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Is the Arch Index Meaningful

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ABSTRACT

C. W. LUNG, S. W. YANG, and L. F. HSIEH, Is the Arch Index Meaningful. Korean Journal of Sport Biomechanics, Vol. 19, No. 2, pp. 187-196, 2009. The foot type is classified into normal, high or low arch according to either foot print or medial longitudinal arch (MLA) height. Plantar fasciitis, heel pain, Achilles tendinitis, stress fracture, metatarsalgia, knee pain, shin splint pain, and etc are common foot disorders and associate to the foot type. The purpose of this study was to evaluate several suggested bony inclination used to classified the abnormal foot and if the arch index (AI) was correlated with foot morphology. Lateral view and dorso-plantar view of radiographic images and flatbed scanner measurements obtained from 57 college students were analyzed. Results showed that AI measured in this study was higher than Caucasian Americans and European, but similar with African. The ethnic origin could influent the AI distribution. The AI provided a simple quantitative means of assessing the structure of lateral and medial longitudinal arches. The correlation coefficients of true bone height with AI could be further improved by normalized foot width rather than foot length. AI also demonstrated as a good indicator of inclination between calcaneus-fifth metatarsal (CalM5) and calcaneus-first metatarsal (CalX), it is a good means to classify the foot type.

KEYWORDS : FOOT MORPHOLOGY, ARCH INDEX, INCLINATION ANGLE, RADIOGRAPHY

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Ⅰ. Introduction

The bony structure alignment of the foot has a great influence on human mobility performance. Lower extremity injury and tendon-muscular pain are highly related to the foot structure. The high-arch-foot runner shows a greater incidence of lateral ankle sprain, Achilles tendonitis and tibia stress fracture injury; while the low arch foot runner has higher occurrence on knee pain, plantar fasciitis, and midfoot sprain injury. Therefore, knowing the exact foot type in order to obtain an adequate orthotic intervention or exercise program is very important to prevent the foot from injury.

There are at least four methods to classify the foot type based on the morphological measurement, such as visual non-quantitative inspection, anthropometric measure (Burns & Crosbie, 2005), footprint index (Cavanagh & Rodgers, 1987), as well as radiographic parameters are commonly used (Chen et al., 2006). Among these methods, the radiographic measurement is the most reliable method to assess the morphology of the medial longitudinal arch (McCrory et al., 1997). A foot is categorized into either normal, high or low arch according to the several variables measured from the radiographic images, including talo-calcaneal angle (TalCal), calcaneal-fifth metatarsal angle (CalM5), calcaneal pitch angle (CalX), calcaneal-first metatarsal angle (CalM1), or talo-first metatarsal angle (TalM1). TalCal normally ranges from 25 to 45 degrees. A large angle means a larger hindfoot valgus angulations which suggests a lower arch foot (Aronson et al., 1983). CalM5 normally ranges from 150 to 170 degrees, with the larger the angle the lower the navicular height or lower arch foot.(Moller, 2000) CalX has normal range from 20 to 25 degrees, which checks the calcaneal inclination. A small CalX suggests a lower arch height (Saltzman et al., 1995). CalM1 is the measure of the forefoot and hindfoot with normal range from 140 to 160 degrees, a larger degree suggests a lower arch (Thompson et al., 1982). TalM1, ranging from -4 to 4 degrees, is a medial view measurement of the forefoot and hindfoot. Flatfoot shows a higher angle (Gould, 1983).

Although the radiographic measurement is accurate and reliable, the time consume, X-ray dose as well as the cost present certain draw back; arch index (AI) was therefore introduced by Cavanagh and Rodgers. By statically analyzing 107 feet, the authors concluded that the normal AI value fit in the quartiles distribution is ranged from 0.206 to 0.263 and the mean value was 0.230 + 0.0463 (Cavanagh & Rodgers, 1987) . The method was soon adapted and has been considered as a convenient means to determine the foot type (Hawes et al., 1992;McPoil & Cornwall, 2006). An AI of less than 0.21 has the indication of a high-arch foot and the value greater than 0.26 is indicative of a flatfoot. How well the simple means (AI) can represent the foot type has been studies by McCrory (McCrory et al., 1997) and Menz (Menz & Munteanu, 2005). The results showed that the correlation between the AI and navicular height was 0.45 ~ 0.67, and the correlation increased when the navicular height was normalized to foot length (r = 0.52 ~ 0.71). McCrory et al. (McCrory et al., 1997) suggested that although the AI provided a simple quantitative method to assess the foot type, only half of the diagnostic accuracy among subjects. This might be because only the midfoot structure was considered, not including the foot structure as a whole. The flatfoot might be associated with excessive forefoot varus combined with hindfoot excessive valgus (Greisberg et al., 2003). This might also explain the inconclusive intervention efficacy using the arch support in the midfoot area to correct the alignment of forefoot and hindfoot. The purpose of this study was to find the best correlation of the simple measurement method (AI) from footprint to the bony constructed angles from X-ray.

II. Methods

This study comprised 57 college students (28 men and 29 women, aged 21.3 ± 2.5 years; 166.9 ± 8.3 cm tall; weighted 60.9 ± 12.4 kg, and BME 21.7 ± 3.5 kg/m2). All foot-examinations were carried out at Shin Kong Wu Ho-Su memorial hospital, Taipei with Institutional Review Board approval; and all subjects were given informed consent prior to participation. Exclusion criteria were history of injury on the lower extremities which could have changed bone structure within six months prior to the commencement of experimental test.

Arch index calculation

The footprint was scanned using an A3 size flatbed scanner (GT-15000; Epson TM, Japan) with the subject quite standing upright posture. The arch index was then calculated by drawing the lines that constructed the most board tangent of medial and lateral apexes of the footprint image (L1 and L2, Figure 1) as well as the mid-line of foot L3 (Tareco et al., 1999) which differed from the line constructed using the second toe tip to mid heel center point described by (Cavanagh & Rodgers, 1987). The mid-line of foot L3 extended from the most anterior digit border to the most posterior heel border; and the toeless portion was then equally divided into three regions. The AI was calculated as the ratio of the middle effective area to the entire toeless footprint area.

Radiographic image examination

The foot bony morphology was determined via radiographic measures. Arterial-Posterior view and dorso-plantar view radiographs were taken by a standard technique in a full weight-bearing standing posture (McCrory et al., 1997;Komeda et al., 2001). The digital 2D radiographic images were examined and 36 bony land markers were identified (Komeda et al., 2001). A Cartesian coordinate system was set the origin at the lowest ground contact point of the calcaneus with X-axis connecting to the lowest contact point of first metatarsal head as shown on Figure 2A.

Five additional lines (Figure 2A) on the talus, calcaneus, first metatarsal, and fifth metatarsal from the lateral radiographs were then constructed using anatomical land markers as following:

1. Talar line: the longitudinal axis of the talus determined by two points equidistant from the cephalic and caudal margins of the body and the neck of the talus (Aronson et al., 1983);
2. Calcaneal line: longitudinal axis of the calcaneus defined by two points equidistant from the cephalic and caudal margins of the posterior tuberosity and at the level of the sustentaculum tali (Aronson et al., 1983);
3. Calcaneal pitch line: drawn along the inferior surface of the calcaneus (Kalen & Brecher, 1988);
4. First metatarsal line: determined by the four points of superior and inferior cortices of the shaft of the first metatarsal bone (Younger et al., 2005);
5. Fifth metatarsal pitch line: drawn along the inferior surface of the fifth metatarsal bone (Komeda et al., 2001);

Foot type classification angles were then constructed by these five lines:

1. TalCal: formed by Talar line and Calcaneal line, the angle is used to check the excessive heel

valgus (Aronson et al., 1983);

2. CalM5: formed by calcaneal pitch line and fifth metatarsal pitch line, the angle is commonly used to classify the flatfoot (Younger et al., 2005);
3. CalX: formed by calcaneal pitch line and X-axis, the angle is used to describe the calcaneal inclination (Saltzman et al., 1995);
4. CalM1: formed by intersection of calcaneal line and first metatarsal line, it is also commonly used to classify the flatfoot (Saltzman et al., 1995);
5. TalM1: formed by intersection of tarsal line and first metatarsal line (Younger et al., 2005);

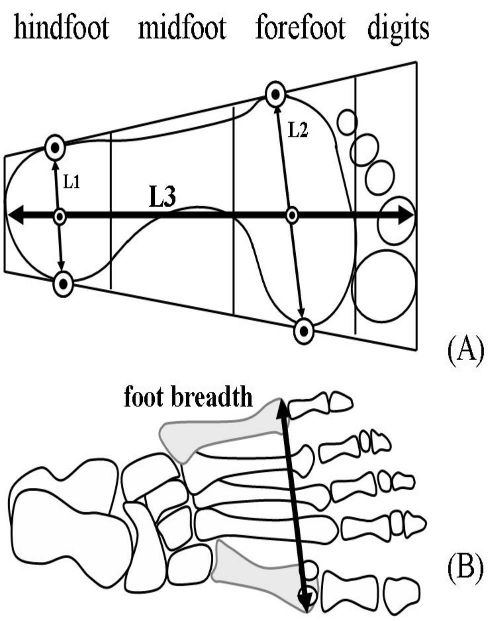

Figure 1. Weight-bearing dorso-plantar view. (A) Contact area, the lines L1 and L2 that constructed the most board tangent of medial and lateral apexes of the footprint image as well as the mid-line of foot L3. The mid-line of foot L3 extended from the most anterior digit border to the most posterior heel border. The medial axis divided the toeless footprint area into thirds. The AI was calculated as the ratio of the area of the middle third of the toeless footprint to the entire toeless footprint area; (B) Radiographic, foot breadth was taken from the metatarsal width.

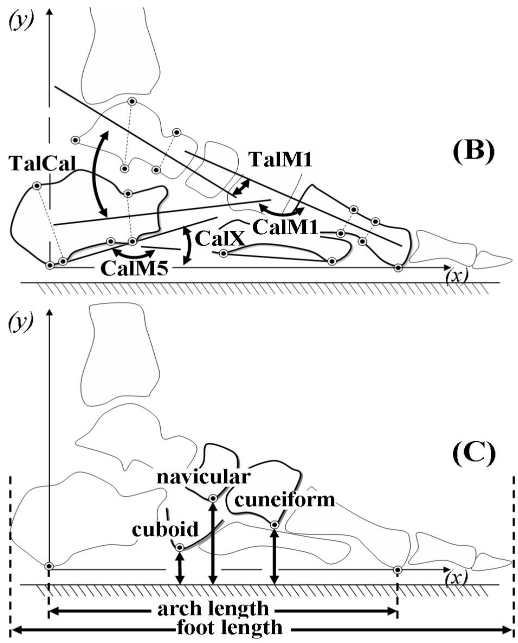

Figure 2. (A) The angle of the foot, TalCal: talocalcaneal angle; CalM5: calcaneal-fifth metatarsal angle; CalX: calcaneal pitch angle; CalM1: calcaneal-first metatarsal angle; TalM1: talo-first metatarsal angle; (B) The length and height of the foot, it is include the foot length, arch length, cuboid height, navicular height, and cuneiform height.

The foot breadth (Figure 1B) in this study was taken from the metatarsal width, which was defined from the most lateral point of the 5th metatarsal head to the most medial point of the 1st metatarsal head (Bryant et al., 2000). The foot length (Figure 2B) was formed from the most posterior point of the calcaneus to the most anterior point of the distal phalanx of whichever toe being on the ground (McCrory et al., 1997). The vertical distances of medial arch (Figure 2B) were calculated from the most inferior edge of cuboid, navicular, and cuneiform bones to the X-axis defined as cuboid, navicular, and cuneiform height, respectively (Younger et al., 2005;McCrory et al., 1997). Those measurements were further standardized by the foot length and foot breadth (McCrory et al., 1997;Menz & Munteanu, 2005).

Table 1. The correlation coefficients (r) of AI with anthropometric and radiographic parameters,
(N = 114 feet; AI mean (SD) = 0.255 (0.067); AI rang = 0.050 ~ 0.407.

parameters	mean	(SD)	min	~	max	r	p	
anthropometry								
age (yr)	21.3	(2.5)	18.0	~	33.0	0.045	0.638	
height (cm)	166.9	(8.3)	147.5	~	188.0	-0.066	0.488	
mass (kg)	60.9	(12.4)	38.3	~	100.0	0.147	0.119	
BMI (kg/m2)	21.7	(3.5)	15.7	~	31.9	0.239	0.011	
Foot length (mm)	245.5	(18.2)	205.1	~	295.6	-0.102	0.278	
Foot breadth (mm)	90.1	(6.3)	75.1	~	105.8	0.171	0.069	
arch length (mm)	159.0	(11.4)	132.3	~	190.9	0.055	0.559	
cuboid height (mm)	16.3	(4.1)	5.6	~	26.8	-0.595	<0.001	(*)
navicular height (mm)	34.4	(7.2)	19.3	~	57.4	-0.580	<0.001	(*)
cuneiform height (mm)	24.0	(4.7)	12.8	~	40.9	-0.516	<0.001	(*)
Bone angle (°)								
	27.8	(5.8)	17.0	~	41.8	0.262	0.005	(*)
CalM5	160.9	(6.6)	146.3	~	177.4	0.699	<0.001	(*)
CalX	17.4	(6.7)	2.0	~	32.5	-0.707	<0.001	(*)
CalM1	152.5	(5.4)	138.1	~	163.9	0.527	<0.001	(*)
TalM1	0.2	(8.6)	-20.0	~	20.4	0.506	<0.001	(*)
Normalized foot length (%)								
arch length/foot length	64.8	(2.0)	60.1	~	68.6	0.373	<0.001	(*)
cuboid height/foot length	6.7	(1.7)	2.1	~	10.1	-0.551	<0.001	(*)
navicular height/foot length	14.0	(2.8)	8.1	~	21.0	-0.562	<0.001	(*)
cuneiform height/foot length	9.8	(1.9)	5.1	~	14.9	-0.481	<0.001	(*)
Normalized foot breadth (%)								
arch length/foot breadth	176.8	(11.9)	152.5	~	237.9	-0.126	0.182	
cuboid height/foot breadth	18.1	(4.7)	6.1	~	28.2	-0.623	<0.001	(*)
navicular height/foot breadth	38.3	(8.1)	21.4	~	60.4	-0.626	<0.001	(*)
cuneiform height/foot breadth	26.7	(5.3)	13.8	~	43.1	-0.568	<0.001	(*)

TalCal: talocalcaneal angle; CalM5: calcaneal-fifth metatarsal angle;
CalX: calcaneal pitch angle; CalM1: calcaneal-first metatarsal angle; TalM1: talo-first metatarsal angle.
* indicates statistically significant correlation ($p<0.01$)

Data Analysis

Both feet of the same subject was considered as independent foot (Menz, 2004).The normality of data distribution was check first by the Kolmogorov-Smirnov test, the significant level for this test was set to 5%. Pearson correlation coefficients with significance of 1% was used for the correlations between AI and measurements (Chen et al., 2006).

Ⅲ. Results

The results of the Kolmogorov-Smirnov test showed that the all of the parameters were normally distributed ($p > 0.05$). The measured variables of 114 feet were used for the following analysis.

The subjects' characteristics are shown in table 1. The mean AI was 0.255 ± 0.067 (ranged from 0.050 to 0.407, normal foot type ranged from 0.219 to 0.295) (Table 1). The AI was independent to demographic parameters such as age, height, mass, BMI, foot length, foot breadth, or arch length. However, medial arch height of cuboid, navicular, and cuneiform had strong correlation with the AI value ($p < 0.001$) (Table 1).

Four angles bony angles (CalM5, CalX, CalM1, and TalM1) were correlated to the AI, especially CalM5 ($r = 0.699$) and CalX ($r = -0.707$) were strong related to the AI. The CalM5 had the quartiles 25% to 75% ranged from 156.6° to 164.9°, and CalX's quartiles ranged from 13.8° to 22.1° (Table 2).

The 25 to 75% quarterlies of true navicular height were 28.7 to 39.8 mm. The heights of cuboid, navicular, and cuneiform normalized by both foot length and breadth were significantly correlated to the AI. Among these normalized heights, navicular height/foot breadth showed the strongest correlation with the AI ($r = 0.626$) (Table 3).

Ⅳ. Discussion

The AI measured in this study (0.255 ± 0.067) was higher to that of Caucasian Americans (0.23 ± 0.05) (Cavanagh & Rodgers, 1987) and European (0.23 ± 0.05) (van Schie & Boulton, 2000). The evaluation of Malawians also showed higher AI (0.26 ± 0.07) which was statistically higher than Caucasian Americans ($p < 0.001$) and Europeans ($p < 0.01$) (Igbigbi and Msamati, 2002). Apparently, the ethnic origin can influence the results (Braun et al., 1980). Therefore, the reported normal AI value of 0.206 to 0.263 needs to justify according to the racial and region, otherwise, the normal upper limit of 0.295 in Taiwanese population will be classified as flatfoot in Caucasian population.

Navicular height is the commonly used to distinguish the foot type (McCrory et al., 1997). Previous studies suggested no consistent correlation of AI with navicular height (Menz & Munteanu, 2005;McCrory et al., 1997;McPoil & Cornwall, 2006). These conflicts might be due to the selected study population, such as the aging effect of thinning fat pad thickness and over body weight of flattening the longitudinal arch (Jahss et al., 1992). The moderate correlation found in our study matched the results by McPoli and Cornwall with similar age group of subjects (McPoil & Cornwall, 2006). Wearing et al. reported that the higher BMI the larger AI , however in this study, the correlation between the AI and BMI was week($r = 0.239$), it might be due to the main population of this study was within normal BMI range (Wearing et al., 2004).

Studies have demonstrated that the AI is a useful means to evaluate the height of navicular and further to classify the foot type, this study provides additional information on the cuboid height which can be used as foot type classification.

Both foot length and breadth can affect the correlation, for instance, subjects with the same navicular height, the one who has a longer foot length may be classified in to lower arch group. Normalized the navicular height by the foot length did improve the correlation with AI (Table 3, Queen 2007, McCrory 1997), but this study and some others showed adverse results (Menz & Munteanu, 2005); However, normalized with the foot breadth showed better improvement. The foot breadth may be more impartment than foot length in obtaining better correlation with AI.

Table 2. Mean, standard deviation (SD), and quartile (Q) of anthropometric and radiographic parameters, n = 114 feet.

parameters	-2SD	-1SD	Q1	Q3	+1SD	+2SD
anthropometry						
AI	0.121	0.188	0.219	0.295	0.322	0.390
age (yr)	16.3	18.8	20.0	23.0	23.9	26.4
height (cm)	150.3	158.6	160.0	172.0	175.2	183.6
mass (kg)	36.0	48.5	50.8	67.5	73.3	85.7
BMI (kg/m2)	14.7	18.2	19.4	23.4	25.2	28.7
Foot length (mm)	209.0	227.3	233.4	255.6	263.8	282.0
Foot breadth (mm)	77.5	83.8	86.3	94.7	96.5	102.8
arch length (mm)	136.3	147.7	151.5	165.5	170.4	181.7
cuboid height (mm)	8.0	12.2	13.6	19.1	20.4	24.5
navicular height (mm)	20.1	27.3	28.7	39.8	41.6	48.7
cuneiform height (mm)	14.6	19.3	21.2	27.1	28.7	33.4
Bone angle (°)						
TalCal	16.1	21.9	23.9	32.3	33.6	39.5
CalM5	147.7	154.3	156.6	164.9	167.5	174.1
CalX	3.9	10.7	13.8	22.1	24.1	30.8
CalM1	141.7	147.1	149.1	156.9	157.8	163.2
TalM1	-17.0	-8.4	-6.0	4.7	8.9	17.5
Normalized foot length (%)						
arch length/foot length	60.9	62.8	63.8	66.3	66.8	68.7
cuboid height/foot length	3.3	5.0	5.4	7.9	8.3	10.0
navicular height/foot length	8.5	11.2	11.7	16.0	16.8	19.6
cuneiform height/foot length	6.0	7.9	8.6	11.1	11.7	13.6
Normalized foot breadth (%)						
arch length/foot breadth	152.9	164.8	169.1	184.1	188.7	200.7
cuboid height/foot breadth	8.8	13.5	15.2	21.5	22.8	27.4
navicular height/foot breadth	22.2	30.3	32.5	43.5	46.4	54.4
cuneiform height/foot breadth	16.2	21.4	23.3	30.0	31.9	37.2

TalCal: talocalcaneal angle; CalM5: calcaneal-fifth metatarsal angle; CalX: calcaneal pitch angle; CalM1: calcaneal-first metatarsal angle; TalM1: talo-first metatarsal angle.

TalCal angle is used to demonstrate the subtalar valgus (Aronson et al., 1983). This study suggests that it is not a good variable to classify the foot type and the AI can't be used extensively in the assessment subtalar valgus. The TalM1 was proposed as the medial longitudinal arch identifier for patients with symptomatic flatfoot (Younger et al., 2005). The result of mild correlation between the AI and TalM1 (r = 0.506) was consistent with other study (Chen et al., 2006). This result indicated that the bone relation in the forefoot could contribute to the change in the AI. Healthcare professionals treating flatfoot should note that the cause of an increase in the AI might originate from the pathology of the forefoot.

Table 3. The correlation coefficient between the AI and navicular height

study	age (year)	height (m)	mass (kg)	BMI (kg/m2)	r NH	r NH/FL
Palpation a						
Hawes et al.,1992(Canada)	34.2 (20.4~71.4)	177.0±6.6	77.7±9.8	–	-0.39	–
McPoil and Cornwall,2006(USA)	26.3 (21~38)	–	–	–	-0.48	–
Queen et al.,2007(USA)	24.8±2.1	–	73.3±16.3	–	-0.42	-0.61
Radiography b						
McCrory et al.,1997 (UK)	63.3±13.1	1.7±0.1	70.0±10.5	–	-0.67	-0.71
Menz and Munteanu,2005(Australia)	78.6±6.5	1.61±0.08	69.9±13.3	26.8±4.4	-0.52	-0.51
McPoil and Cornwall,2006(USA)	26.3 (21~38)	–	–	–	-0.45	–
present study(Taiwan)	21.3±2.5	166.9±8.3	60.9±12.4	21.7±3.5	-0.58	-0.56

Abbreviation: NH, navical height; NH/FL, nevaical height divided by foot length; a navicular height determined by palpation. A caliper was used to measurement the height between the bottom of the navicular tuberosity and the floor. b navicular height determined by radiography.

The inclination angle of CalM5, CalX showed strong correlations with the AI (r = 0.699 and r = -0.707, respectively). The CalM1 and CalM5 have been used to describe the medial and lateral longitudinal arch of the foot, and the CalX has been used to describe the inclination of the calcaneus (Saltzman et al., 1995). Simkin and Leichter suggested that in a vertical jump the change of inclination of the calcaneus had higher energy storage than the height change of longitudinal arch (Simkin & Leichter, 1990). Arangio & Salathe, also found that the medial displacement of calcaneal could reduce the excess forces in the longitudinal arch of the flat foot(Arangio & Salathe, 2001). These findings indicated that the calcaneus inclination could affect the AI value.

Recent studies considered the bone alignment of the entire foot as the predictor of the height of medial longitudinal arch. Foot posture index (FPI) (Burns & Crosbie, 2005) was scored by visual examination of the pictures of the foot posture. Although the method was easy and low in cost, the rathe examination and objective bias is unavoidable influencing the evaluation results. Besides, it can't provide a simple quantitative of bone heights and angles.

Ⅴ. Conclusions

The AI measured in this study was higher than Caucasian Americans and European, but similar with African. The ethnic origin could influent the AI distribution. This study suggested that AI provided a simple quantitative means of assessing the structure of lateral and medial longitudinal arches. The correlation coefficients of true bone height with AI could be further improved by normalized foot width rather than foot length. AI also provided as a good indicator of inclination between calcaneus-fifth metatarsal (CalM5) and calcaneus-first metatarsal (CalX).

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