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Research article

STATURE ESTIMATION FROM FOOT OUTLINE MEASUREMENTS IN ADULT BIDAYUHS OF EAST MALAYSIA BY REGRESSION ANALYSIS

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ABSTRACT

Stature estimation from foot impression plays a vital role in forensic investigation. The present study aims to estimate stature from bilateral foot outlines collected from 240 consenting Bidayuhs (120 males, 120 females) residing in East Malaysia and to generate population-specific equations. Ten outline length measurements were taken viz. five from left and five from right foot. The results indicated high significant positive correlation between height and foot outline lengths. The correlation coefficient (R) in pooled sample (0.854-0.878) shows comparatively higher than those of individual male (0.755-0.779), and female foot outline (0.666-0.750). Linear regression analysis presents smaller error of estimate. Thus, regression equations were derived for stature estimation from foot outlines lengths among Bidayuhs of East Malaysia even when sex remains unknown.

Keywords: Forensic Science, Forensic anthropology, Stature, foot outline, Bidayuh ethnic.

Introduction

An aspect of human identification that has received scant attention from forensic anthropologists is the study of human foot and foot impressions made by the foot [1]. Person identification using footprint analysis is also an emerging biometric technique [2]. The characteristic features can provide useful clues to establish identity whenever complete or partial two dimensional (2D) and three dimensional (3D) foot impressions are recovered at the crime scenes [3]. Foot impressions are found at crime scenes since offenders often remove their footwear, either to avoid noise or to gain better grip in climbing walls, etc, while entering or exiting [4]. Examination of footprint [5-9], foot outline [10-12] and foot [13-17] can help in estimation of an individual's stature because of the existence of a strong correlation between one's stature and foot/footprint/foot outline length. The footprint provides the size dimensions of the foot's plantar surface actually touching the floor or hard surface, which produces a two-dimensional (2D) footprint impression. On the other hand the foot outline provides the size parameters of the fleshed bare foot and also represents the boundaries of the foot's impression in soft soil, mud, or any other substances that produces a three-dimensional (3D) footprint impression [18]. The review of literature revealed that very limited studies were conducted on stature estimation from foot outline [10-12] measurements. Most of the foot/foot print/foot outline studies have been conducted on mixed population. The researchers cautioned that racial and cultural aspects of foot morphology must be considered while conducting the foot impression study [19]. The people from different regions and races in a country bear different morphological features and hence a single formula cannot represent for all races or regions in a country [6,9-12]. The researchers have concluded that toes-to-heel footprint/foot outline length in a foot impression has more reliability of prediction than from any other measurements, such as breadth at ball/heel and big toe breadth/length [6,9,11,12]. Hence, the present study attempts the stature estimation from all toes-to-heel lengths in foot outlines and to derive population specific equations suitable for Bidayuh ethnic, an indigenous community found in Sarawak state, East Malaysia on the northern Borneo Island.

Source: http://www.units.muohio.edu/ath175/student/hewesgr/

Fig 1. Map of Malaysia showing the sampling point, Sarawak, East Malaysia

Materials and method

The study was carried out at Sarawak state, East Malaysia. The subjects were from colleges, universities and general public. The Bidayuhs are the native people of Sarawak state, one of the two states in East Malaysia. Fig 1 depicts the area of sample collection in East Malaysia. Before started the research, concurrence was obtained from Sarawak Chief Minister vide No. JKM.P/DEV/16/005/12(44), for sample collection. Informed consent was also obtained from all participants and followed the

procedure in accordance with the ethical standards of Universiti Sains Malaysia Human Research Ethic Committee {Ethical approval No.USMKK/PPP/JEMPeM [247.4.(2.12]/Amend (01) dated 8th April 2012 of USM}.

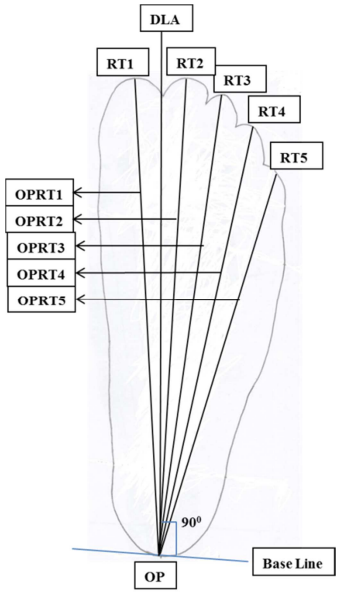

Fig 2. Landmarks and diagonal length measurements on right foot outline

The subjects' age ranged from 18 to 70 years. Subjects with any apparent foot-related disease, pregnancy, orthopedic deformity, physical impairment, injury, disorders and below 18 years of age were excluded from the study. Stature of each subject was measured using a portable body meter measuring device (SECA model 206) following the standard procedure [10,12]. Considering the diurnal variation in stature, the height of the subjects was measured approximately at a fixed time in the evening. The diurnal change in height of a person was reported and confirmed by the researchers [20,21].

Just prior to sample collection, the subjects were advised to wash their feet with soap and water. Then the subject was requested to place the left foot on an A4 size white paper and the foot outline was drawn with a sharp-pointed pencil. The pencil was held perpendicular to the paper as it traced around the margin of the foot. With the foot still on the paper, the anatomical landmarks of the foot, namely mid-rear heel point (pternion, OP) in the base line BL and most anterior points of all toes (LT1–LT5) were marked. The procedure was repeated for the right foot and for the other subjects [10-12]. Following Krishan [12] and Nataraja Moorthy [10-11], the designated longitudinal axis (DLA) and base line (BL) were drawn on the foot outlines. Then five diagonal foot outline lengths were taken from the mid-rear heel point (OP) to most anterior point of each left toe (LT1, LT2, LT3, LT4, and LT5). The left foot outline lengths were designated as OPLT1, OPLT2, OPLT3, OPLT4, and OPLT5. The procedure was repeated for the right foot and the right foot outline lengths were designated as OPRT1, OPRT2, OPRT3, OPRT4, and OPRT5. Fig 2 shows the land marks and length measurements in a right foot outline. All foot outlines and information relating to participants were coded with sample ID for anonymity.

The data were analyzed using PASW Statistics version 20 (Predictive Analytic Software). Bilateral asymmetry was calculated for each of the foot outline measurements and tested for significance using one sample t-test. The linear regression analysis method was employed to derive regression equations for stature estimation from various foot outline lengths since stature estimation from foot outline length is more accurate and reliable with linear regression analysis [22].

Results and discussion

All foot outline lengths exhibit statistically positive significant correlation with stature. Table-1 shows the descriptive statistics of stature measurements in males, females and pooled sample. In males, the stature ranges from 147.0 to 184.5 cm (mean 165.3 cm) and in females, it ranges from 139.0 to 169.5 cm (mean 153.6 cm). In pooled sample, the stature ranges from 139.0 to 184.5 cm. The result showed that means stature is found to be significantly higher in males than females.

Table-2 presents descriptive statistics of foot outline lengths in males, females and pooled sample. The mean foot outline length measurements in males (21.19-25.21 cm) are found to be significantly higher than females (19.40-23.29cm) showing the existence of gender difference. First toe-heel length (OPRT1 and OPLT1) measurement is found to be the longest in both males and females on right and left sides.

Table-3 depicts the bilateral difference or bilateral asymmetry (left–right) in foot outline lengths among males and females. The left foot outline lengths are larger than the right in both males and females. The mean left length measurements in T2 to T5 are longer than right in both genders but not forensically significant.

Table 1. Descriptive statistics of stature (in cm) in males, females and pooled sample of adult Bidayuhs in East Malaysia.

Variable	Male (N = 120)					Female (N = 120)					Pooled sample (N =240)				
	Min	Max	RD	Mean	SD	Min	Max	RD	Mean	SD	Min	Max	RD	Mean	SD
Stature	147.0	184.5	37.5	165.3	6.5	139.0	169.5	30.5	153.6	5.5	139.0	184.5	45.5	159.5	8.4

SD: standard deviation; RD: range difference; Min: minimum; Max: maximum; N: sample size

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Table 2. Descriptive statistics of foot outline length (in cm) measurements in males, females and pooled sample of adult Bidayuhs in East Malaysia.

Variables	Male						Female						Pooled sample					
	N	RD	Min	Max	Mean	SD	N	RD	Min	Max	Mean	SD	N	RD	Min	Max	Mean	SD
OPLT1	120	6.6	21.9	28.5	25.17	1.1	120	4.5	21.3	25.8	23.27	0.9	240	7.2	21.3	28.5	24.22	1.4
OPLT2	120	7.2	21.3	28.5	25.04	1.2	120	5.2	20.6	25.8	23.00	1.0	240	7.9	20.6	28.5	24.02	1.5
OPLT3	120	7.4	20.2	27.6	24.24	1.2	120	5.3	20.0	25.3	22.24	0.9	240	7.6	20.0	27.6	23.24	1.5
OPLT4	120	7.3	18.9	26.2	22.95	1.1	120	4.8	19.0	23.8	21.09	0.9	240	7.3	18.9	26.2	22.02	1.4
OPLT5	120	6.9	17.2	24.1	21.22	1.0	120	4.5	17.2	21.7	19.48	0.8	240	6.9	17.2	24.1	20.35	1.2
OPRT1	120	6.3	22.5	28.8	25.21	1.0	120	5.4	20.8	26.2	23.29	1.0	240	8.0	20.8	28.8	24.25	1.4
OPRT2	120	6.6	21.9	28.5	25.02	1.1	120	6.0	20.5	26.5	22.98	1.0	240	8.0	20.5	28.5	24.00	1.5
OPRT3	120	6.8	20.9	27.7	24.19	1.1	120	6.0	19.7	25.7	22.18	1.0	240	8.0	19.7	27.7	23.19	1.5
OPRT4	120	6.2	19.9	26.1	22.93	1.0	120	5.5	18.7	24.2	21.00	0.9	240	7.4	18.7	26.1	21.97	1.4
OPRT5	120	6.0	18.0	24.0	21.19	1.0	120	4.7	17.3	22.0	19.40	0.8	240	6.7	17.3	24.0	20.30	1.3

Min: minimum; Max: maximum; OPLT1 to OPLT5: left lengths from anterior part of toes outlines LT1- LT5 to outline mid-rear outline heel point OP; OPRT1 to OPRT5: right lengths from anterior part of toes outline RT1-RT5 to mid-rear outline heel point OP; RD: range difference; SD: standard deviation; N : sample size.

Table 3.One-sample t-test of bilateral differences (left–right) in foot outline length measurements among males and females in adult Bidayuh ethnics of East Malaysia.

Variables	Male (n = 120)				Female (n = 120)			
	Mean difference (left-right)	SD	t-Value	P-Value	Mean difference (left-right)	SD	t-Value	P-Value
T-1 (OPLT1 –OPRT1)	-0.0367	0.38	-1.05	0.298	-0.0225	0.37	-0.69	0.492
T-2 (OPLT2 –ORT2)	0.0183	0.37	0.54	0.590	0.0150	0.34	0.48	0.633
T-3 (OPLT3 – OPRT3)	0.0508	0.36	1.54	0.126	0.0650	0.32	2.22	0.029*****
T-4 (OPLT4 – OPRT4)	0.0208	0.34	0.67	0.507	0.0883	0.33	2.90	0.004*****
T-5 (OPLT5 – OPRT5)	0.0250	0.30	0.91	0.367	0.0833	0.30	3.07	0.003*****

OPLT1 to OPLT5: left lengths from anterior part of toes outlines LT1- LT5 to outline mid-rear outline heel point OP; OPRT1 to OPRT5: right lengths from anterior part of toes outline RT1-RT5 to outline mid-real outline heel point OP; SD: standard deviation; *p-value < 0.05 is significant.

Table 4. Linear regression equations for stature estimation from different foot outline length measurements on left and right sides among adult male Bidayuhs in East Malaysia.

Variables	Regression Equations	SEE	*R*	R^2
OPLT1	51.756 + 4.510 OPLT1	4.307	0.758	0.574
OPLT2	58.874 + 4.250 OPLT2	4.267	0.763	0.582
OPLT3	61.233 + 4.292 OPLT3	4.323	0.756	0.571
OPLT4	61.045 + 4.542OPLT4	4.296	0.759	0.576
OPLT5	57.101 + 5.099 OPLT5	4.310	0.757	0.574
OPRT1	43.272 + 4.840 OPRT1	4.324	0.755	0.571
OPRT2	52.857 +4.494 OPRT2	4.287	0.760	0.578
OPRT3	53.067 + 4.639 OPRT3	4.220	0.769	0.591
OPRT4	49.507 + 5.049 OPRT4	4.143	0.779	0.606
OPRT5	54.221 + 5.241 OPRT5	4.297	0.759	0.576

OPLT1 to OPLT5: left lengths from anterior part of toes outline LT1- LT5 to outline mid-rear heel point OP; OPRT1 to OPRT5: right lengths from anterior part of toes outline RT1-RT5 to outline mid-rear heel point OP; SEE: standard error of estimate; R^2: coefficient of determination ; p-value < 0.001 is significant.

Table 5. Linear regression equations for stature estimation from different foot outline length measurements on left and right sides among adult female Bidayuhs in East Malaysia.

Variables	Regression Equations	SEE	*R*	R^2
OPLT1	49.284 + 4.484 OPLT1	3.735	0.735	0.541
OPLT2	65.148 + 3.846 OPLT2	4.067	0.675	0.455
OPLT3	67.953 + 3.851 OPLT3	4.112	0.666	0.443
OPLT4	60.724 + 4.404 OPLT4	3.996	0.689	0.474
OPLT5	53.439 + 5.142 OPLT5	3.868	0.712	0.508
OPRT1	56.514 + 4.169 OPRT1	3.665	0.747	0.558
OPRT2	66.713 + 3.781 OPRT2	3.821	0.721	0.519
OPRT3	66.743 + 3.917 OPRT3	3.878	0.711	0.505
OPRT4	59.270 + 4.492 OPRT4	3.738	0.735	0.540
OPRT5	53.116 + 5.181 OPRT5	3.644	0.750	0.563

OPLT1 to OPLT5: left lengths from anterior part of toes outline LT1- LT5 to outline mid-rear heel point OP; OPRT1 to OPRT5: right lengths from anterior part of toes outline RT1-RT5 to outline mid-rear heel point OP; SEE: standard error of estimate; R^2: coefficient of determination ; p-value < 0.001 is significant.

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Tables- 4 to 6 show the linear regression equations for stature estimation in adult males, females and pooled sample through various foot out line lengths. The standard error of estimate (SEE) in case of female foot outline length (3.644-4.112) is comparatively lower than that of males (4.143-4.324) and pooled sample (4.029-4.390). The correlation coefficient (R) between stature and various foot outline lengths is statistically significant (<0.001). R values are found to be more in the pooled sample (0.854-0.878) when compared with males ((0.755-0.779) and females (0.666-0.750).

Table 6. Linear regression equations for stature estimation from different foot outline length measurements on left and right sides among pooled sample of adult Bidayuhs of East Malaysia

Variables	Regression Equations	SEE	*R*	R^2
OPLT1	31.750 + 5.273 OPLT1	4.170	0.869	0.755
OPLT2	42.531 + 4.868 OPLT2	4.331	0.858	0.736
OPLT3	44.842 + 4.931 OPLT3	4.390	0.854	0.729
OPLT4	41.951 + 5.336 OPLT4	4.306	0.860	0.739
OPLT5	39.045 + 5.917 OPLT5	4.197	0.867	0.752
OPRT1	31.682 + 5.269 OPRT1	4.151	0.870	0.757
OPRT2	41.698 + 4.906 OPRT2	4.228	0.865	0.748
OPRT3	42.838 + 5.030 OPRT3	4.194	0.867	0.752
OPRT4	39.995 + 5.438 OPRT4	4.029	0.878	0.771
OPRT5	40.142 + 5.879 OPRT5	4.049	0.877	0.769

OPLT1 to OPLT5: left lengths from anterior part of toes outline LT1- LT5 to outline mid-rear heel point OP; OPRT1 to OPRT5: right lengths from anterior part of toes outline RT1-RT5 to outline mid-rear heel point OP; SEE: standard error of estimate; R^2: coefficient of determination ; p-value < 0.001 is significant.

It is common to find the 2D footprints at indoor crime scenes while foot outline (3D footprint) mostly at outdoor crime scenes left by perpetrator. The foot outline can be scientifically analyzed to establish the biological profile and confirm an association of an accused with the crime scene [11]. The present investigation shows that stature and foot outline size are found to be larger in males than females, showing the existence of a statistically significant sex difference. This may be attributed to general male–female differences and natural size in both sexes [8] and this finding is in accordance with the previous studies [4,8-11]. The investigation revealed that the left length measurements are found to be larger in both sexes and hence the existence of left-sided asymmetry. This finding is concordant with previous population studies viz. Malaysian Malays [4], Malaysian Chinese [10], Ibans of East Malaysia [11], Jat Sikh of North India [23] and Egyptian populations [24]. The age range of the subjects is considered appropriate since the average length of adult's foot is attained at 16 years in male and 14 years in females. Commonly, stature at 18 years is accepted as adult, although there are small increments in stature after this [25].

Researchers indicated that regression equations can be derived for stature estimation using foot and hand measurements with a great accuracy and a small SEE, i.e. about 2–6 cm. The standard error of estimate (SEE) in the present investigation shows lower value and hence the regression equations can be used to estimate stature from foot outline measurements. The SEE in case female foot outlines length is comparatively lower than males and pooled sample. The correlation coefficient (R) between stature and various foot outline lengths is statistically significant (<0.001). The R value of pooled sample gave more significant correlation than separately obtained for males and females. Considering real crime scenarios, where the sex of the perpetrator is unknown, it is suggested that a better regression equation that can be used for stature estimation is the one without sex indicators.

Conclusion

The result of this investigation provided regression equations for stature estimation from foot outline (complete or partial) measurements in Bidayuhs of East Malaysia. The regression equation derived for the pooled sample can be employed to estimate stature when the sex of the perpetrator remains unknown, as in real crime scenarios. It is important to note that the people from different races and regions of Malaysia bear different morphological features depending upon their geographical distribution and primary racial characteristics and a single formula cannot represent all parts of the country. It would be incorrect to utilize the equations derived for Bidayuhs to any other populations either in Malaysia or any other populations in the world. Hence it is suggested that similar studies should be conducted on other ethnic groups living in different parts of the world so that effect of genetic and environment can be investigated in forensic terms.

Conflict of interest

The authors have no conflict of interest to declare.

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