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Research Article

Estimation of stature from foot outline measurements in Ibans of East Malaysia by regression analysis

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Abstract

Objective: To derive regression equations for stature estimation from foot outline lengths of Iban ethnics in East Malaysia.

Material and methods: The study was carried out at Sarawak state, northern Borneo Island in East Malaysia, involving 320 adult Iban subjects (160 males and 160 females).Informed consent and Human Ethical Approval were obtained. The heights of the individuals were recorded with portable height measuring device (SECA 206) and foot outlines were collected following the standard procedure. The data obtained were analyzed with PASW 20 computer software and derived regression equations to estimate stature from foot outline lengths of Iban ethnics.

Results: Investigation revealed that all foot outline lengths exhibit statistically positive significant correlation with stature ($p<0.001$). The mean stature and foot outline lengths are found to be significantly higher in males than females. Correlation coefficient (R) values are found to be higher in the pooled sample (0.845–0.870) when compared with males (0.718–0.772) and females (0.695–0.748).

Conclusion: The result of this investigation provided population specific regression equations for stature estimation from foot outline (complete and partial) lengths in Ibans of East Malaysia. The regression equations derived for the pooled sample can be used to estimate stature when the sex of the footprint remains unknown, as in real crime scenarios.

Keywords: Forensic Science, Forensic anthropology, Stature, foot outline, Iban ethnics

1. Introduction

The crime scene investigator needs to make rapid and accurate assessments in the field such as identifying possible suspects. A person's stature is one identifying characteristic that is often used. There is a relationship between each part of the body and the whole body[1]. An aspect of human identification that has received scant attention from forensic anthropologists is the study of human feet and the footprints made by the feet[2]. Person identification using footprint analysis is also an emerging biometric technique[3]. The characteristic features can provide useful clues to establish identity whenever complete or partial 2D and 3D foot impressions are recovered at the crime scenes[4]. 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[5]. Analysis of foot[6-12] and footprints[13-18] help in estimation of an individual's stature because of the existence of a strong correlation between one's stature and foot/footprint 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 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 footprint impression[19]. The review of literature revealed that very limited studies were conducted on stature estimation from foot outline measurements.[5,13,20,21]

Most of the foot/foot print 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 print study[22]. 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[10-18]. 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[4,23-28]. So, the present study attempts the stature estimation from all toes-to-heel lengths in a foot outline and to derive population specific equations suitable only for Iban ethnic, an endogamous group in Borneo Island, East Malaysia.

2. Material and Methods

2.1 Research location

The study was carried out at Sarawak state, East Malaysia. The subjects were from colleges, universities and general public. The Ibans are the native people of Borneo Island, East Malaysia and most Ibans are located in Sarawak, one of the two states in East Malaysia. They were originally farmers, hunters, and gatherers. Figure-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}.

Figure-1: Map of Malaysia showing the sampling point, Sarawak, East Malaysia

Source: https://www.google.com/search?q=malaysia+map&source=lnms&tbm=isch

2.2 Recording of stature

The subjects' age ranged from 18 to 82 years. Subjects with any apparent foot-related disease, pregnancy, orthopedic deformity, physical impairment, injury or disorders 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. 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[11,13]. All the measurements were taken by the co-author to avoid inter-observer error.

2.3 Recording of foot outline and diagonal length measurements

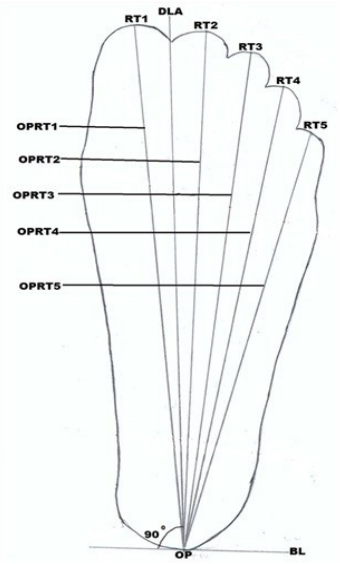
Just prior to research participation, the subjects were advised to wash their feet with soap and water. Then the subject was requested to place the left foot on an A4 size white paper and the foot outline was drawn with a sharp-pointed pencil. The pencil was held perpendicular to the paper as it traced 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[13,20].

Following Krishan[20] and Nataraja Moorthy[13], 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 length measurements 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. Figure-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.

2.4 Statistical analysis

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. Pearson's correlation coefficients between various feet outline lengths and stature were obtained. 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 regression analysis[31].

Figure-2: Landmarks and diagonal length measurements on right foot outline



2. Results

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 143.0 to 179.2 cm (mean 164.8 cm) and in females, it ranges from 135.0 to 171.4 cm (mean 153.5 cm). In pooled sample, the stature ranges from 139.0 to 179.2 cm. The results showed that mean stature is found to be significantly higher in males than females.

Table -1: Descriptive statistics of stature (cm) in males, females and pooled sample in adult Ibans of East Malaysia

Variable	Male (N = 160)					Female (N = 160)					Pooled sample (N =320)				
	Min	Max	RD	Mean	SD	Min	Max	RD	Mean	SD	Min	Max	RD	Mean	SD
Stature	143.0	179.2	36.20	164.8	5.719	135.0	171.4	36.40	153.5	6.207	135.0	179.2	44.20	159.2	8.245

SD- Standard deviation; RD- Range difference; Min- Minimum; Max- Maximum; N- Sample size

Table-2 depicts descriptive statistics of foot outline lengths in males, females and pooled sample. The mean foot outline length measurements in males (20.88-24.88 cm) are found to be significantly higher than females (19.06-22.77) 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 – 2: Descriptive statistics of foot outline lengths (cm) in males, females and pooled sample in adult Ibans of 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	160	6.6	21.3	27.9	24.84	1.1	160	5.5	20.0	25.5	22.72	1.1	320	7.9	20.0	27.9	23.78	1.5
OPLT2	160	6.9	20.6	27.5	24.63	1.1	160	5.6	19.9	25.5	22.43	1.1	320	7.6	19.9	27.5	23.53	1.6
OPLT3	160	6.8	19.9	26.7	23.74	1.1	160	5.8	19.1	24.9	21.66	1.1	320	7.6	19.1	26.7	22.70	1.5
OPLT4	160	6.8	18.9	25.7	22.54	1.1	160	5.1	18.2	23.3	20.61	1.1	320	7.5	18.2	25.7	21.58	1.5
OPLT5	160	5.7	17.8	23.5	20.98	1.0	160	4.9	17.0	21.9	19.12	1.0	320	6.5	17.0	23.5	20.05	1.4
OPRT1	160	7.5	20.8	28.3	24.88	1.1	160	5.6	20.3	25.9	22.83	1.1	320	8.0	20.3	28.3	23.86	1.5
OPRT2	160	6.2	21.0	27.2	24.64	1.1	160	6.0	20.0	26.0	22.50	1.2	320	7.2	20.0	27.2	23.57	1.6
OPRT3	160	6.6	19.9	26.5	23.71	1.1	160	5.1	19.5	24.6	21.65	1.1	320	7.0	19.5	26.5	22.68	1.5
OPRT4	160	6.3	18.9	25.2	22.48	1.1	160	4.9	18.3	23.2	20.58	1.1	320	6.9	18.3	25.2	21.53	1.4
OPRT5	160	5.6	17.8	23.4	20.88	1.0	160	5.0	16.6	21.8	19.06	1.0	320	6.8	16.6	23.4	19.97	1.4

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: Bilateral differences (left–right) in foot outline lengths (cm) in males and females in adult Ibans of East Malaysia

Variables	Male (N = 160)				Female (N = 160)			
	Mean difference (left-right)	SD	t-Value	p-Value	Mean difference (left-right)	SD	t-Value	p-Value
T1 (OPLT1 –OPRT1)	-0.0456	0.40	-1.44	0.152	-0.1069	0.40	-3.57	0.000*
T2 (OPLT2 –OPRT2)	-0.0113	0.39	-0.37	0.713	-0.0688	0.30	-2.50	0.013*
T3 (OPLT3 – OPRT3)	0.0262	0.36	0.92	0.360	0.0156	0.40	0.56	0.573
T4 (OPLT4 – OPRT4)	0.0575	0.37	1.94	0.054	0.0394	0.40	1.41	0.161
T5 (OPLT5 – OPRT5)	0.1006	0.37	3.46	0.001*	0.0663	0.40	2.31	0.022*

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-3 depicts the bilateral differences (left–right) in foot outline lengths among males and females. In male foot outline lengths, the bilateral difference in T5 is significantly larger than other toes. In female length measurements, the bilateral difference in T1is significantly larger than other toes. The mean bilateral differences in foot outlines are smaller and not significant.

Table- 4: Linear regression equations for stature estimation from different foot outline lengths (cm) on left and right sides in males in adult Ibans of East Malaysia

Variables	Regression Equations	SEE	R	R^2	Adj,R^2	Coefficient of t-test	ANOVA
OPLT1	69.873 + 3.824OLT1	3.832	0.744	0.554	0.551	14.004	196.124(1, 158) ; P<0.001
OPLT2	74.471 + 3.670OLT2	3.911	0.732	0.535	0.533	13.495	182.112(1, 158) ; P<0.001
OPLT3	76.486 + 3.722OLT3	3.926	0.729	0.532	0.529	13.397	179.481(1, 158) ; P<0.001
OPLT4	79.914 + 3.768OLT4	3.995	0.718	0.515	0.512	12.955	167.826(1, 158) ; P<0.001
OPLT5	75.157 + 4.275OLT5	3.766	0.754	0.569	0.566	14.448	208.755(1, 158) ; P<0.001
OPRT1	65.564 + 3.990ORT1	3.650	0.772	0.595	0.593	15.244	232.370(1, 158) ; P<0.001
OPRT2	70.368 + 3.835ORT2	3.720	0.761	0.580	0.577	14.759	217.822(1, 158) ; P<0.001
OPRT3	78.028 + 3.661ORT3	3.919	0.730	0.533	0.531	13.442	180.686(1, 158) ; P<0.001
OPRT4	78.826 + 3.826ORT4	3.926	0.729	0.532	0.529	13.395	179.418(1, 158) ; P<0.001
OPRT5	72.601 + 4.419ORT5	3.644	0.772	0.597	0.594	15.286	233.671(1, 158) ; P<0.001

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-Correlation coefficient; R^2-Coefficient of determination; Adj, R^2 - Adjusted R^2. p-value < 0.001 is significant.

Tables- 4 to 6 present the linear regression equations for stature estimation in adult males, females and pooled sample through various foot out line lengths with ANOVA. The standard error of estimate (SEE) in case of male foot outline length (3.644-3.995) is comparatively lower than that of females (4.312-4.477) and pooled sample (4.072-4.419). 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 (0.845-0.870) when compared with males ((0.718-0.772) and females (0.695-0.748).

Table-5:Linear regression equations for stature estimation from different foot outline lengths (cm) on left and right sides in females in adult Ibans of East Malaysia

Variables	Regression Equations	SEE	R	R^2	Adj,R^2	Coefficient of t-test	ANOVA
OPLT1	58.213 + 4.193OLT1	4.282	0.726	0.527	0.524	13.267	176.004(1, 158) ; P<0.001
OPLT2	66.485 + 3.878OLT2	4.344	0.716	0.513	0.510	12.908	166.617(1, 158) ; P<0.001
OPLT3	68.940 + 3.902OLT3	4.318	0.720	0.519	0.516	13.059	170.550(1, 158) ; P<0.001
OPLT4	69.855 + 4.056OLT4	4.363	0.713	0.509	0.506	12.798	163.789(1, 158) ; P<0.001
OPLT5	70.388 + 4.344OLT5	4.477	0.695	0.483	0.480	12.147	147.542(1, 158) ; P<0.001
OPRT1	58.079 + 4.179ORT1	4.293	0.724	0.525	0.522	13.205	174.372(1, 158) ; P<0.001
OPRT2	63.936 + 3.980ORT2	4.132	0.748	0.560	0.557	14.166	200.689(1, 158) ; P<0.001
OPRT3	64.721 + 4.100ORT3	4.145	0.746	0.557	0.554	14.090	198.541(1, 158) ; P<0.001
OPRT4	64.193 + 4.339ORT4	4.153	0.745	0.555	0.552	14.038	197.068(1, 158) ; P<0.001
OPRT5	66.461 + 4.565ORT5	4.210	0.737	0.543	0.540	13.693	187.504(1, 158) ; P<0.001

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-Correlation coefficient; R^2-Coefficient of determination ; Adj, R^2 -Adjusted R^2. p-value < 0.001 is significant

Table-6: Linear regression equations for stature estimation from different foot outline lengths (cm) on left and right sides in pooled sample in adult Ibans of East Malaysia

Variables	Regression Equations	SEE	R	R^2	Adj, R^2	Coefficient of t-test	ANOVA
OPLT1	48.193 + 4.666OLT1	4.188	0.862	0.743	0.742	30.306	918.455(1, 318) ; P<0.001
OPLT2	54.501 + 4.448OLT2	4.268	0.856	0.733	0.732	29.537	872.427(1, 318) ; P<0.001
OPLT3	55.231 + 4.578OLT3	4.305	0.853	0.728	0.727	29.196	852.391(1, 318) ; P<0.001
OPLT4	55.849 + 4.788OLT4	4.419	0.845	0.714	0.713	28.154	792.642(1, 318) ; P<0.001
OPLT5	55.814 + 5.154OLT5	4.311	0.853	0.727	0.727	29.133	848.737(1, 318) ; P<0.001
OPRT1	45.460 + 4.766ORT1	4.119	0.867	0.751	0.750	30.986	960.142(1, 318) ; P<0.001
OPRT2	51.650 + 4.562ORT2	4.072	0.870	0.757	0.756	31.466	990.091(1, 318) ; P<0.001
OPRT3	54.382 + 4.620ORT3	4.214	0.860	0.740	0.739	30.057	903.418(1, 318) ; P<0.001
OPRT4	53.479 + 4.909ORT4	4.258	0.857	0.734	0.733	29.634	878.152(1, 318) ; P<0.001
OPRT5	53.530 + 5.290ORT5	4.098	0.868	0.754	0.753	31.204	973.660(1, 318) ; P<0.001

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-Correlation coefficient; R^2 -Coefficient of determination; Adj, R^2 - Adjusted R^2. p-value < 0.001 is significant.

3. Discussion

It is common to find the 2D footprints at indoor crime scenes while foot outline drawn from 3D footprint at outdoor crime scenes mostly 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. 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[17]. This finding is concordant with previous research findings[5,14,15,17,27]. The size of left foot outline is found to be slightly larger than the right side in both sexes and hence the existence of left-sided asymmetry but not significant. Similar findings were observed in Malaysian Malays[5,14], Malaysian Chinese[13], Indian[17], north Indian male Gujjars[20], male Egyptian[21], north Indian Jat Sikh[32]. The correlation coefficient (R) between foot outline lengths regardless of sex i.e. pooled sample gave more significant result 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. 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[28]. The foot outline lengths show lower SEE in males than females. This finding is accordance with the finding of Indian population[17] but opposite to Malaysian Chinese[13] and Malaysian Malay population [14].

4. Conclusion

The present study provided regression equations for stature estimation from foot outlines (complete or partial) in Ibans 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 regression equations derived in this research is suitable for Iban population in East Malaysia and it would be incorrect to utilize these equations to any other populations either in Malaysia or any other populations in the world.

Authors' contribution

The corresponding author T. Nataraja Moorthy conceived and designed the study and prepared the manuscript for the publication. Hairunnisa, student doing master in forensic science has collected the samples at Sarawak state under the supervision of T. Nataraja Moorthy. No specific funding was allotted for the aforementioned research.

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