Original Article

Normal values of foot arch parameters in adult Hausa population of Nigeria

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Abstract

Background: Deformities of foot arches have been implicated in various lower extremity injuries. Normal values of foot arch parameters have been studied in various populations. However, studies in Nigerian population are very limited and therefore require attention. **Objective:** The objectives of this study were to establish the normal values of foot arch parameters in adult Hausa population of Nigeria, to find the effect of gender on these parameters and to make comparison with previous studies in other populations. **Materials and Methods:** A total of 59 consented subjects (44 males, 15 females) that have no history of lower extremity deformity were recruited. Lateral radiograph of the right foot of each participant was taken in a bilateral standing position. For the medial longitudinal arch, navicular height (NH), first cuneiform height (FCH), calcaneal inclination angle (CIA), and calcaneal-first metatarsal angle (C1MA) were measured. Cuboid height (CH) and calcaneal-fifth metatarsal angle (C5MA) were measured for the lateral longitudinal arch. Measurements for angles and heights were performed using a universal plastic goniometer and a plastic ruler, respectively. **Results:** The mean (standard deviation [SD]) value of the NH was found to be 2.89 (0.54) cm, FCH 2.08 (0.44) cm, CIA 16.57° (3.30°), and C1MA 140.05° (5.63°). The mean (SD) of CH and C5MA was found to be 1.19 (0.31) cm and 160.96° (4.69°), respectively. There was no significant mean difference in those parameters between males and females. **Conclusion:** The mean values of foot arch parameters in adult Hausa population of Nigeria is comparable to previous studies on other populations, but generally lower than those of Caucasians. Similarly, our findings showed that gender has no significant effect on foot arch parameters.

Key words: Arch, foot, Hausa population, measurement, parameters

INTRODUCTION

The human foot is among the unique features of his anatomy that distinguishes him from other mammals (Hernandez *et al.*, 2007). Its evolution from that of quadruped mammals to bipedal foot of humans

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includes the formation of foot arches and adduction of first metatarsal bone (Lautzenheiser and Kramer, 2013). These anatomical structures provide humans with the ability to receive and transmit weight to the ground effectively and to adapt to uneven surfaces to facilitate bipedal gait. The foot arches are composed of a longitudinal arch, consisting of medial and lateral parts, and a transverse arch. In fact, the development of the medial longitudinal arch of the foot is the most important stage in the evolution of human bipedal locomotion (Saltzman *et al*., 1995). Compared to other parts of the body, the foot is greatly affected by anatomical variations, particularly the medial longitudinal arch (Cavanagh and Rodgers, 1987). These wide ranges of anatomical variations in the foot are consequences of heredity, age, gender, race, environmental conditions, and lifestyle as well as factors associated with footwear (Razeghi and Batt, 2002; Menz and Munteanu, 2005).

Foot posture can be classified into three categories based on the morphology of the medial longitudinal arch: (i) a normally aligned (normal) foot, (ii) pronated (low-arched or flat) foot in which the arch is below the normal range with the medial side of the foot coming into complete or near complete contact with the ground, and (iii) supinated (high-arched) foot in which the height of medial longitudinal arch is abnormally high. These variations in arch height have a considerable influence on lower limb gait kinematics, functional ability, and predisposition to musculoskeletal injury (Menz *et al*., 2012). For example, low-arched runners exhibit more medial injuries of soft tissue structures, particularly at the knee. The most common injuries include general knee pain, patellar tendinitis, and plantar fasciitis (Williams *et al*., 2001). On the other hand, high-arched runners exhibit more lateral injuries of bony structures particularly at the foot and ankle. The most common injuries include lateral ankle sprain, stress fractures of the fifth metatarsal, and iliotibial band friction syndrome (Williams *et al*., 2001).

Normal values of several parameters of arches of the foot have been studied among various populations. However, despite its clinical significance, studies on arches of the foot in Hausa population of Nigerian are very limited (Dahiru *et al*., 2013). Therefore, a study on this matter is required. Moreover, since racial differences have some influence on the anatomical structures (Braun *et al*., 1980), it is paramount to find the standard cut-off values for each population to avoid misdiagnosis. While several methods are available for the measurement of foot posture, radiographic measurements are considered to be the gold standard technique in the examination of bony structures of the foot (Pohl and Farr, 2010). The objectives of this study were therefore: to establish the normal values of foot arch parameters in adult in Hausa population of Nigeria, to find the effect of gender on these parameters and to make comparison with those values reported by previous studies in other population by using a radiographic approach.

MATERIALS AND METHODS

Subjects

This study was carried out at the Radiology Department of the Abubakar Tafawa Balewa University Teaching Hospital (ATBUTH), Bauchi, Nigeria. A total of 59 consented subjects (44 males, 15 females) that have no history of lower extremity deformity, lumbosacral injury, neurological disorder, or any systemic disease affecting the lower extremity were randomly recruited to participate in the study.

Ethical Approval

The study was approved by the Research and Ethics Committee of the ATBUTH.

Procedures

Lateral radiographs of the participants' right feet were obtained as they stood on a custom-made wooden platform kept at a distance of 100 cm from the X-ray tube, placing equal weight on both feet. The radiographic film cassette was placed vertically adjacent to the medial border of the right foot [Figure 1]. The same exposure of 6.3 mAs at 55 kV was maintained for each participant while acquiring the radiographs.

Measurements

Each X-ray film was placed on X-ray viewer for measurements [Figures 2 and 3]. A sharp pencil was used for drawing lines on the anatomical landmarks. On the radiographs, navicular height (NH), first cuneiform height (FCH), calcaneal inclination angle (CIA), and calcaneal-first metatarsal angle (C1MA) were measured for the medial longitudinal arch. Cuboid height (CH) and calcaneal-fifth metatarsal angle (C5MA) were measured for the lateral longitudinal arch. Measurements for angles and heights were performed by using a universal plastic goniometer and a plastic ruler, respectively.

Figure 1: The procedure for taking lateral radiographs of the foot

Figure 2: Measurement of navicular height, cuboid height and first cuneiform height

Figure 3: Measurement of calcaneal inclination angle, calcaneal-first metatarsal angle and calcaneal-fifth metatarsal angle

Definition of Terms

Navicular height

The height of the navicular bone was measured as the perpendicular distance from the most inferior aspect of the navicular bone to the horizontal supporting surface (Lung *et al*., 2009).

First cuneiform height

FCH was measured as the perpendicular distance from the most inferior aspect of the first cuneiform bone to the horizontal supporting surface (Lung *et al*., 2009).

Calcaneal inclination angle

This was measured as the angle formed between the tangent to the inferior surface of the calcaneus and horizontal supporting surface (Lung *et al*., 2009).

Calcaneal-first metatarsal angle

This was measured as the angle formed between the tangent to the inferior surface of the calcaneus and a line drawn along the dorsum of the midshaft of the fist metatarsal (Saltzman *et al*., 1995).

Cuboid height

This was measured as the perpendicular distance from the most inferior aspect of the cuboid to the horizontal supporting surface (Lung *et al*., 2009).

Calcaneal-fifth metatarsal angle

The C5MA was defined as the angle formed between the tangent to the inferior aspect of the calcaneus and a line drawn along the inferior aspect of the fifth metatarsal (Lung *et al*., 2009).

Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics (version 22) software, Armonk, New York. Normality of the data was checked using Kolmogorov–Smirnov test which showed that both the male and female data were normally distributed. An independent *t*-test was used to compare the mean differences in parameters between males and females. Since there was no significant difference in foot arch parameters between males and female groups, we combined data in the subsequent analysis. The descriptive statistics of the parameters are expressed as mean (standard deviation [SD]), 95% cxonfidence interval (CI), including minimum and maximum values.

RESULTS

The characteristics of the participants (age, height, and weight) were analyzed. The overall mean (SD) age of the male and female participants was 24.49 (5.42) (range 18–35) years, height 167.76 (7.39) (range 148–186) cm, and weight 57.72 (9.01) (range 40–82) kg. For detailed demographic data of the male and female participants, please refer to Table 1.

The mean (SD), 95% CI and range of values of the parameters studied are presented in Table 2. The overall mean (SD) of the NH was found to be 2.89 (0.54) (range 1.9–4.2) cm, FCH 2.08 (0.44) (range 0.8–3.0) cm, CIA 16.57° (3.30°) (range 12°–26°), and C1MA 140.05° (5.63°) (range (122°–155°). The mean (SD) of CH and C5MA was found to be 1.19 (0.31) (range 0.60–1.9) cm and 160.96° (4.69°) (range 151°–176°), respectively.

An independent *t*-test shows no significant difference between males and female groups in all the parameters ($P > 0.05$ and 95% CI crosses 0 in all parameters).

Comparison of our findings with previous studies is presented in Table 3.

DISCUSSION

The aims of our study were to establish standard cut-off values of foot arch parameters in normal adult Hausa population of Nigeria, to find the influence of gender on these parameters and to make comparison with values reported in other populations. Result of independent *t*-test showed no significant gender difference in foot arch parameters ($P > 0.05$ and 95% CI crosses 0 in all parameters). In general, the mean values of foot arch parameters found in our study are in agreement with previous studies (Barinem and Udoaka, 2015; Dahiru *et al*., 2013, Lung *et al*., 2009), but comparatively lower than those reported among Caucasians (Cavanagh *et al*., 1997, Saltzman *et al*., 1995; Menz and Munteanu, 2005;

Table 1: Characteristics of the participants

Gender	Characteristics	Mean (SD)	95% CI (lower, upper)	Minimum	Maximum
Male (*n*=44)	Age (years)	24.18 (5.09)	22.63, 25.72	18	35
	Height (cm)	169.84 (5.68)	168.11, 171.56	159	186
	Weight (kg)	58.88 (9.38)	56.03, 61.74	44	82
Female (*n*=15)	Age (years)	25.40 (6.40)	21.85, 28.94	18	35
	Height (cm)	161.66 (8.60)	156.90, 166.43	148	178
	Weight (kg)	54.33 (7.01)	50.44, 58.21	40	68
Overall (*n*=59)	Age (years)	24.49 (5.42)	23.07, 25.90	18	35
	Height (cm)	167.76 (7.39)	165.83, 169.68	148	186
	Weight (kg)	57.72 (9.01)	55.38, 60.07	40	82

SD - Standard deviation, CI - Confidence interval, *n* - Number of subjects

Table 2: Descriptive statistics of the measured parameters (*n*=59)

Parameters	Gender	Mean (SD)	95% CI (lower, upper)	Minimum	Maximum	*P**
NH (cm)	Male	2.95 (0.54)	2.79, 3.12	1.9	4.2	0.139
	Female	2.71 (0.52)	2.42, 3.00	2.0	3.8	
	Overall	2.89 (0.54)	2.75, 3.03	1.9	4.2	
FCH (cm)	Male	2.13 (0.45)	1.99, 2.27	0.80	3.0	0.173
	Female	1.95 (0.40)	1.73, 2.17	1.20	2.8	
	Overall	2.08 (0.44)	1.97, 2.20	0.80	3.0	
CIA (°)	Male	16.38 (3.34)	15.36, 17.40	12	26	0.422
	Female	17.20 (3.40)	15.31, 19.08	12	21	
	Overall	16.57 (3.30)	15.71, 17.43	12	26	
C1MA (°)	Male	140.18 (5.94)	138.37, 141.98	122	155	0.763
	Female	139.66 (4.74)	137.03, 142.29	133	148	
	Overall	140.05 (5.63)	138.58, 141.51	122	155	
CH (cm)	Male	1.18 (0.33)	1.08, 1.29	0.60	1.90	0.744
	Female	1.22 (0.27)	1.06, 1.37	0.80	1.80	
	Overall	1.19 (0.31)	1.11, 1.27	0.60	1.90	
C5MA (°)	Male	161.45 (4.72)	160.01, 162.89	151	176	0.173
	Female	159.53 (4.45)	157.06, 161.99	151	166	
	Overall	160.96 (4.69)	159.74, 162.19	151	176	

*No significant gender difference using independent *t*-test. NH - Navicular height, FCH - First cuneiform height, CIA - Calcaneal inclination angle, C1MA - Calcaneal-first metatarsal angle, CH - Cuboid height, C5MA - Calczaneal-fifth metatarsal angle, CI - Confidence interval, SD - Standard deviation

Murley *et al*., 2009). Variation in ethnicity could be the reason for these differences (Braun *et al*., 1980).

The height of the navicular bone is the commonly used criteria for the determination of arch height and classification of foot posture. A decrease in the NH below the normal range indicates the presence of flatfoot deformity. We found a mean NH of 2.89 (0.54) cm, which is comparable to those reported in Taiwanese (Lung *et al*., 2009) and Indians (Roy *et al*., 2012) populations. Roy *et al*. also reported slight gender differences in NH, with the male subjects having higher values than the female counterparts. In contrast, we found no significant differences between males and females in all the parameters. The findings of Lautzenheiser and Kramer, (2013) are consistent with ours, as they reported no significant differences in angular measurements of foot arch parameters between male and female groups. The mean NH found in the present study is however; lower than the values reported by Cavanagh *et al*., (1997) in healthy British population. Height of the first cuneiform bone is also a good determinant of foot posture, with lower value signifying a decrease in arch height. The mean FCH in our study is 2.13 (0.45) cm, which is similar to the value reported by Lung *et al*. among Taiwanese population.

The CIA measures the inclination of the calcaneus, which makes it a good predicator of hindfoot alignment. It decreases in low-arched feet. We found a mean CIA of 16.57° (3.30°). This is consistent with the findings of Dahiru *et al*., 2013 who reported a mean CIA of 15.42° (2.94°) and 15.08° (2.87°) among Hausa ethnic group and overall Nigerian population, respectively. Similarly, Barinem and Udoaka, (2015) reported comparable values among Nigerian population with no significant statistical difference between males and females. However, on comparison with studies among Australian (Murley *et al*., 2009; Menz and Munteanu, 2005; Bryant *et al*., 2000), American (Saltzman *et al*., 1995; Lautzenheiser and Kramer, 2013), British (Cavanagh *et al*., 1997), and Turkish (Akdogan *et al*., 2012) populations; our findings showed that Hausa population have lower CIA, which indicates a flatter arch. Moreover, Yalcin *et al*. (2010) reported a mean CIA of 41.0° (6.9°), the value of which ranged from 18° to 66° (Yalcin *et al*., 2010). Comparatively, this value is more or less twice our finding. In fact, a study among Turkish with flatfoot deformity revealed a mean CIA of 14.50° (3.55°) and 10.84° (2.49°) among asymptomatic

Table 3: Comparison of our findings with those reported in previous studies

Parameters	Population	Subjects	Age (years)	Mean (SD)	Authors
NH (cm)	Present study	59 asymptomatic	18-35	2.89 (0.54)	
	Taiwanese	57 asymptomatic	18-33	3.44 (0.72)	Lung *et al.*, 2009
	Australian	95 symptomatic	62-94	3.11 (6.50)	Menz and Munteanu, 2005
	Australian	30 asymptomatic	23-68	3.13 (7.30)	Bryant *et al.*, 2000
	British	50 asymptomatic	63.3	4.02 (0.82)	Cavanagh *et al.*, 1997
FCH (cm)	Present study	59 asymptomatic	18-35	2.08 (0.44)	
	Taiwanese	57 asymptomatic	18-33	2.40 (0.47)	Lung *et al.*, 2009
CIA (°)	Present study	59 asymptomatic	18-35	16.57 (3.30)	
	Nigerian	302 asymptomatic	-	14.50 (3.55)	Barinem and Udoaka, 2015
	Nigerian	63 asymptomatic	-	15.08 (2.87)	Dahiru *et al.*, 2013
	Turkish	50 symptomatic	4-78	22.98 (4.01)	Akdogan *et al.*, 2012
	Turkish	95 asymptomatic	11-85	41.0 (6.90)	Yalcin *et al.*, 2010
	Taiwanese	57 asymptomatic	18-33	17.40 (6.70)	Lung *et al.*, 2009
	Australian	91 asymptomatic	18-47	20.90 (3.40)	Murley *et al.*, 2009
	Australian	95 symptomatic	62-94	21.0 (7.0)	Menz and Munteanu, 2005
	Australian	30 asymptomatic	23-68	24.2 (5.8)	Bryant *et al.*, 2000
	American	100 symptomatic	46	21.0 (6.0)	Saltzman *et al.*, 1995
	British	50 asymptomatic	63.3	22.50 (6.10)	Cavanagh *et al.*, 1997
C1MA (°)	Present study	59 asymptomatic	18-35	140.05 (5.63)	
	Taiwanese	57 asymptomatic	18-33	152.50 (5.4)	Lung *et al.*, 2009
	Australian	91 asymptomatic	18-47	132.8 (4.0)	Murley *et al.*, 2009
	Australian	95 symptomatic	62-94	133.0 (9.0)	Menz and Munteanu, 2005
	American	100 symptomatic	46	132.0 (10.0)	Saltzman *et al.*, 1995
CH (cm)	Present study	59 asymptomatic	18-35	1.19 (0.31)	
	Taiwanese	57 asymptomatic	18-33	1.63 (4.10)	Lung *et al.*, 2009
C5MA (°)	Present study	59 asymptomatic	18-35	160.96 (4.69)	
	Taiwanese	57 asymptomatic	18-33	160.90 (6.60)	Lung *et al.*, 2009

*Asymptomatic refers to normal subjects without foot problems, **Symptomatic refers subjects with foot problems. NH - Navicular height, FCH - First cuneiform height, CIA - Calcaneal inclination angle, C1MA - Calcaneal-first metatarsal angle, CH - Cuboid height, C5MA - Calcaneal-fifth metatarsal angle, SD - Standard deviation

and symptomatic group respectively, which is similar to our findings in normal Hausa population. In addition to this, the CIA of the flatfoot group of Australian population reported by Murley *et al.*, (2009) also similar to our normal population. This is a further confirmation that adult Hausa population have lower arch compared to Caucasians [Table 3].

The C1MA is a measure of the relationship between forefoot and hindfoot (Lung *et al.*, 2009), larger angle indicates flatfoot deformity. The mean C1MA in our study was found to be 140.05° (5.63°), which is higher than those reported by (Murley *et al.*, 2009; Saltzman *et al.*, 1995; Menz and Munteanu, 2005), but similar to the mean value of the flatfoot Australians reported Murley *et al.*, 2009. This also indicates flatter arch in Hausa population compared to the Caucasians. Although the mean NH, FCH, CIA, CH, and C5MA in this study appears to be similar to those reported in Taiwanese (Lung *et al.*, 2009), their C1MA proves otherwise, showing larger value compared to our population. In addition, their C1MA ranges from 138.1° to 163.9°, which is more than our range of 122° to 155°. This could be due to the differences in the anatomy of the forefoot or its relationship with midfoot since the mean values of the bony structures of the hindfoot and midfoot bone are similar in both populations.

The mean height of the cuboid bone found in our study is 1.19 (0.31) cm, which is similar to the findings of Lung *et al.*, (2009). CH has also been found to be a good parameter for classifying foot type (Lung *et al.*, 2009). Larger C5MA also indicates flatfoot. We found a mean C1MA of 160.96° (4.69°) in our study. This value is also similar to those reported by Lung *et al.*, 2009.

This study has some limitations. First, it was conducted in Northern part of Nigeria where other ethnic minorities residing alongside Hausa communities often regard themselves as Hausas. Hence, some of these might be erroneously included in our study and thus our sample could not be purely native Hausa's. Second, the study was conducted in northern Nigeria where Hausa ethnic groups are predominant. Thus, generalization of our findings to include Hausa population residing elsewhere must be made with caution since environmental factors are reported to have some influence on arch morphology.

CONCLUSION

The normal values of foot arch parameters among adult Hausa population of Nigeria have been established. Based on our findings, normal values of these parameters differ considerably from other races. We found that Hausa

population have flatter arch compared to Caucasians. Therefore, we conclude that using the normal values of foot arch parameters of a particular population to diagnose foot deformities in another population might be masked by errors leading to misdiagnosis.

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Conflicts of Interest
There are no conflicts of interest.

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