STATURE ESTIMATION FROM THE ANTHROPOMETRIC MEASUREMENTS OF FOOT OUTLINE IN ADULT INDIGENOUS MELANAU ETHNICS OF EAST MALAYSIA BY REGRESSION ANALYSIS

Hairunnisa Bt Mohd Anas Khan[1] and T. Nataraja Moorthy[2]

[1] Forensic Division, Chemistry Department of Malaysia, Bintulu, Sarawak State , East Malaysia.
[2] School of Health Sciences, Universiti Sains Malaysia, Health Campus Kubang Kerian, Kelantan State, Malaysia.

ABSTRACT

A person's stature is an identifying characteristic in forensic investigation. Footprint is the one of the valuable physical evidence encountered in the crime scenes. Analysis of footprints helps in estimation of an individual's stature because of the existence of strong correlation between foot impression and height. Foot impressions are still found at crime scenes, since offenders often tend to remove their footwear either to avoid noise or to gain better grip in climbing walls, etc., while entering or exiting. In Asian countries like India, Malaysia, Sri Lanka, Thailand, Indonesia, there are people who still have the habit of walking barefoot. 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 while 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. The review of literature revealed that very limited studies were conducted on stature estimation from foot outline measurements. Most of the foot/foot impression 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. In stature estimation using foot impression, formulae derived for a particular population is erroneous to apply for other populations. Hence the present study aims to derive population specific equations to estimate stature from foot outlines of indigenous Melanau ethnics of East Malaysia.

INTRODUCTION

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[1]. There is also a relationship between each part of the body and the whole body. Nothing exemplifies this truth more than the relationship that various parts of the body have to the stature of an individual[2]. In this manner, an individual's footprint may represent his or her identity. The characteristic features in foot impression 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]. In Asian countries like India, Malaysia, Sri Lanka, Thailand, Indonesia, there are people who still have the habit of walking barefoot. Foot impressions are still found at crime scenes, since offenders often tend to remove their footwear either to avoid noise or to gain better grip in climbing walls, etc., while entering or exiting[4]. Analysis of foot [5-11] and footprints [12-18] 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[12]. The review of literature revealed that very limited studies were conducted on stature estimation from foot outline measurements[19-22]. 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[20]. 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 [4-20]. 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[17-22]. Hence, the present study attempts the stature estimation from all toes-to-heel lengths in a foot outline and to derive population specific regression equations suitable for Melanau ethnics, an endogamous group in Borneo Island, East Malaysia.

MATERIALS AND METHODS
Research location

The study was carried out at Sarawak state, East Malaysia. Sarawak state is home to 28 ethnic groups, each with their own distinct language, culture and lifestyle. The subjects were from colleges, universities and general public. The Melanaus are a people who live on the island of Borneo, primarily in Sarawak, east Malaysia. They are among the earliest settlers of Sarawak, and speak a Northwest Malayo-Polynesian language. They are mostly farmers, fishermen, and reputed as some of the finest boat-builders and craftsmen.

Figure-1 depicts the sampling area in East Malaysia located in Borneo Island. 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}.

Source: www.malaysiamap.org/map-search-detail1c0f.html

Figure 1: Map of Malaysia showing the sampling area, Sarawak state of east Malaysia in Borneo Island

Sample collection

Recording of stature

The study involved 210 adult Melanaus (105 males, 105 females) of age ranged from 18 to 59 years. Subjects with any apparent foot-related disease, pregnancy, orthopedic deformity, physical impairment, injury, disorders and age below 18 years 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[20-22]. 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[23-24]. The stature of each subject was measured following Krishan[20] and Nataraja Moorthy[21] as follows. Stature was measured without head and footwear using a portable body meter measuring device. The body meter was suspended upright against the wall and measurements were taken to the nearest 0.5 cm. The subject was advised to stand under the body meter with his heels together and weight evenly distributed between both feet. Stature was measured in cm as the vertical distance between the vertex and the sole of the foot when the individual was standing barefoot with head held in the Frankfurt horizontal plane with eyes looking forward. The measurements were repeated until concordant values were achieved.

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. Following Krishan[20] and Nataraja Moorthy[21], 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.
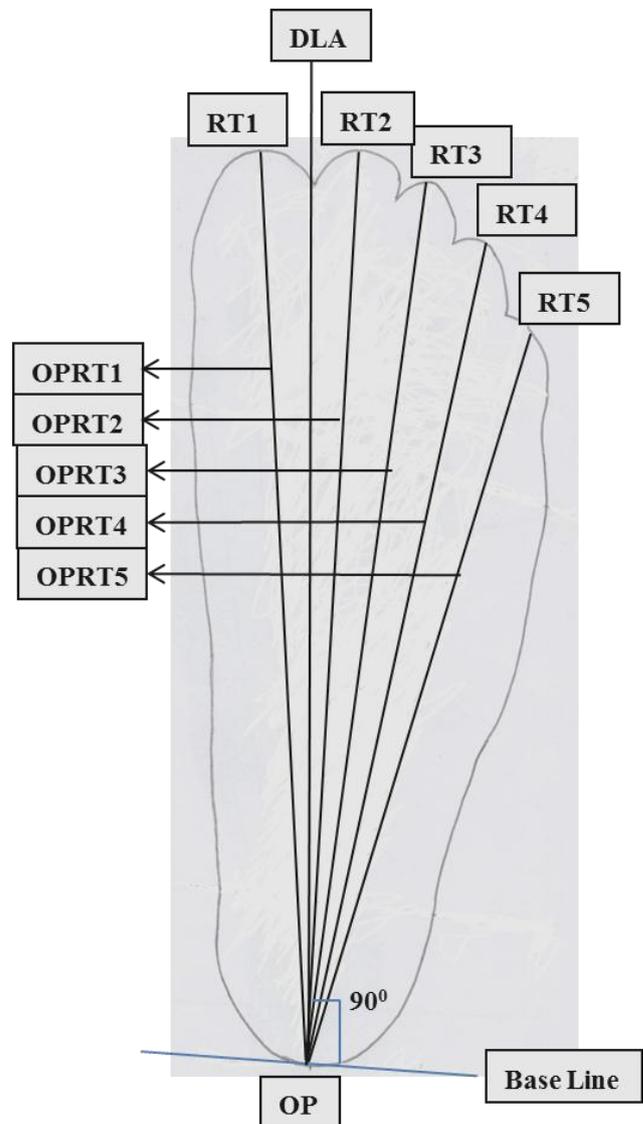
Figure 2: Landmarks and diagonal length measurements on right foot outline

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 (R) 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[25].

RESULTS

All footprint and foot outline measurements 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 153.5 to 187.5 cm (mean 165.7 cm) and in females, it ranges from 137.0 to 170.2 cm (mean 153.3 cm). In pooled sample, the stature ranges from 137.0 to 187.5 cm. The results showed that mean stature is found to be significantly higher in males than females.

Table 1: Descriptive statistics of stature in males, females and pooled sample of adult Melanau ethnics in East Malaysia.

Variable	Male (N = 105)					Female (N = 105)					Pooled sample (N =210)				
	Min	Max	RD	Mean	SD	Min	Max	RD	Mean	SD	Min	Max	RD	Mean	SD
Stature	153.5	187.5	34.0	165.7	5.7	137.0	170.2	33.2	153.3	5.9	137.0	187.5	50.5	159.5	8.5

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

Table-2 depicts descriptive statistics of foot outline lengths in males, females and pooled sample. The mean foot outline length measurements in males (21.3-25.3 cm) are found to be significantly higher than females (19.2-21.1) 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 length (in centimetres) measurements in males, females and pooled sample of adult Melanau ethnics in East Malaysia.

Variables	Male (N =105)						Female (N=105)						Pooled sample (N=210)					
	N	RD	Min	Max	Mean	SD	N	RD	Min	Max	Mean	SD	N	RD	Min	Max	Mean	SD
OPLT1	105	7.0	22.9	29.9	25.3	1.1	105	5.5	20.5	26.0	23.0	1.0	210	9.4	20.5	29.9	24.1	1.6
OPLT2	105	7.7	22.8	30.5	25.2	1.1	105	6.0	19.7	25.7	22.7	1.1	210	10.8	19.7	30.5	24.0	1.7
OPLT3	105	7.6	22.1	29.7	24.4	1.1	105	5.9	18.9	24.8	23.0	1.1	210	10.8	18.9	29.7	23.2	1.6
OPLT4	105	7.3	20.8	28.1	23.1	1.0	105	5.2	18.3	23.5	20.8	1.0	210	9.8	18.3	28.1	22.0	1.5
OPLT5	105	6.6	19.2	25.8	21.4	1.0	105	5.1	16.7	21.8	19.3	1.0	210	9.1	16.7	25.8	20.3	1.4
OPRT1	105	7.0	23.0	30.0	25.3	1.1	105	5.2	20.5	25.7	23.1	1.0	210	9.5	20.5	30.0	24.2	1.5
OPRT2	105	7.1	22.9	30.0	25.1	1.1	105	5.7	19.9	25.6	22.7	1.1	210	10.1	19.9	30.0	23.9	1.6
OPRT3	105	7.5	21.9	29.4	24.3	1.1	105	5.4	19.3	24.7	21.9	1.1	210	10.1	19.3	29.4	23.1	1.6
OPRT4	105	7.5	20.6	28.1	23.0	1.0	105	4.9	18.4	23.3	20.8	1.0	210	9.7	18.4	28.1	21.9	1.5
OPRT5	105	6.3	19.2	25.5	21.3	1.0	105	4.5	17.0	21.5	19.2	0.9	210	8.5	17.0	25.5	20.3	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 : number of samples.

Table 3 presents means, standard deviations, T-value and P-value of one-sample t-test of bilateral differences (left–right) in foot outline length measurements among males and females In foot outlines, bilateral asymmetry is found at T-3 in males and no significant asymmetry is observed in other toes.

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

Variables	Male (N = 105)				Female (N = 105)			
	Mean difference (left-right)	SD	t-Value	P-Value	Mean difference (left-right)	SD	t-Value	P-Value
T-1 (OPLT1 –OPRT1)	-0.0352	0.36	-1.00	0.321	-0.0876	0.33	-2.68	0.009*
T-2 (OPLT2 –ORT2)	0.0705	0.36	2.03	0.045	-0.0114	0.34	-0.34	0.731
T-3 (OPLT3 – OPRT3)	0.1076	0.31	3.57	0.001*	0.0371	0.34	1.11	0.268
T-4 (OPLT4 – OPRT4)	0.0848	0.31	2.80	0.006*	0.0171	0.31	0.56	0.577
T-5 (OPLT5 – OPRT5)	0.0857	0.30	2.94	0.004*	0.0714	0.32	2.28	0.024*

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 (in centimeters) from different foot outline length measurements on left and right sides among adult male Melanau ethnics in East Malaysia (N= 105).

Variables	Regression Equations	SEE	R	R^2	Adj,R^2	Coefficient of t-test	ANOVA
OPLT1	65.656 + 3.956 OPLT1	3.576	0.780	0.608	0.604	12.635	159.645(1, 103) ; *P*<0.001
OPLT2	69.155 + 3.831 OPLT2	3.730	0.757	0.573	0.569	11.765	138.420(1, 103) ; *P*<0.001
OPLT3	70.887 + 3.888 OPLT3	3.806	0.746	0.556	0.551	11.352	128.862(1, 103) ; *P*<0.001
OPLT4	69.664 + 4.161 OPLT4	3.823	0.743	0.552	0.547	11.258	126.735(1, 103) ; *P*<0.001
OPLT5	74.457 + 4.264 OPLT5	3.914	0.728	0.530	0.526	10.782	116.261(1, 103) ; *P*<0.001
OPRT1	64.754 + 3.986 OPRT1	3.812	0.745	0.554	0.550	11.320	128.135(1, 103) ; *P*<0.001
OPRT2	66.680 + 3.941 OPRT2	3.886	0.733	0.537	0.532	10.926	119.374(1, 103) ; *P*<0.001
OPRT3	70.861 + 3.906 OPRT3	3.910	0.729	0.531	0.527	10.803	116.705(1, 103) ; *P*<0.001
OPRT4	72.344 + 4.060 OPRT4	3.874	0.735	0.540	0.535	10.990	120.785(1, 103) ; *P*<0.001
OPRT5	75.885 + 4.214 OPRT5	3.924	0.727	0.528	0.523	10.730	115.130(1, 103) ; *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^2: coefficient of determination ; Adj, R^2 : Adjusted R^2. p-value < 0.001 is significant.

Table 5:Linear regression equations for stature estimation(in centimeters) from different foot outline length measurements on left and right sides among adult female Melanau ethnics in East Malaysia (N=105).

Variables	Regression Equations	SEE	R	R^2	Adj,R^2	Coefficient of t-test	ANOVA
OPLT1	42.873 + 4.802OPLT1	3.195	0.844	0.712	0.709	15.955	254.575(1, 103) ; *P*<0.001
OPLT2	54.488 + 4.346OPLT2	3.389	0.822	0.676	0.673	14.651	214.644(1, 103) ; *P*<0.001
OPLT3	57.188 + 4.375OPLT3	3.540	0.804	0.646	0.643	13.721	188.277(1, 103) ; *P*<0.001
OPLT4	55.557 + 4.692OPLT4	3.420	0.818	0.670	0.667	14.456	208.974(1, 103) ; *P*<0.001
OPLT5	59.749 + 4.854OPLT5	3.697	0.784	0.614	0.611	12.808	164.046(1, 103) ; *P*<0.001
OPRT1	41.916 +4.826OPRT1	3.304	0.832	0.692	0.689	15.206	231.224(1, 103) ; *P*<0.001
OPRT2	53.807 + 4.374OPRT2	3.551	0.803	0.644	0.641	13.654	186.422(1, 103) ; *P*<0.001
OPRT3	53.809 + 4.536OPRT3	3.530	0.805	0.648	0.645	13.781	189.928(1, 103) ; *P*<0.001
OPRT4	54.815 +4.732OPRT4	3.478	0.812	0.659	0.655	14.095	198.681(1, 103) ; *P*<0.001
OPRT5	58.766 + 4.924OPRT5	3.824	0.766	0.587	0.583	12.106	146.565(1, 103) ; *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^2: coefficient of determination ; Adj, R^2 : Adjusted R^2.
p-value < 0.001 is significant

Table 6: Linear regression equations for stature estimation (in centimeters)from different foot outline length measurements on left and right sides among pooled samples of adult Melanau ethnics in East Malaysia (N=210).

Variables	Regression Equations	SEE	*R*	R^2	Adj,R^2	Coefficient of t-test	ANOVA
OPLT1	40.922 + 4.912OPLT1	3.506	0.911	0.830	0.829	31.880	1016.317(1, 208) ; *P*<0.001
OPLT2	49.083 + 4.607OPLT2	3.644	0.904	0.816*	0.816*	30.420	925.403(1, 208) ; *P*<0.001
OPLT3	50.867 + 4.687OPLT3	3.756	0.897	0.805	0.804	29.304	858.698(1, 208) ; *P*<0.001
OPLT4	49.156 + 5.026OPLT4	3.712	0.900	0.810	0.809	29.735	884.153(1, 208) ; *P*<0.001
OPLT5	52.503 + 5.262OPLT2	3.909	0.888	0.789	0.788	27.879	777.257(1, 208) ; *P*<0.001
OPRT1	38.327 + 5.007OPRT1	3.683	0.901	0.813	0.812	30.032	901.903(1, 208) ; *P*<0.001
OPRT2	45.985 + 4.742OPRT2	3.804	0.894	0.800	0.799	28.845	832.054(1, 208) ; *P*<0.001
OPRT3	48.309 + 4.812OPRT3	3.816	0.894	0.799	0.798	28.736	825.776(1, 208) ; *P*<0.001
OPRT4	48.159 + 5.083OPRT4	3.805	0.894	0.800	0.799	28.840	831.741(1, 208) ; *P*<0.001
OPRT5	52.464 + 5.285OPRT5	3.983	0.884	0.781	0.780	27.213	740.568(1, 208) ; *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^2: coefficient of determination ; Adj, R^2 : Adjusted R^2.
p-value < 0.001 is significant

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 with ANOVA. The standard error of estimate (SEE) in case of female foot outline length (3.195-3.824) is comparatively lower than that of males (3.576-3.914) and pooled sample (3.506-3.983). The correlation coeffic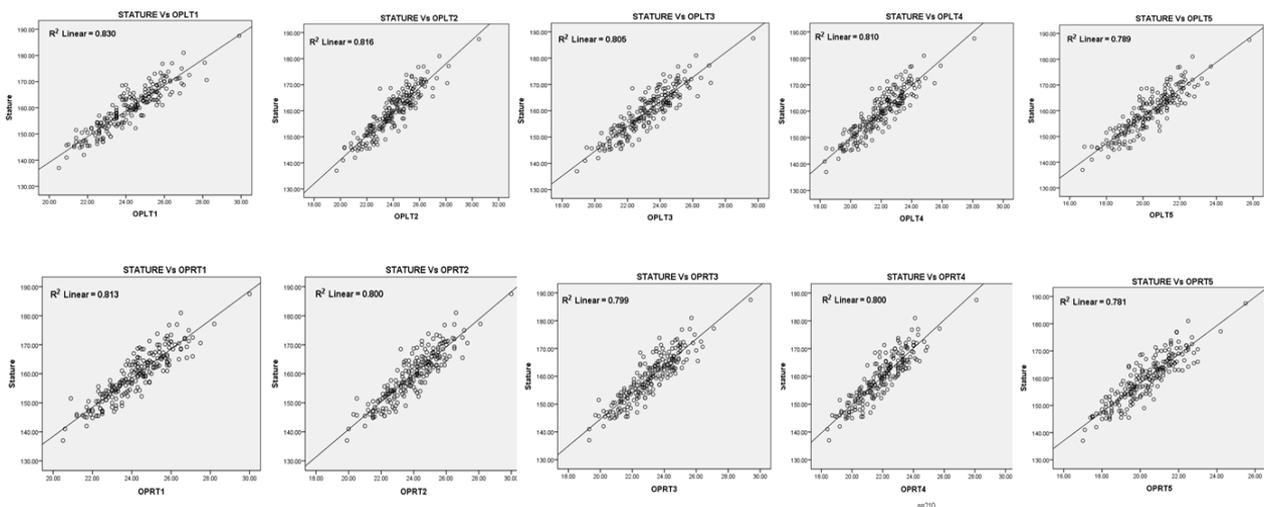ient (R) between stature and various foot outline lengths is statistically significant (<0.001). R values are found to be more in the pooled sample (0.884-0.911) when compared with males ((0.727-0.780) and females (0.766-0.844). The coefficient of determination (R^2), the predictive accuracy, is found to be higher in the pooled sample (0.781-0.830) when compared with males (0.528-0.608) and females (0.587-0.712) and all measurements are

found to be positive and statistically significant for stature estimation.

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 perpetrators [22]. 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[26]. This finding is concordant with previous research findings [4,10,17,21,22]. The size of male left foot outline is found to be slightly larger in T-3 than the right side but in female the bilateral asymmetry i.e. left-sided asymmetry is not significant. The significant bilateral asymmetry were observed by other researchers in Egyptian[14], Malaysian Malays[17], north Indian male Gujjars [20], Malaysian Chinese [21], Ibans of East Malaysia[22] and Indian population [26]. Philip did not find significant bilateral asymmetry while working on the footprints of south Indian population[2]. Similarly Ilayperuma[5] and Robbins[27] also did

not find significant bilateral asymmetry in various measurements of the feet of the Sri Lanka and U.S. population. 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 age range of the subjects in this investigation is considered appropriate since the average length of adult's foot is attained at 16 years in male and 14 years in females[29,30]. Commonly, stature at 18 years is accepted as adult, although there are small increments in stature after this[31,32]. It is interesting to note that the correlation coefficient (R) between stature and foot outline measurements regardless of sex, i.e. when male and female subjects are pooled together, gave a more significant result than the correlations separately obtained for the males and females. The scatter graphs obtained by plotting various foot outline lengths and height in the pooled sample visually (Figure 3) confirm the strong positive correlation between height and foot outline length measurements. This finding is consistent with previous studies of Malays[4] Malaysian Chinese[21] and Indians[26]. 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.

Figure 3: Illustrative example of scatter graphs showing the relationship between various foot outline lengths and stature in pooled sample of Malanau ethnics in east Malaysia (N=210).

CONCLUSION

The result of this investigation provided regression equations for stature estimation from foot outline (complete or partial) measurements in Melanaus of East Malaysia in northern Borneo Island. 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 to estimate stature from foot outline measurements derived for Melanaus to any other populations either in Malaysia or any other populations in the world. Hence it is suggested that similar studies should be continued 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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