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Comparison of ratio loaded and unloaded foot area of flat foot and healthy foot in younger adults

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Abstract. This study is aimed to investigate loaded and unloaded foot area ratio (RFA, ratio of foot area) as special tests for the basis of clinical examination of flat foot and healthy foot. Type of foot is determined by Cavanagh's arch indexes (AI) which is the ratio between mid foot area to entire footprint area excluding the toes. Type of foot is called high arch when AI<0.21, normal/healthy foot when 0.26>AI > 0.21 and flat foot when AI>0.26. The entire loaded foot and footprint area for evaluating AI derived from a digital footprint is modified from document scanner, while the entire unloaded foot area derived from a 3D scanner. One hundred and two healthy students (87 males and 15 females, average aged 20 years and average BMI 22.51 kg/m^2) is asked voluntarily for doing footprint and scan. From 102 subjects found 63 participants identified as flat foot and 31 subjects are healthy feet. This study proves that the higher the value of AI the higher the value of RFA and foot type can be predicted by the value of RFA. For type of foot is high arch RFA<0.49, for healthy foot 0.55>RFA>0.49 and for flat foot RFA>0.55.

1 Introduction

The foot supports the body weight and are subjected to many ground reaction forces during daily activities. Foot acts as a lever to resist thrust during walking, running and jumping. Arch is a segmental elevation of the foot which can be classified into three arches: medial longitudinal arch (MLA), lateral longitudinal arch and transverse arch [1]. Variation in the height of MLA leads to two main common foot deformities, pes planus (flat foot) and pescavus (high arch). Pes planus is a flat foot condition in which MLA diminishes, otherwise for high MLA is called pes cavus [2]. A normal foot must be plantigrade, have normal anatomical disposition and physiomechanics, be resilient with proper springiness to provide a rhythmic normal gait [3].

Some parameters are considered as the predisposing factors of flat foot, such as age, sex, body composition, family history, and types of footwear [4]. Males were twice more reliable to have flat foot than females. Overweight and obese children were more likely to have flat foot with proper weight [5].

Cavanagh's and Staheli's arch index were most commonly used for clinical diagnosis by using footprint. Cavanagh's arch index (AI) determine arch type from division of mid foot area to entire footprint area excluding the toes (Fig. 1a). If AI less than 0.21, arch type of foot is called high arch. If AI is between 0.21 and 0.26, arch type of foot is called normal arch, and If AI is greater than 0.26, arch type of foot is called flat foot [6]. Staheli has characterized the width of the foot in the area of the arch and heel and the ratio between these widths was called the Staheli's plantar arch index (Fig. 1b) [7]. A normal plantar arch index (PI), according to the Pediatric Orthopaedic Society is the one comprised within 2 standard deviations (SD) of the population average. If PI values are equal or above the sum of 2 is considered as flat foot.

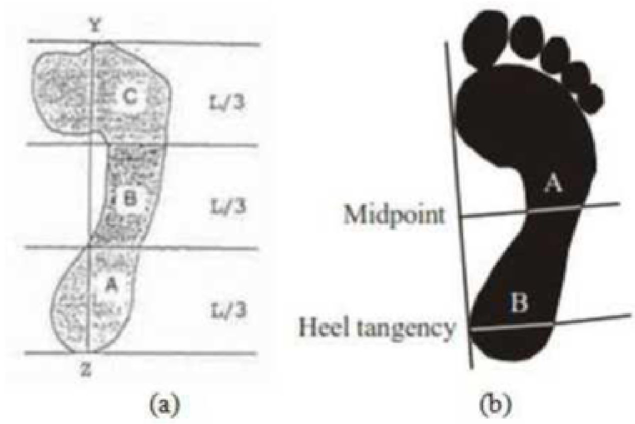

Fig. 1. Cavanagh's and Staheli's arch index

This study is aimed to investigate ratio loaded and unloaded foot area (RFA, ratio of foot area) as special tests for the basis of clinical examination of flat foot and healthy foot. Type of foot determine by Cavanagh's arch index (AI) where healthy foot is equal to normal foot. If this test showed the significant relationship between RFA to AI, than RFA can be used as an alternative tool for the diagnosis of types of foot which is simpler to apply.

2 Methods

This research is a cross sectional study. A total of 102 subjects comprising 87 males and 15 females, average aged 20 years (range 17-26 years) and average BMI 22.51 kg/m2 (range 15.21-41.60 kg/m2) were used for the study. The subjects are students of Mechanical Engineering Department of Diponegoro University, Semarang Indonesia. All subjects had no deformities of the lower limb or history of fractures of the foot based on the check up at Diponegoro National Hospital Semarang. The measurements of AI and foot area were carried out at the Center for Biomechanics, Biomechatronics, Biomaterials, and Biosignals Processing (CBIOM3S) of the Central Laboratory of Research and Services *(UPTLab. Terpadu)* Diponegoro University.

For each subject, footprints were obtained using digital footprint modified from document scanner (Fig. 2a) [8]. To produce clear image, the amount of light from the environment must be minimized and the foot is cleaned by dipping into warm water (± 30

°C) for about 2-3 minutes and dried with tissue paper. The scanning process occurs when the research subject is really standing in an upright posture above the platform which can be
assisted by the operator.

To calculate contact area with and without the toes, uncontacted foot must be removed using MATLAB Software. The procedure is as follows: 1) read the footprint image (Fig.2b) using *imread* function, 2) change the RGB image to gray scale image using *rgb2gray* function, 3) input the index level of image for filtering, 4) change the grayscale image to black and white image with *im2bw* function [9]. The results are obtained only images foot in contact as apparent in Fig. 2c. Calculating the entire loaded foot area (including the toes) is done by using *bwarea* function in MATLAB, but it is still in pixel unit. To change the foot area in pixels to mm^2, scanner resolution data is needed. The scanner is set to scan in 200 ppi (default setting of scanner). The entire loaded foot area can

$$\left(\frac{\text{area in pixels}}{\text{scanner resolution}}\right)^2 \times 645.16\ \text{mm}^2 \quad (1)$$

(a) (b) (c)

Fig. 2. Scanning of the foot using flatbed document scanner

The Cavanagh's arch index is calculated using MATLAB through the following procedures: 1) read the footprint image Fig. 2c and remove the toes using *bwareaopen* function, 2) use *imcrop* function to cut the image in the upper and lower limits, 3) divide image into 3 regions at the same length (Fig. 1 a), 4) calculate the area of each region using *bwarea* and divide the middle third area with all area of footprint without the toes. Equation 2 shows the calculation of AI as follow:

$$AI = \frac{B}{(A + B + C)} \quad (2)$$

Where A, B and C are rear foot area, mid foot area and fore foot area respectively.

3 Results

Subjects were divided into 3 groups according to their foot types (Table 1). High archs comprising 7 males and 1 female with average AI 0.182 ± 0.027 (range 0.125 to 0.204) and average RFA 0.46 ± 0.04 (range 0.388 to 0.539), healthy feet comprising 28 males and 3 females with average AI 0.236 ± 0.015 (range 0.210 to 0.260) and average RFA 0.52 ± 0.05

(range 0.437 to 0.607) and flat feet comprising 52 males and 11 females with average AI 0.319 ± 0.040 (range 0.261 to 0.385) and average RFA 0.61 ± 0.09 (range 0.400 to 0.860).

Table 1. Average AI and RFA of the subjects according to foot types.

Foot type and Gender	Amounts	Age (years)	BMI (kg/m^2)	AI	LFA (mm^2)	ULFA (mm^2)	RFA
High arch							
Male	7	20.29 (1.60)	21.00 (4.26)	0.190 (0.015)	9393.29 (1092.45)	20657.71 (1157.99)	0.45 (0.05)
Female	1	23.00	16.85	0.125	7455.00	15535.00	0.48
Healthy foot							
Male	28	20.14 (2.01)	22.01 (3.52)	0.238 (0.015)	10906.46 (1113.55)	20855.93 (1686.97)	0.52 (0.05)
Female	3	21.33 (4.04)	19.69 (3.93)	0.218 (0.011)	7763.33 (573.93)	15799.33 (952.52)	0.49 (0.05)
Flat foot							
Male	52	19.98 (1.90)	23.16 (4.49)	0.318 (0.039)	13134.18 (2152.75)	21354.19 (1966.82)	0.62 (0.09)
Female	11	19.18 (1.17)	22.93 (3.75)	0.319 (0.046)	10574.81 (2068.15)	18272.00 (1269.30)	0.58 (0.10)

Values are expressed as mean ± (standard deviation). AI, Cavanagh's arch index; LFA, loaded foot area; ULFA, unloaded foot area; and RFA, ratio of foot area = LFA/ULFA

Fig. 3a shows the comparison between average AI and average RFA according to foot types. There was a significant relationship between average AI to average RFA which can be presented by linear regression (equation 3) with coefficient of correlation r = 0.99 (Fig. 3b).

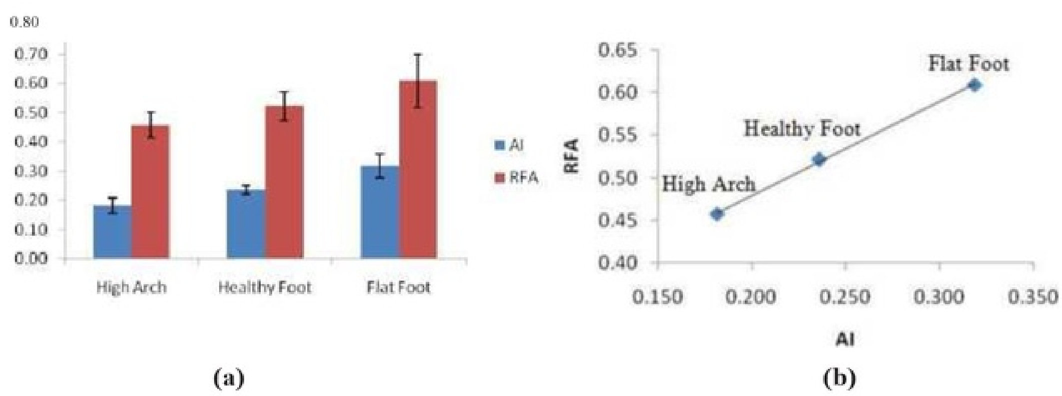

Fig. 3. Comparison and the relationship between AI and RFA according to foot types

The data showed that the overall prevalence of healthy foot and flat foot were 30.39% and 61.76% respectively. The prevalence of flat foot in male and female students are 50.98% and 10.78% respectively (Table 2)

Table 2. The comparison of prevalence of healthy and flat foot (%)

Subjects	High arch	Healthy foot	Flat foot
Male	6.86	27.45	50.98
Female	0.98	2.94	10.78
Total	7.84	30.39	61.76

4 Discussion

The current study shows that the prevalence percentage of flat foot among the total population is 61.76%, two times greater than healthy foot [14-17]. Flat feet were high in males than females, the prevalence of flat feet was 50.98% in males and 10.78% in females. The prevalence percentage of flat feet were also higher 23.50% in males and 7.85% in females compared to the healthy feet [18-20].

The result of foot area found that male had significantly greater foot area than female. This result is corresponding to the research by Lee et al. [19], Periyasamy et al. [20] and Wunderlich et al [21]. The average LFA for normal feet are 10906.46 mm^2 in males and 7763.33 mm^2 in females and the average ULFA are 20855.93 mm^2 in males and 15799.33 mm^2 in females. Offcourse the average foot area of flat foot is greater than normal foot and male had significantly greater foot area than female too. The average LFA for flat feet are 13134.18 mm^2 in males and 10574.81 mm^2 in females and the average ULFA are 21354.19 mm^2 in males and 18272.00 mm^2 in females.

Because the result of measurement of LFA for flat foot are greater than healthy foot and increasing of ULFA for flat foot inversely linear with the increasing ULFA for healthy foot, offcourse RFA of flat foot is greater than healthy foot. The average RFA for healthy foot and flat foot are 0.52 ± 0.05 and 0.61 ± 0.09 respectively.

In this study the technique employed for obtaining footprints is simple, non-invasive, easy to apply and does not use radiation as well. This scanner can tackle shortage of wet foot test which is not accurate because of the difficulty of knowing that the subjects are standing in upright position when printing their foot at a piece of paper [22]. But the method for classifying foot types by Cavanagh's arch index is rather difficult compared to the Staheli's arch index [7][15]. From the result of this study which showed that significant correlation between AI and RFA, classifying foot types can be done simpler only by measuring LFA using flatbed document scanner and ULFA using 3D scanner compared to the Cavanagh's arch index.

5 Conclusion

This study proves that the higher the value of AI the higher the value of RFA and foot type can be predicted by the value of RFA. For type of foot is high arch RFA < 0.49, for normal/healthy foot $0.55 > RFA > 0.49$ and for flat foot $RFA > 0.55$.

The method for classifying foot types by calculation of the ratio entire loaded and unloaded foot area is simpler and easy to apply compared to the Cavanagh's AI. It is not necessary to divide the footprint image (without the toes) into 3 regions and calculating the area of each region which rather difficult to build in application software. Even the footprint image can be done by wet foot test with a little bit carefully on a piece of paper chart and the entire loaded foot area is calculated by the amount of squares which printed ink on paper.

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