In *pes planus* or flat foot, the head of the talus bone is displaced medially and distal from the navicular. As a result, the spring ligament and tendon of the tibialis posterior muscle are stretched, so much that the individual with *pes planus* loses the function of the Medial Longitudinal Arch (MLA) (Pranati et al., 2017).

Types and functions of the foot arch

The arch of the foot demonstrates two extreme anatomical structural positions; the high arch or pes cavus and the flat arch or pes planus. The high or pes cavus is one of the foot pathologies characterized with the presence of abnormally high plantar longitudinal arch which does not flatten with weight bearing. The prevalence of pes planus declines with age, in children with ligament laxity and early shoe wearing which impairs longitudinal arch developments (Hernandez et al., 2007). Although two distinct arches function to support the foot, the medial longitudinal arch has been found to be the arch of clinical significance, because it helps protect the foot from injuries (Xiong et al. 2010). The lower limb, especially the foot, is among the most distinctive features of human anatomy (Hernandez et al., 2007). An important highly variable structure characteristic of the human foot is its medial longitudinal arch, which provides necessary shock absorption for the foot during activities. Traditionally, feet are classified as being high, normal or low arched. A high arched foot is supposed to be at increased risk of injuries to the bony structures on the lateral aspect of the foot (over-supinated), whereas a low arched foot can be at greater risk for soft tissue damage on the medial part of the foot (over-pronated) (Xiong et al. 2010). Foot arch has been identified as a crucial structure contributing to the functions of the human foot and lower limb. Arch height could affect the foot pressure distribution during static standing and dynamic movements.

The Arch Index

A previous study has established the metrics to quantify the arch as per the plantar contact area known as the arch index (AI), which is calculated from mid-foot area divided by the summation of forefoot area (excluding toes area), mid-foot area, and rear-foot area (Cavanagh and Rodgers ,1987).The arch index has been widely used to identify the foot type such as high arch foot, normal arch foot and low arch foot according to the index value, as reported by Cavanagh and Rodgers (1987). The arch index is necessary to determine any foot pathology and possible treatment. The arch index less than 0.21 is classified as high arch foot, between 0.21 and 0.26 is classified as normal arch foot, and higher than 0.26 is indicated as low arch foot. The arch index can be directly influenced by the foot contact areas, especially the mid-foot. Wearing et al. (2004) believed that body fat mass could affect the arch index, and increased fat mass could increase the contact area of the mid-foot resulting in an increased arch index, which was reported as low arch or flat foot. Foot types, including high arch, normal arch, and low arch, were previously reported with different structures and functional performance (Hillstrom et al., 2013). High arch feet can cause instability of the ankle and increase the risk of ankle sprains. It may be due to problems associated with genetics or neurology (WebMd, 2005). Symptoms of high arch foot include foot pain while walking, claw toes and shortened foot length (WebMd, 2005). Similarly low arch may contribute to problems associated with the joint and muscle stress. Symptoms of low arch include swelling, pain and stiffness of the foot arch (Adam, 2024).

Foot arch and quality of life

Foot arch height influences the quality of life (Lopez et al., 2018; Lopez et al., 2014). Low arch foot pronates excessively during running stance, while normal arch is characterized by an arch slightly raised from then ground during weight bearing. High arch foot is rigid and inflexible and may cause ankle stability as well as metatarsal fractures. Due to repeated stress caused by high arch, individuals with this condition tend to develop hairline fractures in bones of the foot. Insoles support based on foot plantar shape was believed to increase perceived comfort. Sun et al. (2009) developed a three-quarter shoe insole in length, exhibiting altered pressure distribution over the plantar region, thus increasing comfort. Footwear companies designed functional shoes, such as arch support, for the cohort of different foot types, respectively. However, assigning shoes as per foot types were proven not helpful to reduce the injury risk during the military training among soldiers (Knapik et al., 2014; Feng et al., 2017). Stearne et al. (2016) provided direct evidence to support the energy-sparing spring theory of the arch and found that restricting arch compression increased the energy cost in the level run by hindering the arch's elastic energy storage, which was not effective during walking or incline running. It was reported that estimating dynamic medial longitudinal arch deformation using static foot metrics, such as foot posture index and medial longitudinal arch angle may not be reliable; thus, an assessment was proposed (Langley et al., 2015).

Relationship between Foot Arch and Body Mass Index

Previous studies have reported that a strong correlation was observed between BMI categories and foot arches. An increase in the body weight and body mass index (BMI) literally influences the foot arch, especially those with flat foot (low arch) (Agic et al., 2006). Even though obesity has repeatedly been associated with the presence of flat foot (Pehlivan et al., 2009). In overweight and obese individuals, changes in their foot shape were observed due to excessive biomechanical loading and pressure (Crosbie and Burns, 2008).

Staheli's Plantar Arch Index

The assessment of plantar arch development called "the plantar arch index" obtained by the relationship between arch region width and heel region width obtained on a footprint was proposed by Engel and Staheli (1974) and Staheli et al. (1987). Staheli's plantar arch index method is used to determine the incidence of pes planus. Footprint parameters act as an essential tool in assessing the foot arch or foot shape (Shariff et al., 2017).

Aim of the study

Having worked as academics and researchers in the University of Uyo for several years, we have been physically observing students on campus with different foot arches where movement and physical activity is much more prevalent. Surprisingly, these scenarios seem to be seen in both athletes who are involved sporting activities such as football and non-athletes. The desire to discover the implication or impact of these foot differences on the individual during sporting activities and while engaging in any other physical activities, for instance, trekking, brought about the necessity of this research work. Anthropologically, this research has never been done in the University of Uyo community. Comparison was made between athletes and non-athletes to ascertain the presence and type of foot arch in the two categories of students. Thus, this investigation seeks to serve as basis for further learning and research as well as minimizing the incidence of foot injuries due to utilization of appropriate techniques and preventive measure.

Method

Simple random sampling method was used throughout the duration of this study.

Materials

The following materials were used for this research; endorsing ink, plain paper (A4), plain tile, roller brush, wipes, isopropyl alcohol, cotton wool, pencil and meter rule. The above named materials made inking and measurement of participants as well as recording of data obtained during this study easier and possible.

Study design

The cross sectional descriptive design involving participants were selected using simple random sampling technique (Shariff et al. 2017). The use of this sampling method provided an opportunity for each member of the population to have an equal chance of being selected, resulting in the collection of large data from this random subset.

Focus

A total of 800 students aged between 18-30 years drawn from the University of Uyo community where the research was carried out, volunteered for the study. Large data were obtained to provide an equal opportunity for each member of the subset to be randomly selected.

Research question(s)

The pertinent question concerning this study is *"are there presence of foot deformities among students at University of Uyo?"*

Approach to participants, consent and ethics

Research ethics committee guidelines from University of Uyo, Nigeria such as informed consent from the participants and adult participants aged eighteen (18) and above, relating to the use of human subject for research purposes were carefully followed (Vollmann and Winau, 1996).

Methodology

The dynamic footprints of the participants were obtained manually within the University of Uyo community using the endorsing ink, plain paper (A4), plain tiles, roller brush, wipes, cotton wool and isopropyl alcohol. The participants were asked to place their feet on a plain tile which had been impregnated with endorsing ink that had been evenly distributed across the area of the tile using the roller brush, in order to make an impression on the plain white A4 sheet of paper. Both feet (right and left in male and female athlete/non-athlete) were cleaned using isopropyl alcohol using wipes to finally clean off the ink stain. The plantar arch index (PAI) was calculated by dividing the obtained footprints in three equidistant regions excluding the toes with the use of pencil and meter rule using the formular; PAI=B/(A+B+C), where A = fore-foot, B = mid-foot and C= hind-foot (Staheli et al. 1987) and expressed as MARF(Male athletes-right foot), MALF(Male athletes-left foot), MNARF(Male non-athletes-right foot), MNALF(Male non-athletes-left foot) for male and FARF(Female athletes-right foot), FALF(Female athletes-left foot), FNARF(Female non-athletes-right foot), FNALF(Female non-athletes-left foot) for females respectively. Measurement of PAI is shown in figure 1.

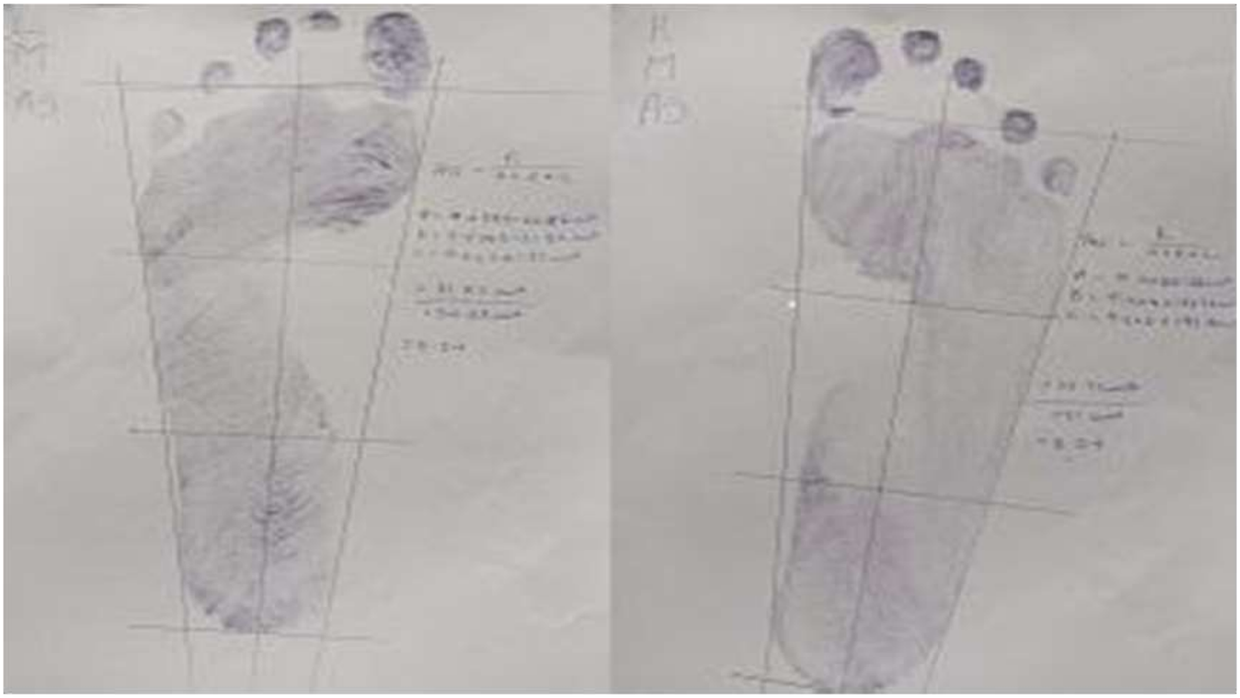

Figure 1: Image showing measurement of participants' footprint
Source: PAI measurement obtained from the participants.

In the table below, a total of 800 participants were used for this study including 500 male students (388 and 112 athletes and non-athletes respectively) and 300 female students (60 and 240 athletes and non-athletes respectively).

Category	Male	Female
Athlete	388	60
Non-Athlete	112	240
Total	500	300

Table 1: Showing the total number of participants

Study Setting

Participants whose footprints were used for this research were both male and female (500 and 300 respectively) students at University of Uyo, Nigeria. The study population was identified because of the following reasons: proximity and social relationship between students and the researchers.

Study Duration

The study took two months to be concluded.

Inclusion Criteria

The following individuals were included in the study: athlete and non-athlete, male and female gender.

Exclusion Criteria

The following individuals were excluded in the study: individuals with any recent fracture, individuals with neurological impairments, individuals not willing to participate and individual with trauma-like condition and bad ankle condition. The above mentioned exclusion criteria were chosen to prevent any false positive or false negative results obtained throughout the period of this study.

Results/Findings

Finding 1: *Male Athletes and Male Non-Athletes*

The table below shows the presence of cavus foot in the male athletes when compared to male non-athletes with normal foot arch. The PAI indexing the male athletes (0.20±0.001

and 0.20±0.001 for both right and left legs respectively) corresponds to Cavanagh and Rodgers arch index. This indicates the prevalence of high arch in male athletes. This type of arch arrangement in the male athletes could be attributed to the various sporting activities they engaged in.

MARF(Male athletes-right foot)	0.20±0.001$^{N.S, ***}$
MALF(Male athletes-left foot)	0.20±0.001*
MNARF(Male non-athletes-right foot)	0.25±0.007***
MNALF(Male non-athletes-left foot)	0.23±0.006*

Table 2: Comparison between Right and Left foot of Male Athletes and Male Non-Athletes[1]

Finding 2: Female Athletes and Female Non Athletes

The table below shows the presence of cavus foot in the female athletes when compared to female non-athletes with normal arch. The PAI index in the female athletes (0.20±0.003 and 0.19±0.002 for both right and left legs respectively) corresponds to Cavanagh and Rodgers arch index. Similar to what happened among male athletes, female athletes were found with high arch pattern. This may be connected to the various sporting activities, they actively engaged in.

FARF(Female athletes-right foot)	0.20±0.003$^{N.S}$
FALF(Female athletes-left foot)	0.19±0.002**
FNARF(Female non-athletes-right foot)	0.23±0.008$^{***, N.S}$

[1] N=4 @P<0.05, MARF vs. MALF – (N.S) Not significant between groups; MARF vs. MNARF– (***) Significantly different between groups; MARF vs. MNALF– (***) Significantly different between groups; MALF vs. MNARF – (*) Significantly different between groups; MALF vs. MNALF– (*) Significantly different between groups; MNARF vs. MNALF – (***) Significantly different between groups.

FNALF(Female non-athletes-left foot)	0.20±0.009 *, N.S

Table 3: Comparison between Female Athletes and Female Non Athletes

Finding 3: Male and Female Athletes

The table below shows the presence of cavus foot in both male and female athletes. The PAI index in both male and female athletes correspond to Cavanagh and Rodgers arch index. Both male and female students at the University of Uyo actively involved in sporting activities were found to possess high arch pattern.

MARF(Male athletes-right foot)	0.20±0.001 NS
MALF(Male athletes-left foot)	0.20±0.001 NS
FARF(Female athletes-right foot)	0.20±0.003 NS
FALF(Female non-athletes-left foot)	0.19±0.002 NS

Table 4: Comparison between Male and Female Athletes. Note: Not significant between the groups @ $p < 0.05$

Finding 4: Male and Female Non-Athletes

The table below shows the presence of normal foot arch in both male and female non-athletes. The PAI index in both male and female non-athletes correspond to Cavanagh and Rodgers arch index. Non- athletic male and female were found to possess normal arch pattern. This is as a result of their noninvolvement in sporting activities.

MNARF(Male non-athletes-right foot)	0.25±0.007 NS
MNALF(Male non-athletes-left foot)	0.23±0.006 NS
FNARF (Female non-athletes-right foot)	0.23±0.008 NS
FNALF(Female non-athletes-left foot)	0.22±0.009 NS

Table 5: Comparison between Male and Female Non- Athletes. Note: Not significant between the groups @ $p < 0.05$

Discussion

The purpose of this current study was to explore the impact of the different foot arches on both male and female students at the University of Uyo who engage in sporting activities as well as those who do not engage in sporting activities. It is important to know this impact for research purposes. In findings 1 and 2, we noticed the mean contact indices in male athlete subjects for both right and left foot to be 0.20± 0.001 and that in the female athletes (right and left foot) was 0.20± 0.003 and 0.19±0.002 respectively @ $p<0.05$. Our findings are indicative of cavus foot in male and female athletes of University of Uyo. Our results so far showed that, both male and female athletes have cavus foot. Cavus foot experienced by these set of students could be due to their involvement in rigorous physical activities that involves repetitive high-impact forces and demanding movements. These activities can lead to biomechanical alterations in the foot. Cavus foot may develop in athletes as a result of excessive supination, which is an outward rolling of the foot during weight-bearing activities and female athletes may experience hormonal fluctuations that can influence the development of cavus foot. The repetitive stress and impact can cause the foot arch to become excessively high. Research conducted on male and female collegiate athletes in New York showed a higher prevalence of cavus foot in male athletes compared to female athletes, suggesting that biomechanical differences between genders may contribute to the development of different foot arch types (D'Amico 2019). Athletes engage in rigorous physical activities which require high levels of foot stability and propulsion. The repetitive impact and stress associated with athletic movements can lead to biomechanical alterations in the foot. Research conducted by D'Amico (2019) supports the association between cavus foot and athletic activities. The study examined the foot arch morphology in a group of professional athletes and found a significantly higher prevalence of cavus foot compared to the general population. The authors attributed their findings to competitive high-impact forces experienced during sports, leading to foot biomechanical changes.

Similarly, findings from a comparison between male and female non-athletes showed the mean indices of 0.25± 0.007 and 0.23±0.006 respectively and 0.23±0.008 and 0.22±0.009 in female non-athlete respectively. Our findings on male and female non-athletes as well as female non-athlete indicated the presence of normal foot arch among the female students at the University of Uyo who are not involved in sporting activities. Non-athletes often exhibit normal foot or sometimes planus foot. They typically engage in less physically demanding activities, which may lead to normal or weaker foot muscles and ligaments. Prolonged periods of standing or sedentary lifestyles may contribute to planus foot, where the arch collapses or becomes less pronounced. Biomechanics play a significant role in foot arch development and can contribute to the differences observed between athletes and non-athletes. Prevalence of normal foot may be due to non-involvement in sporting activities while that of planus foot may be due to excessive pronation, which is an inward rolling of the foot.

Excessive pronation can cause the arch to flatten or collapse, resulting in planus foot. In our study, normal foot arch was found to be prevalent among non-athletic students (male and female) of University of Uyo. Prevalence of flat foot also varies among specific populations. For example, studies have shown a higher prevalence in overweight and obese individuals, as excessive weight can contribute to the collapse of the arch. Additionally, certain occupational activities and sports that involve prolonged standing or high-impact movements may increase the risk of developing flat foot. Pourghasem et al. (2016) investigated the prevalence of flat foot in a sample of 1158 school-aged children, reporting a prevalence rate of 32%. Genetics play a significant role in foot arch development and can contribute to the predisposition for certain foot deformities. Studies have identified specific genetic variations associated with both cavus foot condition.

However, the influence of genetics on foot arch morphology is complex and multi factorial. In the case of athletes with cavus foot, genetic factors may interact with biomechanical stressors to amplify the development of a high arch. This suggests that some athletes may have a genetic predisposition to cavus foot, which is further influenced by the demands of their sport. In contrast to athletes, non-athletes typically engage in daily activities that involve less repetitive impact and stress on the feet.

The absence of regular high-impact activities can result in weakened foot muscles and ligaments, leading to a collapse of the arch over time. There are inherent anatomical differences between individuals that can influence foot arch development. Some people may have a naturally high arch, while others may have a naturally low or flat arch. Athletes who have anatomical variations that predispose them to a higher arch may be more likely to develop cavus foot due to the stress placed on their feet during intense physical activities. In contrast, non-athletes may have anatomical factors that contribute to a lower arch or a more pronated foot position. This can be influenced by factors such as bone structure, ligament laxity, or foot alignment. These anatomical differences, combined with less physical activity, can contribute to the development of planus foot.

Hormonal factors, particularly in females, can contribute to the prevalence of different foot arch types. Studies have suggested that hormonal changes, such as those occurring during puberty or pregnancy, can affect ligament laxity and foot structure. Conversely, the hormonal influences on foot structure in non-athletes may differ. For example, hormonal changes during pregnancy can lead to increased foot ligament laxity, which may contribute to the development of planus foot. Athletes are more prone to developing cavus foot due to the biomechanical stressors involved in their intense physical activities, combined with potential anatomical predispositions. Anatomical differences and hormonal influences also play a role in the prevalence of these foot conditions. A study published in the Journal of Foot and Ankle Research examined the foot arch index of 60 athletes participating in different sports, including basketball, handball, soccer, and running. The researchers found that the athletes participating in high-impact sports, such as basketball and handball, had a higher prevalence of flat feet, compared to athletes in lower-impact sports like running (Kulcu et al., 2015). The results suggested that the repetitive and intense loading associated with high-impact sports may contribute to alterations in the foot arch.

Another study published in the Scandinavian Journal of Medicine and Science in Sports investigated the plantar arch index of 309 athletes involved in different sports, including track and field, soccer, basketball, volleyball, and handball. The researchers found that athletes participating in sports requiring quick changes in direction and agility, such as basketball and handball, had a higher incidence of flat feet compared to athletes in sports involving predominantly straight-line running, such as track and field (McPoil et al. 2015). The study concluded that the specific demands of certain sports can influence foot structure and the prevalence of flat feet among athletes. While these studies provide insights into the relationship between athletes and the plantar arch index, it's important to note that individual variations exist within each sport, and other factors like training techniques, footwear, and genetic predisposition may also influence foot arch characteristics. Further research is needed to establish a more comprehensive understanding of the relationship between athletes and the plantar arch index. Based on existing literature, it is hypothesized that athletes may have a higher plantar arch index compared to non-athletes, indicating a higher foot arch. This hypothesis is based on the biomechanical stress or repetitive impact experienced by athletes during physical activities, potentially leading to foot arch adaptations (Kulcu et al., 2015).

Conclusion

Cavus foot is prevalent among students (both male and female) involved in sporting activities in University of Uyo. The occurrence of cavus foot in athletes and normal arch foot in non-athletes can be attributed to a combination of biomechanical factors, injury history, genetic predisposition, body weight and activity levels. Athletes, with high-impact activities and repetitive stress on the foot, often exhibit a higher arch. Non-athletes, on the other hand, may experience normal arch or arch flattening due to genetic factors, excess weight, and a sedentary lifestyle. Understanding these differences can add to existing knowledge in the assessment, prevention, and management of foot conditions in both athletic and non-athletic populations.

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