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Correlation of Loaded and Unloaded Foot Area With Arch Index in Younger Flatfoot

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Abstract. Harris & Beath claimed 23% of human kind population is indicated flatfoot. Identifying flatfoot is by using wet foot test. This footprint is not accurate because of the difficulty to make sure the patient stand upright. Another way is using x-ray to determine height of arch which is a distance from medial longitudinal foot arch to the ground. If the distance is less than certain level, so the foot type is included as flatfoot. Other method proposed by Kulkarni et al. using the footprint index (FPI) which is the ratio of B intercept to A intercept, where the footprint was obtained from pedobarography image. If FPI is lower than 0.63, it is categorized as flatfoot. Another method to determine arch type which is widely used is Cavanagh's Arch Index (AI) from division of mid foot area to entire footprint area (excluding the toes). If AI>0.26, then the foot type is flatfoot. This study is to learn the correlation between entire loaded and unloaded foot area with Cavanagh's AI. The entire loaded foot and footprint area for evaluating AI derived from a digital footprint modified from document scanner, while the entire unloaded foot area derived from a 3D scanner for foot orthotic. One hundred and two healthy asked voluntarily for doing footprint. From 102 subjects found 63 participants identified as flatfoot, 31 subjects are normal feet and 8 subjects identified as high arch. A series of 3 x 3 repeated measures ANOVAs were used to determine statistical differences ($\alpha<0.05$). A significant interaction existed between ratio of entire loaded and unloaded foot area (RFA) subject to all categories of AI ($p<0.05$) also a correlation coefficient of $r=0.67$ has found between RFA and AI on foot type of flatfoot which means that flatfoot can be indicated by RFA.

1 Introduction

Foot is one of the most important parts of the body which interacts with the ground when standing in an upright posture and walk. Human's foot and ankle are the mechanical structure which is complex and strong consist of 26 bones, 33 joints (20 joints are actively used), and more than hundreds of muscles, tendons and ligaments. These

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complex structures keep human body balance during standing and functioning as swing bar when walk or run [1].

Commonly human's foot divided by 3 parts that are rear foot, mid foot, and fore foot or more specifically as heel, arch, and metatarsal region (including the toes) [2]. Arch of the foot (which can elastically deform) has the function to absorb the impact loads during walking or sports activities to minimize injure at the foot. It means that there is a specific correlation between the type of arch and injuries caused by sports activities. Measuring changes in the deformation of foot arch during sports activities would be helpful to know more about the possible mechanisms of injury to the foot [3].

Flatfoot is a condition which arch of the foot inside is flat (called flat arch), so that most of the foot touching the ground [4, 5]. People with flatfoot in the world are quite a lot. Harris & Beat claimed 23% of the normal human population indicated flatfoot [6]. However, the numbers of flatfoot sufferers in many hospitals are not much. It because normally they did not feel the pain/hurt so much when doing activity, so they are rarely checks their foot to the specialist doctor of orthopedic [7]. People with flatfoot commonly sighing to easily tired and in some cases there were found patients that feel pain in ankle and knee caused by un-straight foot [8, 9]. The risks of pain at knee, foot, problems on the ankle (ankle weakness), or damage on the cartilage are increasing when influenced by obesity, injury at foot or ankle, joint inflammation, aging, and diabetes [9]. Commonly foot type flatfoot can be determined by wet foot test which is printing the painted foot to scaled paper, as seen on Figure-1. This footprint is not accurate because of the difficulty to make sure the patient stand upright also the possibility of unprinted parts of foot because the paint applied on foot are not spread evenly [10]. Another way is using x-ray to determine the height of arch by using a distance of medial longitudinal foot arch (largest and most important parts of foot arch) to the ground. More specifically, the distance perpendicular from the lower rim of the navicular tuberosity to the ground which can be represented as an index: arch foot called high and low if the distance is too big or small. If the distance is smaller than a certain level, the feet is flatfoot categories [11].

Fig. 1. Footprints of high arch, normal, and flatfoot from wet foot test.

A study by Kulkarni et al. has found another method to identify flatfoot by using footprint index from ratio of B intercept to A intercept where the footprint was found from pedobarography image. A intercept is a horizontal line from a to b through the center of mid foot, as shown in Figure-2. B intercept is the extension of line A intercept until cut the tangent line which is formed by connection of lateral minimum distance point and lower minimum distance point from Y axis, as shown in Figure- 2 by red dotted line. When this footprint index value is below 0.63, it is classifies as flatfootprint [12].

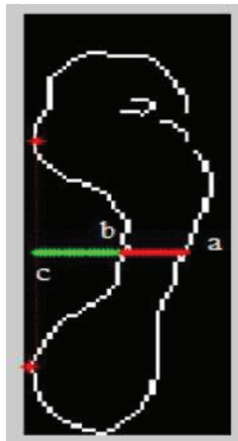


Fig. 2. MATLAB footprint image for calculating footprint index.

Another method to determine arch type which is widely used is Cavanagh's Arch Index (AI). This method is a division of mid foot area by the entire footprint area (excluding the toes). If AI less than 0.21, arch type of foot is called high arch. If AI between 0.21 and 0.26, arch type of foot is called normal arch. If AI greater than 0.26, arch type of foot is called flatfoot [13].

This study is to investigate the correlation between the ratio of loaded and unloaded entire foot area to the Cavanagh's AI which is very important for knowing the changing of shapes and deformation of foot when the sufferer is standing in an upright posture. The entire loaded foot area and footprint for evaluating AI derived from a digital footprint from the modified document scanner, while the entire unloaded foot area derived from a 3D scanner for foot orthotic [14].

2 Materials and methods

2.1 Subjects

One hundred and two healthy students of Mechanical Engineering Dept. Diponegoro University asked voluntarily for doing footprint. From 102 students found 63 participants identified as flatfoot (52 men and 11 women, aged 17-24 years, weight 45-129 kg, height 148- 179 cm) which each of them was no history of musculoskeletal injuries and has no physical defect on bones based on the check up at Diponegoro National Hospital Semarang.

The measurements were carried out at the Laboratory for Biomechanic of the Integrated Laboratory of Technical Service Unit (UPT Lab. Terpadu) at Diponegoro University. Table 1 shows the anthropometric data of the study group.

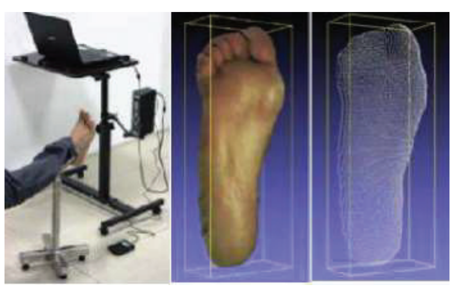
Table 1. Characteristics of the 102 participants.

	Range of Value	Mean and SD
Age (year)	17 – 26	20.0 ± 1.9
Gender (male : female)		87 : 15
Weight (kg)	39 – 129	63.3 ± 13.8
Height (cm)	147 – 185	167.3 ± 6.8
BMI (kg/m^2)	15.21 – 41.60	22.51 ± 4.16

2.2 Measures and procedures

In this study, measuring the entire unloaded foot area is derived from a 3D scanner which is a device that analyses a real-world object or environment to collect data on its shape and possibly its appearance (e.g. color). The collected data can then be used to construct digital three- dimensional models which are useful for a wide variety of applications.

3D Scanner Mini and Scansoft for Foot Orthotic made by Vismach Technology Ltd. China was used in this study. This scanner are active stereo vision 3D tech with white light pattern projection or no laser, so it is safe for eyes without protective glasses, quick capture (0.1 – 0.2 sec), clean 3D mesh, and ± 1.0 mm linier accuracy. The output 3D model of foot is in the standard language (dxf/stl/wrl/obj/ply/asc) format that can be exported into AutoCAD and fabricated by the (.stl) images to the rapid prototyping machine [15]. To obtain a 3D foot image is scanning soles of the feet as seen in Figure-3a. The output can be in the form of 3D plantar of foot, as shown in Figure-3b.



(a) (b)

Fig. 3. 3D scanning of the foot.

To obtain the entire loaded foot and footprint area for evaluating AI was done by scanning the foot of research subjects while standing in an upright posture above the glass window of digital footprint platform, modified from document scanner. Flatbed document scanner sized A4 with color depth 48 bits and optical resolution scanner 2400 ppi was used in this study. Modifications made to the frame and the glass scanner that can withstand loads up to 100 kg and glass used as the glass window is 10 mm thick clear glass, has a low reflection coefficients, and scratch-resistant. The scanner is designed for standing footprint for one foot at a time, as seen as Figure-4a. The scanning process occurs when the research subject is standing in an upright posture above the glass window and the foot is clean. Cleaning process of research subject's feet are by

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dipping into warm water (± 30o C) for about 2-3 minutes and then dried with tissue paper. Figure-4b is the scanning result of research subject's left foot.

(a) (b)

Fig. 4. Footprint tool modified from document scanner.

To calculate contact area with and without the toes (to determine Cavanagh's AI), un-contacted foot (result of footprint image on Figure-4b) must be removed using MATLAB Software. The procedure is as follows: read the footprint image (Figure-4b) using *imread* function, (2) change the RGB image to gray scale image using *rgb2gray* function, (3) input the index level of image for filtering (index level value is gained from the point between contact and un-contact foot, normally between 88 to 96), (4) change the grayscale image to black and white image with *im2bw* function. The results obtained just images foot in contact as apparent in Figure-5b [15].

(a) (b)

Fig. 5. MATLAB evaluation removing un-contacted foot (a) result of RBG image to grayscale image, (b) black and white image after filtering with input of image index level.

2.3 Calculation and procedures

The entire unloaded foot area can be found by Rhinoceros 5.0 software with opening the .dxf file format 3D plantar of foot (Figure-3b) then choose command area. The result is shown at the upper left corner of the software, as shown in Figure-6.

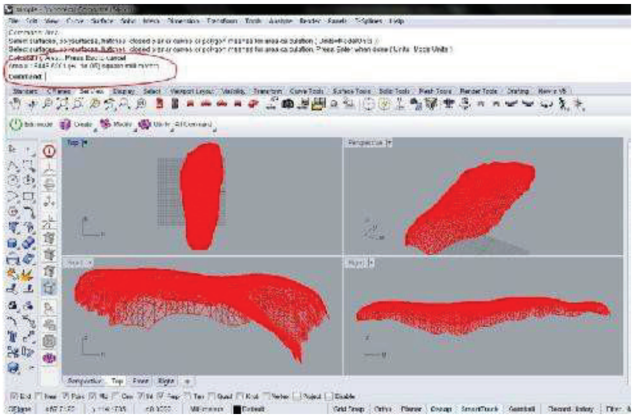

Fig. 6. Evaluating entire unloaded foot area using Rhinoceros 5.0 software.

Calculating the entire loaded foot area is done by using *bwarea* function in MATLAB, as shown in Figure-7. The result is shown in command window (Figure-8), but it is still in pixel unit [16].

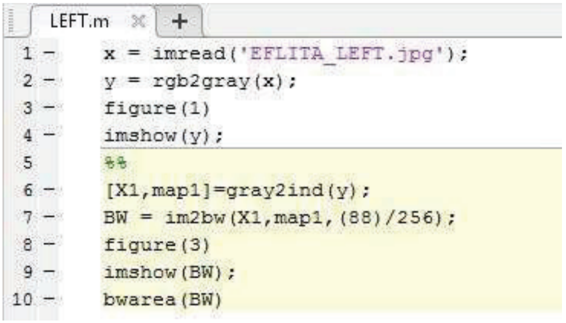

Fig. 7. MATLAB window for calculating foot area.

Fig. 8. MATLAB output window for pixels count of foot area.

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 be measured by using equation (1) as shown:

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

The Cavanagh's arch index is calculated through the following procedures. Draw the line from the center of the heel (at a distance of 15% of foot length, point I in Figure-9a) [17] to the tip of the second toe and extent this line until the heel cup. Mark the point of intersection between heel center lines with heel cup (point K in Figure- 9a). A second line perpendicular to the heel center line is then drawn tangentially to the most anterior part of the outline of the main body of the footprint in front of the metatarsal heads. Mark the point of intersection between these two lines (point j in Figure-9a). The line j-k then divided into equal thirds, as shown in Figure-9b, which divides the foot without the toes into three areas these are rear foot (A), mid foot (B), and fore foot (excluding the toes) (C) area. AI can be determined by equation (2) as follow:

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

where each area is calculated using MATLAB

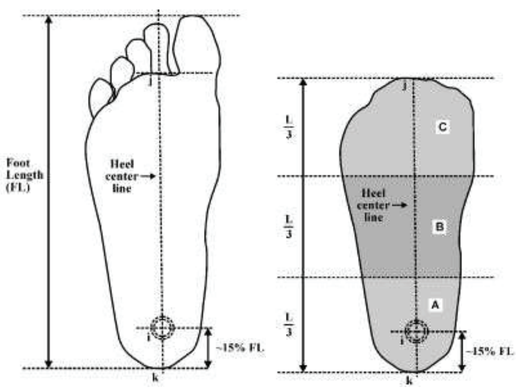

Fig. 9. Cavanagh's arch index.

3 Results

The three foot types (flat, normal, and high arch foot) provided by Cavanagh's AI as dependent variables and the three group of characteristics of the subjects (age, BMI, and ratio of foot area) as independent variables were compared using a 3 x 3 repeated measures ANOVA with Tukey's post hoc testing ($\alpha < 0.05$) using SPSS version 12. Ratio of foot area (RFA) is ratio between entire unloaded foot area and loaded foot area.
Thirty-one feet (30%) were classified as having normal foot, while 63 feet (62%) were classified as having flatfoot, and the remaining 8 feet (8%) were classified as a high arch. Table 2 shows the demographic information for all subjects.

Table 2. Demographic data.

	Age (year)	BMI (kg/m2)	RFA
Normal feet	20.3±2.2	21.78±3.56	0.521±0.050
Flat feet	19.8±1.8	23.12±4.34	0.609±0.091
High Arch	20.6±1.8	20.48±4.21	0.458±0.043
p-Value	0.409	0.008	0.001

In this study, the characteristic of age, BMI, and RFA are grouped into 3 groups, they are: (1) ages categorized by health department of Republic Indonesia: first adolescent (12 – 16 years old); last adolescent (17 – 25 years old); and adults (> 25 years old), (2) BMI: according to the standard rules, an individual is underweight if BMI < 18; normal if 25 ≥ BMI ≥18; and overweight if BMI > 25 [12], and (3) RFA: normal feet (RFA = 0.521 ± 0.050); flatfoot (RFA = 0.609 ± 0.091); and high arch (RFA = 0.458 ± 0.043).

There were significant interaction existed between BMI and AI ($p = 0.008$) and RFA and AI ($p = 0.001$). No significant difference was found in age ($p = 0.409$). From the results of different test between BMI and AI found the significant difference between underweight BMI group and normal BMI group with the result of AI ($p< 0.001$), underweight BMI group and overweight BMI group with the result of AI ($p < 0.001$), between normal BMI group and underweight BMI group with the result of AI ($p < 0.001$), and between overweight BMI group and underweight BMI group with the result of AI ($p < 0.001$).

From the results of different test between RFA and AI obtained significant difference between normal foot RFA group with flatfoot RFA group with the result of AI ($p < 0.001$), between flatfoot RFA group with normal foot RFA group with the result of AI ($p < 0.001$), between flatfoot RFA group with high arch RFA group with the result of AI ($p < 0.001$), and between high arch RFA group with flatfoot RFA group with the result of AI ($p < 0.001$).

Especially for flatfoot type of foot which is main focus in this study, there was a correlation between RFA and AI with coefficient of correlation $r = 0.67$ as shown in Figure-10. No correlation between BMI and age and AI because the coefficient of correlation are $r = 0.33$ and $r = 0.17$ respectively.

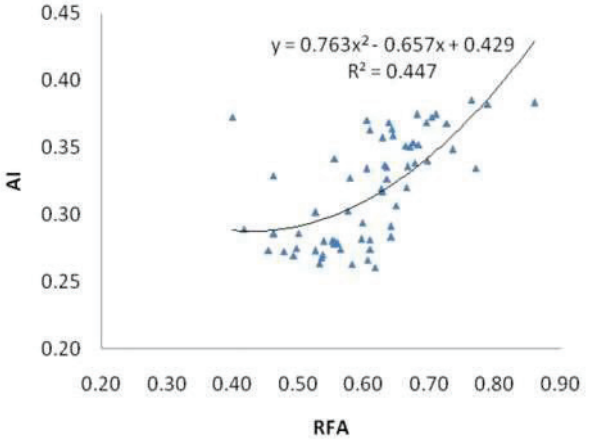

Fig. 10. Relationship between RFA to AI for flatfoot type.

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4 Discussion

The result of this study indicate that no significant difference was found in age ($p = 0.409$), which means there is no difference between the age of subject with all the categories of AI. These results are consistent with research Chuckpaiwong et al. which resulted in no significant difference in age ($p = 0.9$) [18].

The correlation of BMI and AI is contrary. There are significant interaction existed between BMI and AI ($p = 0.008$), meanwhile in the flatfoot type of foot there is no significant correlation between BMI and AI with the coefficient of correlation $r = 0.33$. This is corresponding with statistical result which show that there is no significant differences were found between BMI normal and overweight with the result of AI ($p = 0.98$) and BMI over weight and normal with the result of AI ($p = 1.00$). Research conducted by Chuckpaiwong et al. which correlate 2 types of foot normal foot and flatfoot to height and weight also result no significant differences in weight ($p = 0.32$) or height ($p = 0.73$) between the normal and flatfeet [18].

Research in correlation between ratio of entire loaded and unloaded foot area to AI is new research and never done before. The statistical analyses show that there is significant difference between normal foot RFA and AI flatfoot ($p < 0.001$). Meanwhile, between normal foot RFA and AI high arch $p = 0.019$ ($p < 0.05$). It means there is significant differentiation between RFA groups with every categories of AI. From the result of polynomial regression for flatfoot type is shown that there is significant correlation between RFA to AI with the correlation coefficient $r = 0.67$ (see Figure-10).

In this study, digital footprint from the modified flatbed document scanner shows that there are difference between entire load foot area and area for evaluating AI with the result of wet foot test for about 7%. This result is corresponding to the research by Urry et al. which compared between AI from wet foot test with pressure platforms [10].
Determination of flatfoot's degree based on AI value also has not done before. Based on the Cavanagh and Rodgers research, people indicated as flatfoot if AI > 0.26 [13], in this study AI from flatfoot is grouped into 4 categories those are minor flatfoot (AI = 0.260 – 0.290); moderate flatfoot (AI = 0.291 – 0.334); severe flatfoot (AI = 0.335 – 0.364); and worst flatfoot (AI = 0.365 – 0.385). Table 3 shows the degrees of flatfoot with associate RFA values.

Table 3. Degrees of Flatfoot and associate RFA

Degrees of Flatfoot	Amount of Subjects	RFA	
		Range of Value	Mean and SD
Minor flatfoot	24 (38%)	0.417–0.642	0.543±0.057
Moderate flatfoot	13 (21%)	0.462–0.770	0.612±0.073
Severe flatfoot	15 (24%)	0.556–0.736	0.654±0.042
Worst flatfoot	11 (17%)	0.598-0.860	0.708±0.078

5 Conclusion

Wet foot test which is used widely in entire world (as illustrated in Figure-1) is proved to be un-accurate to identify flatfoot and high arch. The accuracy of footprint is very important due to handling of the flatfoot sufferers when designing orthotic shoes, especially for determining the dimension and contour of insertion of shoe insole in arch area [4].

Foot type identification using digital footprint can be done automatically (with helps of MATLAB software) after research subjects did scanning to determine foot area contact, type of foot (normal, flatfoot, and high arch), degrees of flatfoot, foot length, foot width, and shoes sizing. This digital footprint from modified flatbed document scanner also proved that it can produce an accurate footprint if the subject standing in an upright posture which can be assisted by the operator before scanning process is executed.

The statistical analyses shows there is a significant difference between RFA group and all categories of AI ($p < 0.05$), also coefficient of correlation $r = 0.067$ is found between RFA and AI. It means that flatfoot indication can be determined by RFA. More specific results can be seen from a study flatfoot categorization into 4 categories where the value RFA getting up from degree of flatfoot “minor flatfoot” (RFA = 0.543 ± 0.057) to “worst flatfoot” (RFA = 0.708 ± 0.078), as shown in Table 3. In relation to the deformation of the feet, worst flatfoot (AI = 0.365 – 0.385) means that the deformation of foot is bigger when the subject is standing in an upright posture above the platform. It is also contrary for degree of flatfoot “minor flatfoot” (AI = 0.260 – 0.290) the deformation of foot is small, which is shown by lower RFA value.

This study is advantageous to identify flatfoot and degrees of flatfoot through RFA with lower cost and easier compared to the method of determining height of the arch which research was done by Mall et al. [11], FPI method which was done by Kulkarni et al. [12], and Cavanagh's AI [13].

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