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Estimation of an Individual Stature Using Foot, Foot Outlines and Footprint Measurements in Adult Saudi Population

تقدير طول الجسم للفرد باستخدام قياسات القدم ومخططات وبصمات الأقدام في البالغين السعوديين

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Abstract

Identification of an individual is considered one of the fundamental challenges for forensic scientists, especially from dismembered and mutilated body parts. To limit the pool of conceivable suspects in the forensic investigation process, footprints and foot outlines found at the crime scene are used to ease estimation of stature. The current study aimed to estimate individual stature using foot, foot outline and footprint measurements in a Saudi Arabian population.

A descriptive cross-sectional study was carried out on two hundred healthy medical students from the Faculty of Medicine at the University of Tabuk in Saudi Arabia. Stature measurements and eight foot, foot outline and footprint measurements were taken from both sides.

Saudi adult males were significantly taller than Saudi females. All measurement values were significantly higher in adult males than in adult females. Most measurements were considered to be positive-

Keywords: Forensic Science, Stature Estimation, Foot Measurements, Adult, Saudi Population.

المستخلص

الاستعراف على هوية المتوفى هو أحد التحديات الرئيسية التي تواجه أطباء الطب الشرعي وخاصة مع الجثث غير المكتملة أو المشوهة. ولتضييق الاشتباه بين المحتملين في عملية التحقيق في الطب الشرعي تستخدم بصمات ومخططات الأقدام التى توجد في مسرح الجريمة؛ وذلك لتسهيل تقدير طول الجسم. وتهدف الدراسة الحالية إلى تقديرطول الفرد باستخدام قياسات القدم ومخططات وبصمة الأقدام في سكان المملكة العربية السعودية.وتم إجراء الدراسة على مائتى طالب طب من كلية الطب بجامعة تبوك. ولقد تم أخذ طول الجسم، كما تم أخذ ثمانية قياسات أنثروبيولوجية للقدم ومخططات وبصمات القدممن على الجانبين. وقد وجد أن الذكور السعوديين البالغين أطول من الإناث. وأن قيم جميع القياسات في الذكور ذات دلالة إحصائية أعلى من الإناث. وأن معظم القياسات على كلا الجانبين ارتبط ارتباطًا إيجابيًا مع طول الجسم

الكلمات المفتاحية: علوم الأدلة الجنائية، طول القامة، قياسات الأقدام، البالغ، عينة سكانية سعودية.

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ly correlated with stature in both sexes. Regression equations and multiple regression equations for stature determination from all measurements in both male and females on both sides were created.

This study has demonstrated the reliability and utility of foot, foot outline and footprint measurements in stature estimation in a Saudi Arabian population that comparable standards developed from foot bones.

في كلا الجنسين. وتم استخدام معدلات الانحدار والانحدار المتعدد لتقدير طول الجسم من خلال قياسات القدم الأنثروبيولوجية ومخططات وبصمة الأقدام على كلا الجانبين في الذكور والإناث. لقد أظهرت هذه الدراسة موثوقية وجدوى قياسات القدم ومخططات وبصمة الأقدام فى تقدير طول الجسم في سكان المملكة العربية السعودية مقارنة بتلك المعايير المماثلة التي تم استخدامها من عظام القدم.

1. Introduction

Identification of an individual is considered a major challenge for forensic scientists, especially from dismembered and mutilated body parts. In cases of disaster, traffic accidents, war and explosions, new techniques have been established to identify victims from their remains [1].

To confirm identity, forensic investigators assess gender, age, stature, and race. One of the most fundamental steps in identity estimation is stature and gender assessment [2]. To reduce the number of possible suspects in forensic investigation, footprints and foot outlines found during crime scene investigation are used to estimate stature [3, 4].

A lot of forensic research has confirmed that foot and its footprint are specific to each individual and can give valuable information related to personal identification during the investigation of a crime scene [5, 6].

Forensic investigators have found a correlation between each part of the body; analysis of foot measurements [7-18] and footprints [5, 19-24] can help in stature estimation due to the presence of a relation between foot dimensions and an individual's stature.

Anatomical dimensions of the foot show regional and ethnical variations due to many factors, including genetics, physical activity, climate, and nutrition. Different tools have been created to assess these differences to determine the most probable data about specific populations. Hence, there is an urgent need to create standards for stature estimation and gender identification from foot measurements in different populations. These measurements can also help in assessing differences among populations [25].

Stature estimation can be rendered inapplicable by using anatomic structure especially in fragmented parts of the body but with only one foot, stature can be specified by using anthropometric methods (such as hand measurements, foot measurements) [1].

Hence, the current research is designed to investigate bilateral asymmetry in feet, foot outlines and footprint dimensions in a cohort of Saudi Arabian population with pure Arabian descent that distinguish them from other ethnic groups, to estimate stature based on foot measurements. The study included eight length measurements from the foot, foot outlines and footprints. The research findings may be applicable to a complete or partial foot, and will establish baseline data for the Gulf area, as Saudi Arabia spans most of the Arabian Peninsula and is considered the largest country in the Middle East.

2. Subjects and Methods

2.1. Subjects

The descriptive cross-sectional study was carried on the Saudi Arabian community in Tabuk in the northwest of Saudi Arabia, using a single community to limit nearby bias.

The study subjects consisted of two hundred healthy medical students from the Faculty of Medicine at the University of Tabuk (100 males and 100 females). Subjects were aged from 18 - 25 years. Students with foot deformities, diseases or previous surgeries were excluded from the study.

Before starting the study, the study was approved by the College of Medicine, University of Tabuk Bioethical Committee, and informed consent was gathered from the volunteers. Aims and procedures were fully explained.

To avert inter-observer error, all measurements were obtained by one researcher from bare-footed subjects.

2.2. Methods

Stature and different foot measurements were taken according to the standard procedures and landmarks defined and applied by Vallois [26] and Krishan [27].

A sliding caliper was used to record different foot measurements. A LE 25 Inkless Shoe Print Kit was used to take footprint impressions from subjects. A white A4 paper and a lead pencil were used to trace foot outlines.

Applied measurements:

Following landmarks were recorded from each research subject:

1. Stature is the maximum standing height from feet to vertex. Measurements were taken in centimeters using a standard stadiometer (mechanical measuring rod) (Seca 216).
2. Description of the eight foot, foot outline and footprint measurements are taken from the right and left sides from each subject in centimeters and to the nearest millimeter:
   - Thumb (Big toe) breadth (TB) is the distance from the most laterally projected part of the thumb.
   - Foot metatarsal tibiae to metatarsal fibulae breadth (MB) is the distance between the most prominent point on the medial side of the foot to the most prominent point on the lateral side (which corresponds to the heads of the first to fifth metatarsals).
   - Heel breadth (HB) is the maximum distance from the most protruding point on the medial surface of the heel to the corresponding protrusion on the lateral surface of the heel, the widest distance across the ball of the heel.
   - Foot length (Heel-Toe Lengths: HT1 - HT5) is the distance between the most distal points of each toe to the pternion.

2.3. Statistical procedures

Data were statistically tested using the Statistical Package for Social Sciences version 20.0 computer software (SPSS Inc., Chicago, IL, USA). The descriptive statistical data of the foot, foot outline and footprint measurements were analyzed and the comparisons between values of measurement in both genders were tested with Student's t-test. Asymmetry between both sides in foot, foot outlines and footprint measurements were analyzed using the paired t-test.

Pearson's correlation coefficients between stature and foot, foot outline and footprint measurements were evaluated; a p-value <0.05 is considered to be statistically significant.

Linear and multiple regression equations from various foot, foot outline and footprint measurements of the male and female subjects were used to estimate stature. Multiple regression equations were performed to prove that their prediction accuracy is better than simple linear equations.

3. Results

Descriptive statistics of age and stature in both sexes is indicated in Table-1. Saudi adult males are significantly taller than females ($p<0.05$).

Table 1- Descriptive statistics of age and the stature (cm) in males and females.

Variables	Sex		*p*-value
Age	Males (n=100)	Females (n=100)	
Mean±SD	23.0±0.8	20.4±1.9	<0.001 *
Min-Max	22-25	19-31	
Range	3	12	
Stature			
Mean±SD	170.8±6.4	159.6±8.6	<0.001 *
Min-Max	154.0-178.5	141.5-185.5	
Range	24.5	44	

Statistically significant at $p<0.05$ *
SD: Standard Deviation

Descriptive statistics for foot, foot outline and footprint measurements for both sexes on both sides are indicated in (Table-2). The values of all measurements are significantly higher for Saudi males than Saudi females. The mean difference between both sides is statistically significant for most measurements in both males and females (Table-3).

Pearson's correlation coefficients between foot, foot outline and footprint measurements and stature on both sides in both males and females are indicated in (Table-4). It is observed that most measurements on both sides are positively correlated with stature in both sexes and show statistical significance. In males on right the side, the uppermost correlation is presented by HT3 r = 0.87 and the lowermost by MB print r = 0.02. On the left side, the uppermost correlation is presented also by HT3 r = 0.78 and the lowermost by TB and its print r = 0.05. In females on the right side, the uppermost correlation is presented by HT3 outline r = 0.60 and the lowermost by HB r = 0.06. On the left side, the uppermost correlation is presented by HT2 outline r = 0.56 and the lowermost by TB print r = 0.04.

In this study, equations of liner regression were calculated independently for each measurement, sex, and side. The equation used was as follows: Y (stature) = a (regression coefficient of the dependent variable i.e., stature) + b (the regression coefficient of the independent variable i.e., foot length) x (a measurement i.e., foot length) ± standard error of estimate (SEE). The SEE predicts the deviations of estimated stature from the actual stature. A low value indicates greater reliability in the estimated stature.

Regression equations and SEE for stature determination from foot, foot outline and footprint parameters on both sides in both sexes are listed in (Table-9). In males, SEE ranges between (±3.3 and ±6.4) for the right side and ranges between (±3.6 and ±6.4) for the left side. HT3 exhibits the lowest values on right and left sides for both feet (±3.7 and ±4.5, respectively) and footprint measurements (±4.2 and ±3.7, respectively); while in foot outline measurements, HT2 exhibits the lowest values on right and left sides (±3.3 and ±3.6, respectively). In females, SEE ranges between (±6.6 and ±8.6) for the right side and ranges between (±6.7 and ±8.6) for the left

Table 2- Descriptive statistics of the right and left anthropometric foot, foot outlines and footprints measurements in males and females.

Anthropometric foot measurements	Males (n=100)				Female (n=100)				Independent t-test
	Mean±SD	Min	Max	Range	Mean±SD	Min	Max	Range	*p*-value
Right									
TB	3.0±0.2	2.7	3.5	0.8	2.6±0.2	2.2	3.0	0.8	<0.001*
MB	9.9±0.6	8.6	11.3	2.7	9.0±0.4	8.1	9.6	1.5	<0.001*
HB	6.1±0.5	5.6	7.1	1.5	5.4±0.3	4.7	6.0	1.3	<0.001*
HT1	25.5±1.2	23.8	28.5	4.7	23.1±1.2	20.1	25.5	5.4	<0.001*
HT2	25.0±1.1	23.0	27.5	4.5	23.1±0.9	21.6	25.1	3.5	<0.001*
HT3	24.2±1.2	21.8	26.9	5.1	22.3±1.1	20.1	25.6	5.5	<0.001*
HT4	22.9±1.3	21.0	25.7	4.7	21.1±1.0	19.5	23.2	3.7	<0.001*
HT5	21.2±1.0	19.7	23.2	3.5	19.5±0.8	18.0	21.5	3.5	<0.001*
Left									
TB	3.0±0.2	2.6	3.4	0.8	2.6±0.2	2.0	2.9	0.9	<0.001*
MB	9.9±0.6	8.5	11.1	2.6	9.1±0.4	8.3	10.4	2.1	<0.001*
HB	6.1±0.4	5.5	7.0	1.5	5.4±0.3	4.7	6.2	1.5	<0.001*
HT1	25.5±1.2	23.7	28.6	4.9	23.2±1.0	20.6	25.3	4.7	<0.001*
HT2	25.2±1.1	23.2	27.7	4.5	23.0±1.0	21.6	25.5	3.9	<0.001*
HT3	24.4±1.2	22.5	27.4	4.9	22.3±1.0	20.1	24.8	4.7	<0.001*
HT4	23.3±1.2	21.6	26.5	4.9	21.1±1.0	19.1	23.6	4.5	<0.001*
HT5	21.5±1.1	20.2	24.3	4.1	19.5±0.9	18.1	21.5	3.4	<0.001*
Foot outlines measurements									
Right									
TB	3.2±0.2	2.8	3.5	0.7	2.8±0.3	2.3	3.5	1.2	<0.001*
MB	10.1±0.6	9.3	11.3	2.0	9.3±0.6	8.2	10.5	2.3	<0.001*
HB	5.8±0.3	5.4	6.4	1.0	5.0±0.8	2.5	6.1	3.6	<0.001*
HT1	25.6±1.1	23.5	27.7	4.2	23.9±1.2	21.5	27.0	5.5	<0.001*
HT2	25.3±1.1	22.9	26.8	3.9	23.5±1.2	21.1	26.2	5.1	<0.001*
HT3	24.5±1.1	22.0	26.0	4.0	22.6±1.1	20.7	25.0	4.3	<0.001*
HT4	23.2±1.0	21.3	24.8	3.5	21.5±1.1	19.3	24.0	4.7	<0.001*
HT5	21.6±0.9	19.8	22.8	3.0	20.0±0.9	18.4	22.6	4.2	<0.001*
Left									
TB	3.1±0.3	2.5	3.6	1.1	2.8±0.3	2.3	3.4	1.1	<0.001*
MB	10.1±0.6	9.0	11.2	2.2	9.1±0.6	8.3	10.1	1.8	<0.001*
HB	5.8±0.4	5.0	6.5	1.5	5.0±0.8	2.5	6.2	3.7	<0.001*
HT1	25.7±1.1	23.4	27.8	4.4	23.5±1.2	20.0	27.0	7.0	<0.001*
HT2	25.4±1.3	22.2	27.0	4.8	23.5±1.2	21.4	26.7	5.3	<0.001*
HT3	24.5±1.3	21.5	26.5	5.0	22.6±1.1	20.9	25.3	4.4	<0.001*
HT4	23.3±1.2	21.0	25.4	4.4	21.4±1.0	19.7	24.1	4.4	<0.001*
HT5	21.7±0.9	20.2	22.8	2.6	19.8±1.0	18.6	22.8	4.2	<0.001*
Footprints measurements									
Right									
TB	2.8±0.2	2.4	3.3	0.9	2.8±0.8	2.0	4.8	2.8	<0.001*
MB	9.8±0.6	8.4	10.8	2.4	8.7±0.4	8.2	9.5	1.3	<0.001*

Table 2- Contd..

Anthropometric foot measurements	Males (n=100)				Female (n=100)				Independent t-test
	Mean±SD	Min	Max	Range	Mean±SD	Min	Max	Range	*p*-value
HB	5.1±0.5	4.0	6.1	2.1	4.2±0.9	2.0	5.0	3.0	<0.001*
HT1	24.4±1.1	22.4	26.5	4.1	22.6±1.2	21.0	26.2	5.2	<0.001*
HT2	24.2±1.0	22.3	26.4	4.1	22.7±1.1	21.2	25.6	4.4	<0.001*
HT3	23.4±1.1	21.4	25.4	4.0	21.8±1.2	20.2	24.5	4.3	<0.001*
HT4	22.3±1.1	20.7	24.6	3.9	20.7±1.1	19.3	23.6	4.3	<0.001*
HT5	20.7±0.8	19.2	22.4	3.2	19.1±0.9	17.6	21.2	3.6	<0.001*
Left									
TB	2.7±0.2	2.3	3.1	0.8	2.7±0.6	2.2	4.1	1.9	<0.001*
MB	9.7±0.7	8.7	11.3	2.6	8.8±0.5	8.3	9.8	1.5	<0.001*
HB	5.1±0.4	4.3	5.8	1.5	4.1±0.9	2.0	5.0	3.0	<0.001*
HT1	24.6±1.2	22.6	26.7	4.1	22.9±1.0	21.3	25.8	4.5	<0.001*
HT2	24.4±1.1	22.5	26.1	3.6	22.8±1.1	21.2	25.3	4.1	<0.001*
HT3	23.5±1.0	21.7	25.4	3.7	21.9±1.0	20.1	24.0	3.9	<0.001*
HT4	22.5±0.9	20.9	24.4	3.5	20.8±1.0	19.0	22.9	3.9	<0.001*
HT5	20.7±0.7	19.6	22.1	2.5	19.2±0.9	17.7	21.7	4.0	<0.001*

Statistically significant at p<0.05 *

SD: Standard DeviationPiciderio. Onsenimil mos evellaut qui nonecturibea dipsam, volorestion

Table 3- Bilateral difference for anthropometric foot, foot outlines and footprints measurements (cm) in males and females.

Males	Paired t-test	
	t	*p*-value
Anthropometric foot measurements		
TB	0.86	0.162
MB	0.93	0.698
HB	0.74	0.295
HT1	0.97	0.335
HT2	0.92	0.001*
HT3	0.95	<0.001*
HT4	0.93	<0.001*
HT5	0.93	<0.001*
Foot outlines measurements		
TB	0.32	0.063
MB	0.83	0.229
HB	0.74	0.651
HT1	0.92	0.396

Table 3-Contd..

Males	Paired t-test	
	t	***p*-value**
HT2	0.91	0.053
HT3	0.93	0.091
HT4	0.97	0.020*
HT5	0.92	0.019*
Footprints measurements		
TB	0.69	<0.001*
MB	0.90	0.010*
HB	0.85	0.972
HT1	0.93	0.001*
HT2	0.85	0.016*
HT3	0.93	0.002
HT4	0.89	<0.001
HT5	0.90	0.640
Females		
Anthropometric foot measurements		
TB	0.77	<0.001*
MB	0.68	0.004*
HB	0.70	0.348
HT1	0.87	0.116
HT2	0.96	0.749
HT3	0.95	0.342
HT4	0.91	0.148
HT5	0.91	0.978
Foot outlines measurements		
TB	0.84	0.013*
MB	0.89	<0.001*
HB	0.92	0.952
HT1	0.65	0.001*
HT2	0.93	0.755
HT3	0.95	0.317

Table 3-Contd..

Males	Paired t-test	
	t	*p*-value
HT4	0.93	<0.001*
HT5	0.85	0.001*
Footprints measurements		
TB	0.98	<0.001*
MB	0.77	<0.001*
HB	0.98	0.001*
HT1	0.94	<0.001*
HT2	0.95	<0.001*
HT3	0.95	0.004*
HT4	0.95	0.013*
HT5	0.86	<0.001*

Statistically significant at p<0.05 *

Table 4- Correlation between stature and right and left anthropometric foot, foot outlines and footprints measurements in males and females.

Males Anthropometric foot measurements	Right		Left	
	r	P value	r	*p*-value
TB	0.08	0.413	0.05	0.591
MB	0.33	0.001*	0.13	0.194
HB	0.24	0.014*	0.07	0.467
HT1	0.62	<0.001*	0.54	<0.001*
HT2	0.85	<0.001*	0.48	<0.001*
HT3	0.87	<0.001*	0.78	<0.001*
HT4	0.85	<0.001*	0.76	<0.001*
HT5	0.78	<0.001*	0.74	<0.001*
Foot outlines measurements				
TB	-0.56	<0.001*	-0.33	0.001*
MB	0.17	0.092	-0.17	0.092
HB	-0.34	0.001*	-0.28	0.006*
HT1	0.63	<0.001*	0.63	<0.001*
HT2	0.77	<0.001*	0.64	<0.001*
HT3	0.50	<0.001*	0.63	<0.001*

Table 4-Contd..

Males Anthropometric foot measurements	Right		Left	
	r	P value	r	*p*-value
HT4	0.61	<0.001*	0.71	<0.001*
HT5	0.68	<0.001*	0.76	<0.00*1
Footprints measurements				
TB	-0.36	<0.001*	0.05	0.638
MB	0.02	0.865	0.26	0.009*
HB	-0.18	0.078	-0.07	0.510
HT1	0.68	<0.001*	0.65	<0.001*
HT2	0.64	<0.001*	0.75	<0.001*
HT3	0.64	<0.001*	0.73	<0.001*
HT4	0.63	<0.001*	0.61	<0.001*
HT5	0.54	<0.001*	0.72	<0.001*
Females				
Anthropometric foot measurements				
TB	0.20	0.048*	0.21	0.040*
MB	0.19	0.058	0.56	0.000*
HB	0.06	0.544	0.09	0.363
HT1	0.41	<0.001*	0.47	<0.001*
HT2	0.54	<0.001*	0.55	<0.001*
HT3	0.45	<0.001*	0.47	<0.001*
HT4	0.45	<0.001*	0.48	<0.001*
HT5	0.26	0.009*	0.32	0.001*
Foot outlines measurements				
TB	0.41	<0.00*1	0.24	0.018*
MB	0.13	0.192	0.26	0.009*
HB	0.37	<0.001*	0.29	0.004*
HT1	0.53	<0.001*	0.46	<0.001*
HT2	0.59	<0.001*	0.56	<0.001*
HT3	0.60	<0.001*	0.53	<0.001*
HT4	0.52	<0.001*	0.51	<0.001*
HT5	0.50	<0.001*	0.41	<0.001*

Table 4-Contd..

Males Anthropometric foot measurements	Right		Left	
	r	P value	r	*p*-value
Footprints measurements				
TB	0.21	0.035*	0.04	0.719
MB	0.18	0.067	0.32	0.001*
HB	0.23	0.020*	0.24	0.016*
HT1	0.48	<0.001*	0.49	<0.001*
HT2	0.54	<0.00*1	0.50	<0.001*
HT3	0.57	<0.001*	0.52	<0.001*
HT4	0.55	<0.001*	0.47	<0.001*
HT5	0.45	<0.001*	0.40	<0.001*

r: pearson correlation
Statistically significant at $p<0.05$ *

side. On the right side, HT2 exhibits the lowest values for foot (±7.6), HT1 exhibits the lowest values for foot outline (±6.6) and HT3 exhibits the lowest values for footprint (±7.1). On the left side, MB exhibits the lowest values for foot (±7.1), both HT2 and HT4 exhibit the lowest values for foot outline (±6.7) and HT3 exhibits the lowest values for footprint (±7.2) (Table-5).

The multiple regression equation for stature determination from different collections of foot, foot outline and footprint measurements in both sexes are listed in (Table-6). In males, the lowest value of SEE is ±2.07 on the right side and ±2.34 on the left side. In females, the lowest value of SEE is ±6.17 on the right side and ±6.0 on the left side.

4. Discussion

The estimation of stature is a fundamental stage in any forensic science study, including the anthropological profile of unidentified human remains [28]. Various studies on estimating stature from various body segments have shown that upper extremities have a lower affiliation with stature than lower extremities, and that the foot is the most useful in the context of identity because it is protected by the shoe [29, 30]. Regression analysis is thought to be the most accurate and straightforward method for determining stature from bones [28]. Many studies have been conducted to improve the accuracy of regression equations used to calculate stature using foot and footprint measurements [1, 8, 16, 18].

Our study has included eight measurements for foot, foot outline and footprint parameters in both sides to determine stature by cautiously selecting numerous anatomical landmarks on intact body surfaces. This is to define the characteristic foot features and to create specific regression equations in Saudi population that can distinguish them from other ethnic groups.

We have showed in this study that stature in adult Saudi males is significantly higher than adult females, which is in accordance with the results of numerous studies in various human populations [8, 12, 31]. Stature is an inveterate characteristic and

Table 5- Simple linear regression equations for estimation of stature from anthropometric foot, foot outlines and footprints measurements on both sides in males and females.

Males	Right			Left		
Anthropometric foot measurements	**Regression equations**	**R**	**SEE**	**Regression equations**	**R**	**SEE**
TB	Stature =155.3+5.2TB	0.191	6.3	Stature =154.2+5.6TB	0.173	6.3
MB	Stature =138.5+3.3MB	0.314	6.1	Stature =142.6+2.9MB	0.275	6.2
HB	Stature =146.4+4.0HB	0.292	6.1	Stature =167.8+0.5HB	0.032	6.4
HT1	Stature =89.3+3.2HT1	0.618	5.0	Stature =94.0+3.0HT1	0.578	5.2
HT2	Stature =65.4+4.2HT2	0.742	4.3	Stature =74.7+3.8HT2	0.663	4.8
HT3	Stature =69.0+4.2HT3	0.819	3.7	Stature =75.1+3.9HT3	0.714	4.5
HT4	Stature =84.7+3.8HT4	0.767	4.1	Stature =87.9+3.6HT4	0.679	4.7
HT5	Stature =88.2+3.8HT5	0.641	4.9	Stature =88.2+3.8HT5	0.641	4.9
Foot outlines measurements						
TB	Stature =206.6+(-11.3TB)	0.420	5.8	Stature =188.8+(-5.8TB)	0.268	6.2
MB	Stature =154.8+1.6MB	0.140	6.4	Stature =180.6+(-1.0MB)	0.097	6.4
HB	Stature =228.1+(-9.9HB)	0.484	5.6	Stature =195.8+(-4.3HB)	0.267	6.2
HT1	Stature =64.1+4.2HT1	0.743	4.3	Stature =50.5+4.7HT1	0.780	4.0
HT2	Stature =45.4+5.0HT2	0.862	3.3	Stature =67.2+4.1HT2	0.824	3.6
HT3	Stature =67.8+4.2HT3	0.744	4.3	Stature =72.4+4.0HT3	0.806	3.8
HT4	Stature =64.2+4.6HT4	0.750	4.2	Stature =74.2+4.1HT4	0.784	4.0
HT5	Stature =71.3+4.6HT5	0.654	4.9	Stature =57.4+5.2HT5	0.732	4.4
Footprints measurements						
TB	Stature =195.4+(-8.8TB)	0.331	6.1	Stature =162.5+3.1TB	0.113	6.4
MB	Stature =166.2+0.5MB	0.046	6.4	Stature =145.3+2.6	0.267	6.2
HB	Stature =198.4+(-5.4HB)	0.436	5.8	Stature =199.4+(-5.6HB)	0.328	6.1
HT1	Stature =78.4+3.8HT1	0.662	4.8	Stature =74.2+3.9HT1	0.746	4.3
HT2	Stature =61.8+4.5HT2	0.739	4.3	Stature =50.4+4.9HT2	0.812	3.7
HT3	Stature =65.5+4.5HT3	0.749	4.2	Stature =49.0+5.2HT3	0.819	3.7
HT4	Stature =84.2+3.9HT4	0.656	4.8	Stature =67.5+4.6HT4	0.608	4.7
HT5	Stature =74.8+4.6HT5	0.594	5.2	Stature =59.4+5.4HT5	0.619	5.0

Table 5-Contd..

Males	**Right**			**Left**		
Anthropometric foot measurements	**Regression equations**	**R**	**SEE**	**Regression equations**	**R**	**SEE**
Females						
Anthropometric foot measurements						
TB	Stature =132+10.5TB	0.223	8.4	Stature =139.2+7.9TB	0.175	8.5
MB	Stature =109.8+5.6MB	0.250	8.3	Stature =53.9+11.7MB	0.571	7.1
HB	Stature =149.1+2.0HB	0.060	8.6	Stature =148.5+2.1HB	0.077	8.6
HT1	Stature =107.2+2.3HT1	0.322	8.2	Stature =88.9+3.0HT1	0.369	8.0
HT2	Stature =62.8+4.2HT2	0.464	7.6	Stature =63.6+4.2HT2	0.472	7.6
HT3	Stature =93.8+3.0HT3	0.376	8.0	Stature =90.7+3.1HT3	0.370	8.0
HT4	Stature =97.4+2.9HT4	0.353	8.1	Stature =96.3+3.0HT4	0.367	8.0
HT5	Stature =123.3+1.9HT4	0.195	8.4	Stature =123.3+1.9HT5	0.195	8.4
Outlines measurements						
TB	Stature =130.9+10.2TB	0.388	7.9	Stature =136.8+8.0TB	0.264	8.3
MB	Stature =119.1+4.4MB	0.306	8.2	Stature =110.4+5.4MB	0.348	8.1
HB	Stature =149.3+2.1HB	0.201	8.4	Stature =152.2+1.5HB	0.145	8.5
HT1	Stature =52.7+4.5HT1	0.644	6.6	Stature =102.0+1.5HT1	0.453	7.7
HT2	Stature =63.5+4.1HT2	0.591	6.9	Stature =52.1+4.6HT2	0.626	6.7
HT3	Stature =51.4+4.8HT3	0.613	6.8	Stature =50.1+4.8HT3	0.618	6.8
HT4	Stature =63.9+4.4HT4	0.573	7.1	Stature =44.5+5.4HT4	0.629	6.7
HT5	Stature =67.6+4.6HT5	0.511	7.4	Stature =62.2+4.9HT5	0.546	7.2
Footprints measurements						
TB	Stature =160.5 + (-0.3TB)	0.031	8.6	Stature =163.3 + (-1.4TB)	0.097	8.6
MB	Stature =101.0+6.7MB	0.310	8.2	Stature =101.5+6.6MB	0.356	8.0
HB	Stature =152.6+1.7HB	0.181	8.5	Stature =151.8+1.9HB	0.205	8.4
HT1	Stature =69.7+4.0HT1	0.551	7.2	Stature =62.8+4.2HT1	0.518	7.4
HT2	Stature =65.7+4.1HT2	0.541	7.2	Stature =64.3+4.2	0.512	7.4
HT3	Stature =68.4+4.2HT3	0.566	7.1	Stature =62.8+4.4HT3	0.541	7.2
HT4	Stature =74.6+4.1HT4	0.549	7.2	Stature =67.7+4.4HT4	0.540	7.3
HT5	Stature =80.8+4.1HT5	0.450	7.7	Stature =82.6+4.0HT5	0.438	7.7

SEE: standard error of the estimate
R: Karl Pearson's correlation coefficient

females are genetically shorter than males. The affiliation of stature with the Y chromosome has been reported [32].

In the current study, all measurement mean values in adult females are lower than adult males, and these variations between the two sexes are considered to be statistically significant. These variations in this study proves, the presence of sexual dimorphism, in accordance with previous studies conducted on different populations [12, 32, 33]. This statistically significant discrepancy can be attributed to the late maturation of males than females; therefore, males have two norms of delay of physical development. Additionally, geographic, nutritional and climatic conditions have also been reported to affect stature [12, 32].

In the current study, there is statistically significant bilateral asymmetry in some measurements $p < 0.01$ in both sexes, and this is not consistent across all populations. Hemy et al. [34] found that there is bilateral significant asymmetry in foot measurements of males, the left side being larger than the right side; while for females there is no significant asymmetry. Krishan and Sharma[12] and Jasuja et al.[35] did not detect any statistically significant bilateral asymmetry for both sexes.

The outcomes of the current study also agreed with Rao and Kotian [36] and Kewal Krishan [3], who suggested that the discrepancy between foot measurements of two sides in the same person is not accidental but is in fact due to the predominant foot. Most people have a predominant foot that the body uses most for walking or standing. Remarkably, the predominant foot bones are often exposed to more body weight, which results in enlargement of bones and consequently larger measurements.

The results have shown a highly significant Pearson's correlation coefficient between individual stature and most of the various measurements among both sexes on both the right and left sides. In males, the HT3 was most strongly correlated to stature in both right and left sides (r=0.87 and r=0.78, respectively), while in females on the right side, the uppermost correlation is exhibited by HT3 outline r = 0.60, and on left side, HT2 outline r = 0.56. This indicates that the HT3 and its outline depict greater correlation coefficient with stature than other measurements.

Pearson's correlation coefficients between various foot length parameters and stature from toes in adult males are very high, implying a nearby relevance between them. The same results were obtained by Kewal Krishan [3], Robbins [37], and Ozden et al. [8].

Regression equations are approved as the most fundamental equation in stature estimation from different body measurements used to estimate stature from fragmentary or mutilated body parts [28].

Equations of linear regression are calculated for determining the stature from the foot, foot outline and footprint measurements on both sides in both males and females. In males, the lowest SEE is exhibited by HT2 outline on both right (SEE±3.3) and left sides (SEE±3.6). In females, the lowest SEE is exhibited by HT1 outline (SEE±6.6) on the right side of the foot and HT2 and HT4 outline (SEE±6.7) on the left side of the foot. This proves that foot length outline is the most exact variable for determining stature, which makes it the most reliable variable for predicting stature in both sexes.

However, most previous studies support the view that the best variable for determining stature is foot length and this may be somewhat due to different techniques of measurement used in their studies.

From both correlation coefficient and linear regression, it is noticed that a relatively higher correlation is seen among adult males when compared

Table 6- Multiple linear regression equations for estimation of stature from anthropometric foot, foot outlines and footprints measurements on both sides in males and females

Variables	Right			Left		
	Regression equations	**R**	**SEE**	**Regression equations**	**R**	**SEE**
Male						
Anthropometric foot measurements	Stature= 36.6 +(-11.0TB) +4.4MB +2.1HB +(-9.4HT1)+ 1.4 HT2 + 14.1HT3 + (-9.2HT4) +8.7HT5	0.950	2.07	Stature= 77.8+ (-17.2TB) + 2.1MB +(-3.5HB) +(-9HT1) +6.0HT2 +4.7HT3 +2.8HT4 +2.0HT5	0.914	2.70
Foot outlines measurements	Stature= 51.2 +(-6.8TB) + (-4.6MB) +4.5HB +(-0.3HT1) +6.1HT2 +(-3.6HT3) +4.5HT4 + (-0.1HT5)	0.945	2.19	Stature=90.8 +(-5.8TB) +(-4.0MB) + (-0.3HB) +43.7HT1 +(-2.2HT2) +0.5HT3 +3.8HT4 +0.1HT5	0.936	2.34
Footprints measurements	Stature= 105.8 +(-10.5TB) +2.1MB +(-8.3HB) +3.5HT1 +(-1.6HT2) +0.4HT3 +(-3.0HT4) +6.1HT5	0.914	2.70	Stature= 44.7 +(-4.3TB) +2.8MB +(-7.2HB) +(-4.9HT1) +6.1HT2 +2.9HT3 +3.2HT5	0.924	2.55
Females						
Anthropometric foot measurements	Stature= 69.8 +8.1TB +4.0 MB +(-7.3HB) + (-0.2HT1) +8.6HT2 +(-1.8HT3) +2.1HT4 +(-6.6HT5)	0.675	6.59	Stature= 15.3+ 12.2MB +(-5.9HB) +2.1HT1 +5.1HT2 +(-2.7 HT3) +1HT4 +(-2.8 HT5)	0.740	6.00
Foot outlines measurements	Stature= 39.4 +0.4TB + (-2.1MB) +2.0HB +7.6HT1 +(-9.0HT2) +11.7HT3 + (-2.4HT4) +(-2.7HT5)	0.723	6.17	Stature= 17.0 +3.6TB +0.6MB +4.1HB +0.0HT1 +(-0.2HT2) +(-8.9HT3) +18.4HT4 +(-4.1HT5)	0.700	6.38
Footprints measurements	Stature= 96.9 +5.4TB +1.1MB +3.2HB +2.7HT1 +(-11.6HT2) +32.8HT3 + (-12.8HT4) +(-11.7HT5)	0.670	6.63	Stature= 71.7 +(-7.8TB) +(-2.5MB) +(-1.7HB) +(-0.1HT1) +1.8HT2 +(-0.0HT3) +5.8HT4 +(-1.1HT5)	0.637	6.89

SEE: standard error of the estimate
R: Karl Pearson's correlation coefficient

Multiple regression equations for stature determination from various collections of measurements which are carried out in males and females. It is to adult females, and this exhibits a lower SEE than females, which proposes that accurate prediction of stature might be higher among males than females.

noticed that equations of multiple regression have given lower values of SEE than those values given by equations of linear regression for males (SEE ±2.07) and females (SEE±6.00), which proved the greater accuracy of multiple regression equations compared to linear equations. This proposed that equations for multiple regression are more preferable clues for stature determination than equations of linear regression. These findings are compatible with the previous studies [32, 34].

5. Conclusion

Stature estimation is one of the major components used to build up the biological profile of an individual; therefore, it is essential to use the most reliable and accurate methods to estimate stature. This study has demonstrated the reliability and utility of foot, foot outline and footprint measurements in stature determination in a Saudi Arabian population which is comparable to standards developed from foot bones. Certainly, reliability and utility of these parameters could not be approved for use on other populations.

List of abbreviations

HB: Heel breadth; HT1 - HT5: Foot length (Heel-Toe Lengths); MB: Foot metatarsus breadth; R: Karl Pearson's correlation coefficient; r: Pearson Correlation; SD: Standard deviation; SEE: Standard error of estimate; SPSS: Statistical Package for Social Sciences, computer software; TB: Thumb breadth

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