Evaluating the Differences among the Four Foot Dimension Measurement Methods

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Abstract: - The aim of this study was to evaluate the difference of four methods for collecting foot dimensions. One hundred and thirty healthy male and female students were recruited. The 7 measured foot dimensions were foot length, ball of foot length, outside ball of foot length, foot breadth diagonal, foot breadth horizontal, heel breadth and arch length. The ANOVA results indicated that there were significant differences between four measurement methods on the 7 foot dimensions. The foot dimensions obtained from the 3D scanning method was significantly greater than the others, except for no significant difference with manual technique in foot length and heel breadth dimensions. The dimension obtained from the digital footprint method showed significant differences with the footprint technique in outside ball of foot length and heel breadth dimensions. Moreover, the mean absolute difference (MAD) was calculated to evaluate the repeated precision. Results indicated that the greater MAD values were found in the manual method than the 3D scanning method in all the foot dimensions, except for foot length and heel breath. In summary, using different methods to collect foot dimensions tend to have significant differences in anthropometric measurements. When comparing the foot anthropometric data with other references, it is important to notice the method differences while taking measurements.

Key-Words: - precision, foot dimension, anthropometry, mean absolute difference, laser scanner

1 Introduction

Manually collecting foot anthropometric data with direct measurement instrument is a traditional approach [1]-[3]. The precision of measurement tend to be influenced by the measurement instruments. Using footprint to collect foot dimensions can reduce the measurement time and the footprint can be stored for further analysis, such as calculating arch index. Further, with the advancement of optoelectronic technologies, the scanning technique was employed to collect anthropometry data. The 3D scanning technique can also be applied to capture digital footprint [4]-[5] and to obtain the foot dimensions. Generally, using 3-D scanning technique to collect anthropometric data is a rapid and efficient approach.

Using different technique to collect foot dimensions may lead to inconsistent results. The precision of different apparatus may not equal. Hence, it is important to determine the differences between different measurement methods. For performance evaluation, the mean absolute difference (MAD) was calculated to evaluate the precision of the repeated measurements [6]-[9]. Kouchi et al. [7] evaluated the interobserver errors by using MAD and indicated that the measurements tend to be overestimated due to interobserber and random errors. Thus, the standardization of the measurement procedure and the training is very important. Lu and Wang [8] evaluated the scan-derived anthropometric measurements by using MAD and indicated that some of the scan-derived measurements were significantly different from the corresponding manual measurements.

Moreover, some other comparison studies were also conducted to evaluate the differences between the measurement methods. Daniell [10] compared the two different 3-D scanners and noted that the 3-D scanners both have high precision, and accuracy for measurement. Witana et al. [11] compared the manual, scanning and a new approach which could automatically measure foot dimensions from 3-D scan image and indicated that 8 of the 18 foot dimensions showed significant difference among the three methods. Further, Han et al. [9] examined the differences between scan measurements and manual measurements of the Korean adult females by using MAD and reported that the greater differences were observed in circumference dimensions.

As the previous studies mentioned, collecting foot dimensions by manual, scanning, footprint and digital footprint were the common methods.

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However, the previous studies only examined the differences between 3D scanning and manual measurement. There is little information available on comparing foot dimensions between 3D scanning method and footprint measurements methods. Hence, the aim of this study was to examine the precision of the four selected methods on the 7 foot dimensions. The results of this study can be very useful for understandings the differences among different methods.

2 Method

2.1 Subjects

One hundred and thirty subjects (65 males and 65 females) were recruited for this study. For males, the mean age was 21.25 ± 2.15 (S.D.) years, ranging from 18 to 28 years. The mean height and weight of the male subjects was 174.92 ± 5.82 cm and 68.45 ± 7.57 kg, respectively. For females, the mean age was 21.98 ± 2.94 years, ranging from 18 to 30. The mean height and weight of the female subjects was 162.09 ± 4.30 cm and 52.32 ± 5.89 kg, respectively. All subjects were undergraduate and graduate students in a university. They were healthy and right-handed subjects.

2.2 Experimental apparatus

Four different apparatus were used for collecting 7 foot dimensions in this study (as in Fig. 1). First, a trained experimenter used a digital caliper (Mitutoyo Corp., Tokyo, Japan) to measure foot dimensions based on the specific anatomical landmarks and record the value. The resolution of the digital caliper was within 0.01 mm and the accuracy was 0.01 mm. Each subject was repeatedly measured twice. Secondly, the 3-D foot scanner (INFOOT USB scanning system, IFU-S-01, I-Ware Laboratory Co., Ltd, Japan) was used to automatically collect foot anthropometric data. The accuracy and resolution of the foot scanner was within 1.0 mm and 0.1 mm, respectively [12]. Similar to manual measurement, two repetitions were taken for each foot. The third measurement technique of this study was digital footprint. The 3-D foot models being obtained from the 3-D foot scanner were employed to capture the contour of bottom foot surface as digital footprint. To avoid the noises, the contour at 1.5 mm height from the bottom of foot surface, was used as digital footprint. In addition, the AutoCAD 2009 software package was used to calculate the 7 foot dimensions from digital footprint. Lastly, the footprint was recorded by using the Harris mat. The apparatus could maintain the bottom features of the subjects' foot by inking footprint on a paper.

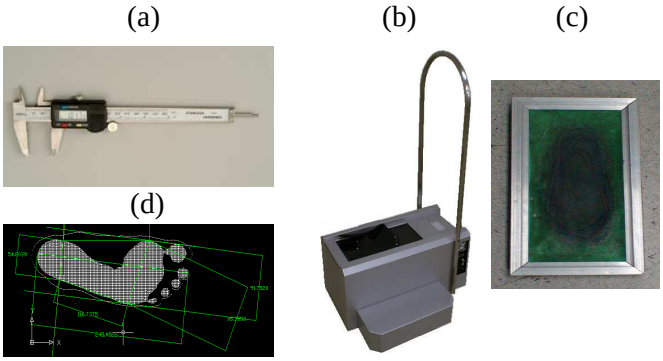

Fig. 1. The four appartus: (a) digital caliper, (b) foot scanner, (c) Harris mat and (d) digital footprint image

2.3 The definition of seven foot dimensions

Seven foot dimensions including foot length (FL), ball of foot length (BFL), outside ball of foot length (OBFL), foot breadth diagonal (FBD), foot breadth horizontal (FBH), heel breadth (HB) and arch length (AL) were measured for comparison using the four different measurement methods. The definitions of the dimensions are presented in Table 1. All the selected dimensions in this study are commonly used in shoes manufacturing.

2.4 Experimental procedure

Before data collection, a well trained experimenter placed 2 landmarks on the subject's right foot surface. The positions of landmarks were the 1st metatarsal protrusion and 5th metatarsal point protrusion. Then, each subject was asked to stand on a plate with a normal upright posture and align his/her posterior point of the heel with a guiding line which pasted on the ground for manual measurement. The subjects were requested to keep their feet separated with shoulder width to ensure their body weight was equal on each foot. Then, the experimenter used the digital caliper to measure the distance between two anatomical points which could represent the selected foot dimensions. For footprint acquisition, subjects stood on a Harris mat with natural standing posture. Keeping the body weight equally distributed on both feet for about 3 s, and the footprint was obtained by ink. For the 3D foot scanning, each participant was requested to wash his/her right foot and use tissue paper to dry their foot surface completely. This procedure was to avoid measurement errors due to particles on foot surface. Then, the subjects stood on a plate and position their right foot in the scanner with a stable standing posture and to avoid foot movement or swing. Each foot dimensions were measured twice for both the manual measurement and the 3D foot scanning methods. The sequence of the four measurements was randomly assigned to each subject.

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Table 1. Definition of the7 foot dimensions

	Dimensions	Definition	
1.	Foot length (FL)	The distance along the X-direction from the end of heel to the tip of longest toe.	
2.	Ball of foot length (BFL)	The distance from the end of heel to the 1st Metatarsal point protrusion.	
3.	Outside ball of foot length (OBFL)	The distance from the end of heel to the 5th Metatarsal point protrusion.	
4.	Foot breadth diagonal (FBD)	The straight distance from the most medially placed point on the head of 1st metatarsal to the most laterally placed point located on the head of 5th metatarsal.	
5.	Foot breadth horizontal (FBH)	The horizontal distance between 1st metatarsal to 5th metatarsal.	
6.	Heel breadth (HB)	The widest distance of the heel.	
7.	Arch length (AL)	The length of the medial border line between the most medial points of the metatarsal and heel region.	

2.5 Data Analysis

One-way ANOVA was conducted to evaluate the differences of the four measurement methods. The independent variable was the four different measurement methods, including manual measurement, 3-D scanning, digital footprint and footprint collection. The dependent variables were the 7 foot dimensions. The significance level was set at α = 0.05. In addition, Duncan's multiple range test (MRT) was employed for post hoc comparisons. The MAD between the repeated measurements was calculated as the performance for precision. The smaller value of MAD indicated the higher precision.

3 Results and Discussion

The ANOVA and Duncan's multiple range test results are shown in Table 2. For all the 7 foot dimensions, there were significant differences between the four measurement methods ($p<0.001$). The foot dimensions obtained from the 3D scanning method were significantly greater than the others, except for the manual measurements in FL and HB dimensions. To compare the differences of the measurements from the digital footprint and traditional footprint, the results of the Duncan's MRT indicate that no significant difference was found, except for OBFL and HB.

Using 3D scanner to collect anthropometric data was more efficient than the other methods. However, the ANOVA results indicated that there were significant differences between manual measurements and scanning measurements in 7 foot dimensions, except for in FL and HB. Using the 3D canner to collect foot dimensions would over estimate the BFL, OBFL, FBD and FBH dimensions. The finding was in consistent with the results being reported by Kouchi and Mochimaru [12] and Witana et al. [11].

Table 3 summarizes the evaluation results in mean absolute difference (MAD). The MAD results indicated that the manual technique had greater MADs than the scanning measurements in all foot dimensions, except for FL and HB. In other words, the scanning method had higher precision of the repeated measurements than the manual method in 4 of the 7 foot dimensions. On the other hand, the manual technique has higher precision than the scanning technique in FL and HB dimensions. It may be caused by the markers placement on foot surface. In this study, two markers were employed to indentify the position of the 1st metatarsal point protrusion and 5th metatarsal head. Zheng et al. [13] indicated that using markers could increase the precision of scanning. However, there is no marker placed on the tip of toes or lateral/medial heel. To calculate the distance of FL or HB, the INFOOT scanning system will automatically find the outside edge. The surface of toes was complex and hard to construct clearly (Fig. 2). It may affect the measurement precision in FL. Moreover, in INFOOT scanning system, the HB distance was defined as the breadth of position at 16% FL straight from the Pternion point to toe. Hence, the precision of HB will also be influenced by instable FL.

Based on the above findings, we can conclude that the 3D scanning measurements were significant greater than the manual measurements in 7 foot dimensions, except for FL and HB. In addition, the scanning technique had high precision with repeated measurements. For MAD result, the manual method had lower MAD than the 3D scanning method in FL and HB. Thus, using manual technique to collect FL and HB dimension was recommended.

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Table 2. ANOVA and Duncan's multiple range test results

Method	FL		BFL		OBFL		FBD		FBH		HB		AL	
Manual	247.68 (15.74)[#]	A	177.74 (12.66)	A	156.97 (10.78)	A	94.75 (7.16)	A	85.20 (7.43)	A	62.61 (4.04)	A	129.08 (11.70)	A
Scanning	249.26 (15.76)	A	181.58 (11.56)	B	164.08 (10.64)	B	99.01 (7.33)	B	97.13 (6.97)	B	63.19 (4.48)	A	Null	
Digital Footprint	232.95 (14.80)	B	170.64 (10.90)	C	153.37 (9.86)	C	87.84 (6.38)	C	85.96 (6.26)	A	50.14 (3.83)	B	142.27 (9.12)	B
Footprint	234.11 (14.62)	B	172.03 (10.56)	C	147.70 (9.30)	D	88.62 (6.45)	C	85.11 (6.18)	A	47.64 (3.89)	C	142.46 (10.33)	B
p-value	***		***		***		***		***		***		***	

[#]Mean (SD) and all dimensions are in mm

***Significant difference among 4 methods ($p<0.001$)

Table 3. Mean absolute differences of the manual and scanning technique

Dimensions	Mean absolute differences	
	Manual	Scan
FL	2.48	2.81
BFL	4.79	3.15
OBFL	4.03	2.69
FBD	2.83	1.84
FBH	3.31	1.65
HB	3.28	3.67

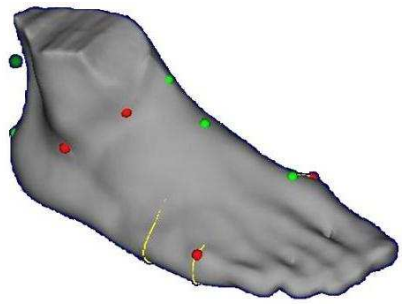

Fig. 2. The incomplete scaning image in toes area

4 Conclusion

This study compared the four different foot dimension measurement methods on 7 foot dimensions. The results indicated that the four methods showed significant differences in the 7 foot dimensions. Comparing the manual and 3D scanning measurement technique, the scanning method tends to overestimate the measurement in BFL, OBFL, FBD and FBH. Thus, the manual technique was recommended to collect FL and HB dimensions for better precision. In addition, there were significant differences between the digital footprint and the footprint technique in OBFL and HB dimensions. It is important to notice the differences in measure methods when comparing the foot anthropometric data with other references.

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