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—  
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# Preface


This volume contains papers presented at 2018 5th International Conference on Biomedical and Bioinformatics Engineering (ICBBE 2018), which was held in Okinawa Institute of Science and Technology Graduate University, Japan during November 12-14, 2018.

ICBBE provides a scientific platform for both local and international scientists, engineers and technologists who work in all aspects of biomedical and bioinformatics engineering. In addition to the contributed papers, internationally known experts from several countries are also invited to deliver keynote and plenary speeches at ICBBE 2018.

The volume includes 26 selected papers which were submitted to the conference from universities, research institutes and industries. Each contributed paper has been peer-reviewed by reviewers who were collected organizing and technical committee members as well as other experts in the field from different countries. 5 topics in the volume are about Bioinformatics and Technology, Biomedical Engineering and Clinical Medicine, Medical Imaging and Image Processing Technology, Drug Design and Pharmacokinetics, as well as Medical Information System and Management. And the volume tends to present to the readers the newest researches results and findings in the field of biomedical and bioinformatics engineering.

The high quality of the program—guaranteed by the presence of an unparalleled number of internationally recognized top experts—can be assessed when reading the contents of the program. The conference will therefore be a unique event, where attendees will be able to appreciate the latest results in their field of expertise, and to acquire additional knowledge in other fields. The program has been structured to favor interactions among attendees coming from many diverse horizons, scientifically, geographically, from academia and from industry.

We would like to express our sincere and grateful appreciation to the conference program chairs, committee members as well as all the reviewers for their great professionalism and efforts in reviewing the submitted papers. We also thank all the participants and sponsors for their valuable contributions and support to ICBBE 2018.



Assoc. Prof. Kuo-Yuan Hwa

ICBBE 2018 General Conference Chair

November 12-14, 2018

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# Measurement and Analysis of Calcaneus Morphometric Parameters from Computed Tomography Images

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## ABSTRACT

This study presents a measurement of the morphology parameters on three-dimensional calcaneus and finds out their correlation with age and body mass index. We included 49 males and 50 females healthy calcaneus as subjects, aged 21–58 years. 3D model of calcaneus was reconstructed directly from computed tomography images by reverse engineering technique. Thirteen linear distances and four angular parameters were measured with two different tools, computer-assisted measurement, and digital vernier scale device. T-tests and Pearson correlation analysis were performed to evaluate parameters relationships. Statistical result presented that significant differences between male and female calcaneal morphologic value found except for  $\beta$  and  $\alpha$  angles. LAL, CFH, MXB, DAFL,  $\theta$ ,  $\beta$ , and  $\gamma$  angles show a strong correlation. There was also a significant correlation between age with MAXL, CBL and  $\gamma$  angle. The p-value in the comparison between computer-assisted and manual measurement for each parameter was less than 0.05, indicating that computer-assisted measurement is an effective method for evaluating the calcaneus morphology parameters.

## CCS Concepts

•Applied computing→Life and medical sciences→Healthcare information system

## Keywords

3D model; Calcaneus morphology; Measurement; Computed tomography.

## 1. INTRODUCTION

The calcaneus is a solid skeletal element with complex contour to specifically designed to withstand the daily stresses of weight bearing. It was reported that the calcaneus is the most common tarsal bone that fractured frequently, about 1-2% of all bone fracture and 60%-65% of the tarsal bone fracture belonging to calcaneus fracture [1,2]. To assess the outcomes of calcaneus fracture recovery, preoperative radiograph was commonly compared to post-operative one. This method may cause the difference in shape and the difficulty to figure out specified geometric values [3]. The morphology of calcaneus and its morphometric values have been a subject of interest to diagnosis procedure and treatment in orthopedic surgery [4,5]. Moreover, the standardized measurement from anatomy

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bone may be beneficial to offer the principal information such as anthropology, forensic science, stature and gender determination [6,7]. The calcaneus morphometric values are commonly measured based on a 2D or 3D environment with certain limitations, such as anatomical measurement cadaver, poor inaccuracy result and limited in large-scale subject of study [8]. Radiograph measurement may also be affected by images mis-orientation and deviation due to foot pain [9], and 3D bone model measurement, which is actually measured in a fixed viewing display of a 2D plane [10]. To date, 3D bone measurement on the model generated from computed tomography (CT) or magnetic resonance imaging (MRI) has become available [11]. This method allows the user to measure bone model surface, linear distance and angle in the 3D environment [12]. The purposes of this study are to measure the calcaneus morphology values in a three-dimensional space and to analyze the correlation between those parameters. Thirteen linear distances and four angles of calcaneus morphologic parameters were measured and statistically analyzed to find out their correlations. This study may provide the basic data about the morphology of calcaneus as a reference for the evaluation of calcaneus fracture risk.

## 2. MATERIALS AND METHODS

### 2.1 Study Subjects

In this study, all subjects were classified into males and females to evaluate the morphology difference in the calcaneus. Ninety-nine of non-damage Taiwanese calcaneus cases consisting of 49 males and 50 females were selected as the subject. The range of age was 21-58 and the average age was 37 years old. A distribution of the samples on age is illustrated in Figure 1. Height, weight, and BMI (body mass index) of all samples were also recorded as part of morphology parameters of the calcaneus.

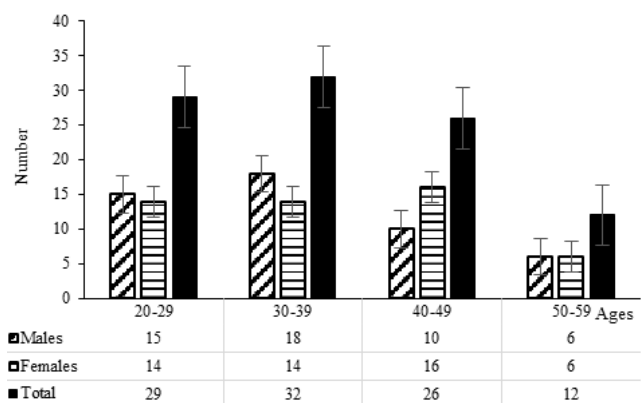


Figure 1. Distribution of sample study.

## 2.2 3D Model Reconstruction

A digitized 3D model of a calcaneus bone was reconstructed from a series of CT images using a PC-based system of computer-assisted preoperative planning tools. An integrated virtual pre-operative planning processing such as 3D visualization, segmentation, reduction, fixation and data output for 3D-printing modeling was established. The system accepts both X-ray and CT images, which are saved as DICOM files, for constructing the digitized model. Imaging data were converted to volume to display isosurface view of the calcaneus model. The system operates in a PC-based environment integrating virtual surgery simulation tools into a single computer program package (PhysiGuide v2.72.) [13]. 3D simulation subject was performed on a desktop computer (Intel® Core™ i5-4440 CPU, 3.1 GHz processor, 4 GB RAM, Windows 7 operating system). Anatomic landmark bone was created on the surface mesh model as the reference point measurement. Then, each of the subjects repositioned on the same coordinate system. 3D model subject could be moved in a linear and angular direction around the X, Y, and Z axes while being measured in a user interface. A typical 3D model of the healthy calcaneus in an isometric position is shown in Figure 2.

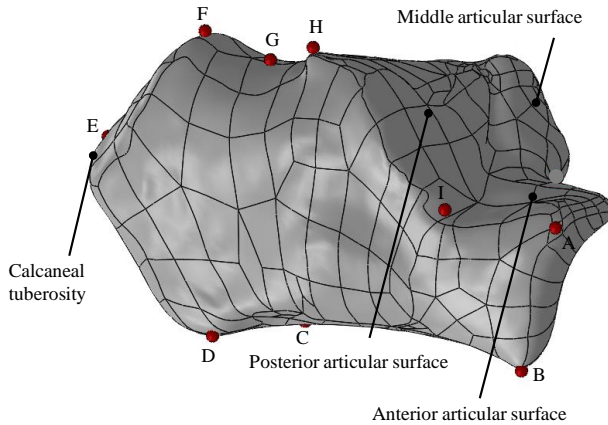


Figure 2. 3D calcaneus model with anatomical landmark.

## 2.3 Measurement of Calcaneus Morphology Parameters

Morphology parameters of a calcaneus were measured refer to an anatomic landmark that pointed on bone surface meshes [4]. There are seventeen of morphology distances were measured and called as parameters, as shown in Figure 3.

The morphology parameters for a 3D calcaneus bone comprise thirteen linear distances (6 lengths, 4 heights, and 3 breadths) and four angles ( $\theta$ ,  $\alpha$ ,  $\beta$ ,  $\gamma$ ). The parameters were automatically measured by snapping a cursor on landmarks using a computer software (MAGICS 13, Materialize Inc). A Detailed description of the calcaneus morphology parameters is listed in Table 1. All parameters are measured either on the sagittal or coronal plane, referred to the methods described in [4,5].

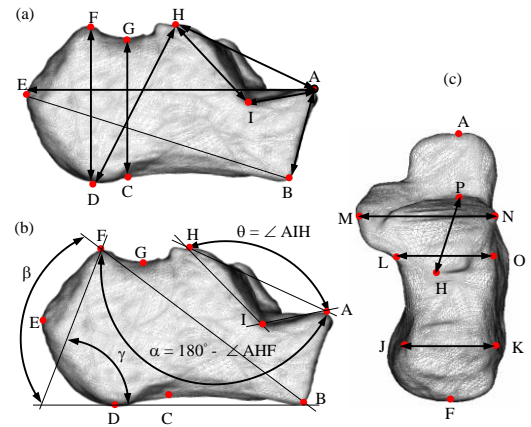


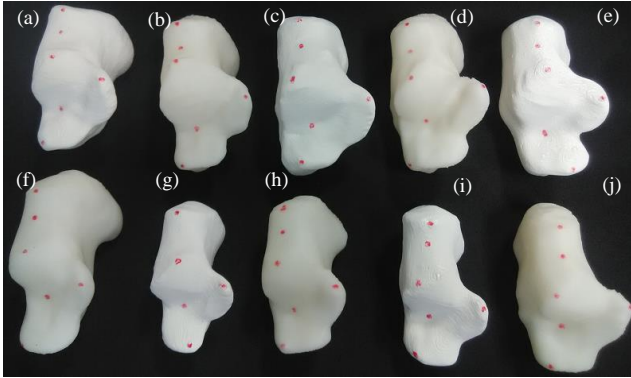
Figure 3. Localization of 3D morphology parameters. (a) linear distance (length and height), (b) angles, and (c) widths.

Table 1. Abbreviation and definition of calcaneus measurement

Abbr.	Measurement	Definition
MAXL	Maximum anteroposterior length	Linear distance between the most anterior talar point (A) and the most posterior point (E) on the calcaneus tuberosity
CBL	Calcaneal body length	Linear distance between the inferior on the cuboidal articular facet point (B) to the posterior point on calcaneus tuberosity (E)
MXBH	Maximum body height	Linear distance between the most superior (F) and inferior on calcaneus tuberosity (D)
MIBH	Minimum body height	Linear distance between superior point (G) and the inferior point on calcaneus body (C)
CBH	Calcaneal body height	Linear distance between the most posterior point (H) and inferior point on tuberosity (D)
LAL	Load arm length	Linear distance between the most anterior point (A) and the most posterior point on the posterior articular facet (H)
LPF	Length of posterior facet	Linear distance between the posterior point (H) and inferior of calcaneocuboid joint (I)
LAP	Length of anterior process	Linear distance between the anterior point (A) and inferior of calcaneocuboid joint (I)
CFH	Cuboidal facet height	Linear distance between the most anterior (A) and inferior on the cuboidal facet (B)
MXB	Maximum breadth	Linear distance between the most lateral point on the posterior articular facet (M) and the medial point on the sustentaculum tali (N)
MIB	Minimum breadth	Minimum distance between the medial (J) and lateral surface of the calcaneus body (K)
DAFB	Dorsal articular facet breadth	Linear distance from the most medial (L) to the lateral points on the posterior facet (O)
DAFL	Dorsal articular facet length	Linear distance between the posterior (H) and the anterior on the posterior articular facet (P)
$\theta$	Gissane's angle	Angular distance from A, I and H points
$\alpha$	Böhler's angle	Angular distance from $180^\circ - \angle AHF$ points
$\beta$	Front angle	Angular distance from $\angle BD$ and $\angle BF$
$\gamma$	Tuber angle	Angular distance from $\angle BD$ and $\perp DF$

## 2.4 Evaluation of Morphology Measurement

Ten calcaneus samples were randomly selected from ninety-nine samples and fabricated physically by using 3D printing technology. All calcaneus models were fabricated layer by layer using a low-cost 3D-printer, (Lulzbot Taz 5, Aleph Objects Inc., USA).



**Figure 4.** Ten samples of 3D printed calcaneus models. a) M-37Y, b) F-23Y, c) M-29Y, d) F-54Y, e) M-44Y, f) M-22Y, g) F-48Y, h) M-29, i) F-21Y, and j) M-29.

The slicing parameters of the 3D printing were set up by default software (LulzBot Cura, 21.04) to generate the numerical controller (NC) tool paths. The printing filament material was Polylactic Acid (PLA) with a diameter of 2.85 mm. The parts were built by depositing the semi-molten material in form of layers with 0.2 mm constantly in each layer. The 3D-printed models are shown in Figure 4. The anatomic landmark was addressed as a reference for measurements. 3D morphology parameters of the calcaneus were measured manually on 3D-printed models using a digital vernier-caliper and a protractor.

## 2.5 Statistical Analysis

All morphology parameters including age, height, weight, and BMI were analyzed using the statistic software Minitab 17 (Minitab Inc., USA). The mean value and standard deviation for each morphology parameter were calculated. Bivariate-Pearson correlation analysis was performed between two variables to ensure the strength of the relationship. Independent samples T-test was conducted to observe calcaneal morphologic parameters between males and females.

## 3. RESULTS

Statistical results for the morphology measurement are listed in Table 2. Significant differences are observed on the angles and even in linear distances between male and female group. The average length in MAXL of the calcaneus was 82.4 and 73.8 mm for males and females, respectively. Similarly, the average height was 44.5 and 39.7 mm, while the minimum height was 39.9 and 35.6 mm. The Gissane's angle was 112.9° for males and 112° for females. While, the Böhler's angle present almost the same value 33.9° and 33° for males and females, respectively. The mean values of the remained parameters for males were slightly greater than those of females, except for a Böhler's angle ( $\alpha$ ). Student's *t*-test was performed independently for each linear distance and angle, and both males and females samples. The parameters with *P* scores less than 0.05 are long arm length (LAL), cuboidal facet height (CFH), maximum breadth (MXB), dorsal articular facet

length (DAFL), Gissane's angle ( $\theta$ ), front angle ( $\beta$ ), and tuber angle ( $\gamma$ ).

**Table 2.** Data description of calcaneus radiograph (age from 20 to 59)

	Overall (n=99)				Males (n=49)				Females (n=50)			
	Mean ±SD	Min	Max	P- Value	Mean ±SD	Min	Max	P- Value	Mean ±SD	Min	Max	P- Value
MAXL	78.1±5.8	65.2	91.4	.271	82.4±4.3	71.3	91.4	.905	73.8±3.5	65.2	83.1	.950
CBL	72.9±5.8	60.8	86.8	.089	77.2±4.4	67.9	86.8	.512	68.1±3.7	60.8	78.2	.721
MXBH	42.1±3.9	31.5	51.2	.770	44.5±2.8	38.8	51.2	.369	39.7±3.2	31.5	46.3	.952
MIBH	37.7±3.3	28.6	45.5	.396	39.9±2.4	35.3	45.5	.317	35.5±2.4	28.6	42.2	.438
CBH	48.3±4.3	37.6	58.2	.727	51.2±3.2	46.5	58.2	.142	45.5±3.2	37.6	52.1	.748
LAL	39.2±3.6	31.6	47.4	.131	41.9±2.7	34.9	47.4	.546	36.7±2.3	31.6	42.0	.953
LPF	25.6±3.1	19.7	33.3	.038	27.6±2.6	22.8	33.3	.338	23.5±2.0	19.7	27.5	.402
LAP	21.5±2.6	16.7	27.9	.458	22.3±2.8	17.1	27.9	.813	20.8±2.2	16.7	25.7	.413
CFH	23.2±2.5	17.1	30.5	.824	24.8±2.2	19.6	30.5	.503	21.7±1.8	17.0	25.5	.680
MXB	43.7±3.9	36.7	52.1	.072	45.9±2.9	37.4	52.2	.130	41.4±3.3	36.7	49.3	.168
MIB	25.5±2.8	19.9	32.7	.200	26.9±2.4	22.4	32.7	.493	24.1±2.6	19.8	32.7	.031
DAFB	30.4±3.2	23.1	41.0	.800	32.1±2.6	27.0	41.0	.214	28.7±2.8	23.1	35.4	.018
DAFL	26.3±2.8	20.9	33.9	.015	27.7±2.5	22.0	33.9	.156	24.8±2.3	20.9	31.8	.050
$\theta$	112.5±5.7	101.4	127.1	.156	112.9±6.1	101.9	127.1	.321	112.0±5.4	101.4	125.7	.398
$\alpha$	33.4±4.0	23.0	42.8	.262	33.9±4.0	25.2	42.8	.491	33.0±4.0	22.9	42.1	.442
$\beta$	36.8±3.3	21.9	45.5	.129	36.9±3.3	21.9	42.3	.013	36.5±3.4	29.3	45.5	.887
$\gamma$	78.4±3.8	69.8	86.9	.293	78.3±3.7	69.9	86.5	.197	78.5±3.9	70.3	86.9	.772

The Bivariate-Pearson correlation test was performed for all parameters, as shown in Table 3. The correlation test between every two variables and the difference between males and female groups were also investigated. Significant correlations were observed among some morphology parameters. Age is strong correlation with MAXL, CBL and  $\gamma$  angle, while parameter BMI is correlation with age only.

There are eight meaningful effect of correlation results between every two variables for males morphology measurement, as shown below:

- (1) MAXL is moderate positive correlation with CBL, MXBH, MIBH, CBH, and DAFB.
- (2) CBL is correlation with MXBH, MIBH, CBH, LAL, and DAFB.
- (3) MXBH is correlation with MIBH, CBH, MIB and  $\beta$  angle.
- (4) MIBH is correlation with CBH, LPF, MIB, DAFB and  $\beta$  angle.
- (5) CBH is moderate positive correlation with LAL.
- (6) LAL is significant correlation with LPF and CFH.
- (7) MXB is moderate positive correlation with MIB and DAFB.
- (8) MIB is strongly significant correlation with DAFB and DAFL.

In addition, BMI, LPF, LAP, CFH, DAFB, DAFL,  $\theta$ ,  $\alpha$ ,  $\beta$ , and  $\gamma$  angle are not significantly correlation with other morphology parameters.

On the other hand, fourteen variables are correlated between every two variables for females morphology measurement, as shown below:

- (1) BMI very strong positive correlation with age.
- (2) CBL very strong positive correlation with MAX.
- (3) MIBH strong positive correlation with MXBH.
- (4) CBH moderate strong correlation with MAXL, and MXBH.

**Table 3. Pearson correlation analysis of calcaneus morphology parameters, top left shows in male and bottom right is in female.**

		Male (n=49)																		
		Age	BMI	MAXL	CBL	MXBH	MIBH	CBH	LAL	LPF	LAP	CFH	MXB	MIB	DAFB	DAFL	θ	α	β	γ
Female (n=50)	Age		.043 .767	-.437** .002	-.396** .005	-.181 .213	-.242 .094	-.285* .047	-.325* .023	-.149 .308	-.285* .047	-.463** .001	-.160 .273	-.218 .133	-.220 .129	-.339* .017	-.016 .912	-.058 .691	.258 .074	.372** .008
	BMI	.421** 7.5		.128 .382	.140 .338	-.004 .979	.222 .125	.028 .846	-.022 .879	.240 .097	-.158 .277	.186 .201	.157 .280	.005 .974	.224 .121	-.57 .699	-.143 .326	-.055 .710	-.085 .562	.205 .157
	MAXL	.051 .723	.186 .195		.907** .000	.509** .000	.485** .000	.607** .000	.528** .000	.367** .005	.397** .000	.599** .000	.242 .094	.381** .007	.531** .000	.299** .037	-.068 .640	-.191 .190	-.088 .550	-.128 .379
	CBL	.144 .320	.315* .026	.872** .000		.512** .000	.410** .003	.600** .000	.358* .012	.270 .061	.229 .114	.437** .002	.244 .091	.300* .036	.403** .004	.277 .054	-.017 .908	-.184 .206	-.128 .380	-.205 .159
	MXBH	.217 .131	.203 .157	.433** .002	.419** .002		.722** .000	.568** .000	.226 .118	.227 .116	.141 .334	.390** .006	.320* .025	.391** .005	.338* .017	.208 .152	-.090 .537	-.262 .069	.498** .000	-.048 .746
	MIBH	-.023 .874	.193 .180	.490** .000	.404** .004	.792** .000		.594** .000	.280 .052	.409** .003	.102 .485	.605** .000	.277 .054	.433** .002	.536** .000	.202 .165	-.186 .201	-.071 .630	.388** .006	.249 .084
	CBH	.149 .301	.135 .348	.478** .000	.403** .004	.719** .000	.579** .000		.181 .214	.225 .120	.217 .134	.493** .000	.282** .050	.260 .071	.375** .008	.144 .325	-.215 .139	.203 .163	.208 .151	-.165 .258
	LAL	.023 .875	.140 .334	.692** .000	.542** .000	.378** .007	.540** .000	.209 .145		.556** .000	.487** .000	.397** .005	.141 .335	.328* .021	.225 .121	.336* .018	.254 .079	.174 .232	-.055 .708	-.070 .630
	LPF	-.037 .800	.233 .103	.497** .000	.376** .007	.305** .031	.458** .001	.062 .667	.734** .000		-.216 .137	.274 .056	.230 .112	.319* .026	.317** .026	.427** .002	-.179 .218	.127 .385	.003 .983	-.109 .455
	LAP	.248 .083	-.035 .810	.449** .001	.300* .034	.227 .112	.245 .087	.410** .003	.445** .001	.077 .595		.297* .038	-.011 .939	.065 .656	.118 .418	.026 .859	-.124 .397	.089 .542	.046 .751	.015 .917
	CFH	-.220 .124	-.033 .823	.427** .002	.273 .055	.330* .019	.446** .001	.369** .008	.284* .045	.349* .013	.157 .276		.262 .069	.238 .099	.413** .003	.197 .174	-.106 .469	-.068 .641	-.083 .570	.294* .040
	MXB	-.023 .876	.068 .639	.491** .000	.510** .000	.384** .006	.472** .001	.455** .001	.355* .011	.318* .025	.209 .144	.361* .010		.374** .008	.443** .001	.361* .011	-.142 .330	.004 .980	-.143 .326	.021 .887
	MIB	.101 .483	.130 .367	.445** .001	.370** .008	.361* .010	.292* .040	.434* .002	.214 .136	.228 .112	.158 .274	.097 .501	.543* .000		.642** .000	.503** .000	.055 .707	-.099 .497	-.016 .914	.086 .556
	DAFB	.021 .883	.316* .025	.463** .001	.324** .022	.345* .014	.436** .002	.462** .001	.294* .038	.476** .000	.186 .196	.257 .071	.492** .000	.635** .000		.366** .010	-.173 .234	-.087 .552	-.019 .895	.157 .282
	DAFL	.043 .767	.319* .024	.501** .000	.391** .005	.345** .014	.498** .000	.385** .006	.444** .001	.477** .000	.023 .874	.249 .081	.485** .000	.529** .000	.629** .000		-.147 .314	-.031 .830	-.103 .483	-.061 .677
	θ	-.210 .143	.062 .667	.084 .561	.160 .267	-.052 .719	.078 .590	-.231 .106	.227 .113	.022 .882	-.429** .002	-.048 .741	-.031 .832	-.201 .162	-.183 .203	-.035 .809		.063 .667	-.134 .359	-.020 .891
	α	.058 .688	-.095 .510	-.202 .160	-.176 .221	-.047 .747	-.031 .832	.270 .058	-.114 .431	-.236 .099	.166 .249	-.258 .071	.111 .442	-.121 .403	.052 .719	-.051 .725	-.041 .779		-.081 .582	-.119 .414
	β	.123 .394	.110 .447	-.0360 .805	-.137 .344	.778** .000	.562** .000	.582** .000	-.001 .995	.032 .825	.020 .891	.081 .576	.075 .607	.237 .098	.243 .089	.218 .128	-.184 .202	.065 .652		-.033 .823
	γ	.011 .939	.009 .951	.043 .767	.041 .777	-.027 .851	.073 .615	.008 .954	.215 .134	.301* .034	-.019 .897	.280* .049	.044 .761	-.018 .899	.173 .230	.160 .268	.090 .536	-.048 .741	-.180 .211	
* p < 0.05, ** p < 0.01 (the bold text is p-value, and the regular text is Pearson correlation coefficient)																				

\* p < 0.05, \*\* p < 0.01 (the bold text is p-value, and the regular text is Pearson correlation coefficient)

**Table 4. T-test evaluation results of computer-assisted and manual measurement.**

Parameters	MAXL	CBL	MXBH	MIBH	CBH	LAL	LPF	LAP	CFH	MIB	MXB	DAFB	DAFL	θ	α	β	γ
p-value	0.026	0.832	0.022	0.270	0.002	0.001	0.114	0.807	0.016	0.695	0.081	0.794	0.502	0.000	0.012	0.617	0.000

- (5) LAL moderate strong correlation with MAXL, and CBH.
- (6) LPF moderate positive correlation with MAXL, and LAL.
- (7) LAP moderate correlation with MAXL.
- (8) CFH moderate correlation with MIBH.
- (9) MIB moderate correlation with MAXL and MXB.
- (10) DAFB correlation with LPF, MXB, and MIB.
- (11) DAFL moderate negative correlation with MXB.
- (12) θ angle moderate correlation with DAFL and MXB.
- (13) β angle strong correlation with MXB, DAFB, DAFL, and moderate negative correlation with θ angle.
- (14) γ angle strong correlation with MXB, DAFB, DAFL, and strong negative correlation with β angle.

In addition, MAXL, MXBH, MXB and α angle are not correlated with other parameters.

Paired *t*-test was performed for computer-assistive measurement on 3D model and manual measurement on the 3D-printed calcaneus. Table 4 shows that the *P* value in the comparison for each parameter was larger than 0.05, except for linear distance CBH, LAL and angular distance θ, α, γ angle. It indicates that those parameters were significant difference under the two measurements. Therefore, computer-assisted measurement can substitute the manual measurement.

## 4. DISCUSSION

In this study, the average morphology parameters obtained were 78.1 mm in length, 42.1 in height, 43.7 in width, 112.5° in Gissane's angle (θ), 33.4° in Böhler angle (α) for all samples, including both male and female groups. To compare with Asians,

- (1) Korean is 77.2 mm in length, 46.9 in height, 41.4 in width, and 9.1° in Böhler angle [14].
- (2) Chinese is 68.6 mm in length, 33.9 in minimum height, and 40.6° in Böhler angle [15].
- (3) Japan is 70.8 mm in length, 41.3 in height, and 38.1 in width [16].

The results show that these parameters are not drastically different. Gissane's and Böhler's angles are two important parameters to assess calcaneus fracture. The normal values are between 120° and 145° for Gissane's angle, and 25° up to 40° for the Böhler's angle [1]. There are gender group differences in the measurement of linear distances and angles, where the values for males were significantly greater than those of females. According to Pearson correlation analysis, some parameters were a strong correlation that statistically significant. One parameter may affect to change multiple parameters that correlate to it, specifically in the significant level of 0.01. Age was correlation with calcaneus length (MAXL), while the parameter BMI was correlation with age, but not significant correlated with other parameters.

For male parameters, strong relationships were found between age and calcaneus length (MAXL) ( $r = -0.438$ ,  $n = 49$ ,  $p = 0.002$ ). However, there were no significant correlation between age and height (MXBH), width (MXB), Böhler's angle ( $\alpha$ ) and Gissane's angle ( $\theta$ ). Relationship between BMI and linear as well as angle distance were not correlated. For female parameters, the results presented no a correlation between age and MAXL, MXBH, MXB,  $\alpha$ , and  $\theta$ .

To verify the results of three-dimensional measurement, the morphology parameters of 3D-printed calcaneus were measured using a digital sliding caliper for linear measurement and a goniometer was used in angle measurement. The results from both measurements, computer-assisted and manual were statistically analyzed, the results were not significantly different. Jamali et al. [12] reported that the computer-assisted measurement would valid and accurate if the threshold deviation within 2 mm or 2° compared to a gold standard. The probability of parameter differences in two method is not significant. The computer-assisted measurement can be used to replace manual measurement. However, several issues in computer-assisted measurement should be taken into account, selecting threshold limit and mesh reducing in 3D reconstruction process might impact to dimension and topology of the 3D model, user interactive and repetitive snapping of the landmark feature points, levels of anatomy understanding and skills of the operation.

## 5. CONCLUSION

The results of this study demonstrate that calcaneus morphology parameters for males are larger than those for women. The average of morphology parameters for both males and females group, 78.1 mm in length, 42.1 in height, 43.7 in width, 112.5° in Gissane angle, 33.4° in Böhler angle, which is in the ranged value of Asian morphology population. Some morphology parameters are strong correlation with other parameters, indicating that one parameter may affect the change of multiple parameters correlated. We found that age is related with a maximum length of anteroposterior (MAXL), while BMI correlated with age but is not correlated with other parameters significantly. Computer-assisted measurement even can offer precise result compare to manual measurement. However, several drawbacks related to 3D reconstruction and measurement might be further improved to increase its accuracy. This study might offer the basic data about the morphology parameters of calcaneus for people living in Taiwan.

## 6. REFERENCES

- [1] Daftary, A., Haims, A.H., Baumgaertner, M.R. 2005. Fractures of the calcaneus: A review with emphasis on CT. *Radiographics*, 25(5), 1215–1226. DOI=<https://doi.org/10.1148/rg.255045713>.
- [2] Galluzzo, M., Greco, F., Pietragalla, M., De Renzis, A., Carbone, M., Zappia, M., Maggioletti, N., D'andrea, A., Caracchini, G., and Miele, V. 2018. Calcaneal fractures: radiological and CT evaluation and classification systems. *Acta Biomed*, 89(1), 138–150. DOI= <https://doi.org/10.23750/abm.v89i1-S.7017>.
- [3] Letta, C., Schweizer, A., and Fünstahl, P. 2014. Quantification of contralateral differences of the scaphoid: A comparison of bone geometry in three dimensions. *Anatomy Research International*, 1-5. DOI= <http://dx.doi.org/10.1155/2014/904275>.
- [4] Qiang, M., Chen, Y., Zhang, K., Li, H., and Dai, H. 2014. Measurement of three-dimensional morphological characteristics of the calcaneus using CT image post-processing. *J. foot and ankle research*, 7(19), 1-9. DOI= <https://doi.org/10.1186/1757-1146-7-19>
- [5] Otag, I., Tetiker, H., Tastemur, Y., Sabanciogullari, V., Kosar, M.I., and Cimen, M. 2017. Morphometric measurements of calcaneus; Boehler's angle and bone length estimation. *Science Journal*, 38(2), 257-263. DOI= 10.17776/cumuscij.291995.
- [6] Bidmos, M., and Asala, S. 2004. Calcaneal measurement in estimation of stature of South African blacks. *J. Phys. Anthropol*, 126(3). pp. 335-342. DOI=<https://doi.org/10.1002/ajpa.20063>.
- [7] Kim, D-I., Lee, S-S., Kim, Y.S. 2010. Statistical analysis of bone elements excavated from the forensic context. *J. Phys. Anthropol*, 23(1). pp. 1-8. DOI= <https://doi.org/10.11637/kjpa.2010.23.1.1>.
- [8] Bonnel, F., Teissier, P., Maestro, M., Ferré, B., and Toullec, E. 2011. Biometry of bone components in the talonavicular joint: A cadaver study. *Orthopaedics and Traumatology: Surgery and Research*, 97(6), pp. S66-S73. DOI= <https://doi.org/10.1016/j.otsr.2011.06.005>.
- [9] Schepers, T., Ginai, A.Z., Mulder, P.G., and Patka, P. 2007. Radiographic evaluation of calcaneal fractures: to measure or not to measure. *Skeletal Radiology*, 36(9), 847-52. DOI= <https://doi.org/10.1007/s00256-007-0330-6>.
- [10] Gutekunst, D.J., Liu, L., Ju, T., Prior, F.W., and Sinacore, D.R. 2013. Reliability of clinically relevant 3D foot bone angles from quantitative computed tomography. *J. Foot and Ankle Research*, 6(38), 1-8. DOI= <https://doi.org/10.1186/1757-1146-6-38>.
- [11] Chou Y.J., Sun S.P., Liu H.H. 2011. Calcaneal osteotomy preoperative planning system with 3D full-sized computer-assisted technology. *J Med Syst*. 35(5), 755-63. DOI= <https://doi.org/10.1007/s10916-010-9465-4>.
- [12] Jamali A.A., Deuel C., Ferreira A., Salgado C.J., Hunter J.C., and Strong E.B. 2007. Linear and angular measurements of computer-generated models: Are they accurate, valid, and reliable? *Computer Aided Surgery*, 12(5), 278–285. DOI= <https://doi.org/10.3109/10929080701680265>.
- [13] Irwansyah, Lai, J. Y., and Lee, P. Y. 2016. Development and clinic study of an integrated preoperative planning system for orthopedic surgery, *In Proc. of the XIV Int. Symp. on 3D Analy. of Human Movement*, Taiwan, 18-21 July 2016, pp. 141-44.
- [14] Kim, D-I., Kim, Y-S, Lee, U-Y, and Han, S-H. 2013. Sex determination from calcaneus in Korean using discriminant analysis. *Forensic Science International*, 228, 1-3. DOI= <https://doi.org/10.1016/j.forsciint.2013.03.012>.
- [15] Zhang, K., Fan, F., Tu, M., Wang, Y.H., and Deng, Z.H. 2017. Estimation of stature and sex from calcaneal measurements in Chinese. *J. Australian Journal of Forensic Sciences*. 49(1), 69-77. DOI= <https://doi.org/10.1080/00450618.2015.1128967>.
- [16] Sakaue, K. 2011. Sex assessment from the talus and calcaneus of Japanese. *Bull. Natl. Mus. Nat. Sci., Ser. D*, 37, 35–48. <https://www.kahaku.go.jp>.