ESTIMATION OF STATURE FROM FOOT OUTLINE IN ADULT MALAYSIAN MALAYALEE ETHNICS FOR FORENSIC INVESTIGATION

T. Nataraja Moorthy[1] & Rasvini Asogan[2]

[1] Associate Professor of Forensic Sciences, Management and Science University, Shah Alam, Selangor, Malaysia.
[2] Forensic Science Program, Management and Science University, Shah Alam, Selangr

ABSTRACT

Identification is a key component in any forensic investigation. Estimation of stature is an identifying characteristics to solve the crime. Foot impression is known to be a valuable scientific evidence encountered in the scenes of crime. Examination of footprint helps in estimation of stature of an individual since there is a strong relationship exists between foot impression and stature. There are people who still have the habit of walking barefoot in Asian countries like Malaysia, Sri Lanka, India, Thailand and Indonesia. The hard surfaces produce two-dimensional footprints 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 foot impression. It is shown that very limited studies were conducted on stature estimation from foot outline measurements. It is important to note that racial and cultural aspects of foot morphology must be considered while conducting the foot impression study. Researchers have cautioned that regression equations derived to estimate stature from foot impression for a particular population is erroneous to apply for other populations. Thus the present investigation is aimed to derive linear regression equations to estimate stature from foot outlines of Malaysian Malayalee ethnics.

INTRODUCTION

The anthropometry-based Bertillon system was invented by French anthropologist Alphonse Bertillon for the purpose of human identification[1]. Stature can be estimated using various body parts since there is a strong relationship exists between each part of the body and whole body[2-6]. Nothing exemplifies this truth more than the relationship that various parts of the body have to the stature of an individual[7]. In this way, an individual's foot impression may represent his or her identity. There are people who still have the habit of walking barefoot in Asian countries like Malaysia, Sri Lanka, India, Thailand and Indonesia[8]. 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[9]. The foot impressions with characteristic features can provide valuable information even from partial foot impressions (2D & 3D) during crime scene investigation[10]. Stature can be estimated from anthropometric measurements of foot[11-16], footprint[17-21] and foot outline[22-25]

because correlation exists between stature and foot/footprint/foot outline. The hard surfaces produce two-dimensional (2D) footprints 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 (3D) footprint impression[26]. Earlier foot/footprint/foot outline studies have been conducted on mixed populations. Researchers have cautioned that regression equations derived to estimate stature from foot impression for a particular population is erroneous to apply for other populations[9-10]. Hence, the present study is aimed to derive population specific regression equations to estimate stature from foot outline measurements of Malaysian Malayalee ethnics.

MATERIALS AND METHODS

Research location

The research location is Peninsular Malaysia, wherein most of the Malayalee are living. The Malaysian Malayalees have ancestral origins in the modern day state of Kerala, on south west coast of India with their mother tongue Malayalam. Although there are more than thirty-five million Malayalam language speakers in India, there are about 135,000 Malayalees are living in Malaysia. They have an association in Malaysia named as "All Malaysia Malaylee Association" or abbreviated as AMMA.

Sample collection

Based on the population, the study involved 110 adult Malaysian Malayalees (50 males, 60 females) of age ranged from 18 to 56 years. Subjects with any apparent foot-related disease, orthopaedic deformity, injury and age below 18 years were excluded from the study. Informed consent and ethical approval were obtained before sample collection. Stature measurements and foot outlines were recorded following the procedure adopted by Nataraja Moorthy[23-25.] Stature of each subject

was measured using a portable body meter measuring device (SECA model 206).

The height of the subjects was measured at a fixed time in the evening because of diurnal variation in stature. After cleaning the feet of the subjects, the left foot was requested to place on an A4 size white paper and the foot outline was drawn with a sharp-pointed pencil and the anatomical landmarks of the foot, namely mid-rear heel point (pternion,P) in the base line and most anterior points of all toes (LT1-LT5) were marked (Figure 1). The procedure was repeated for the right foot and for other subjects. All foot outline samples and information relating to participants were coded with sample ID for anonymity.
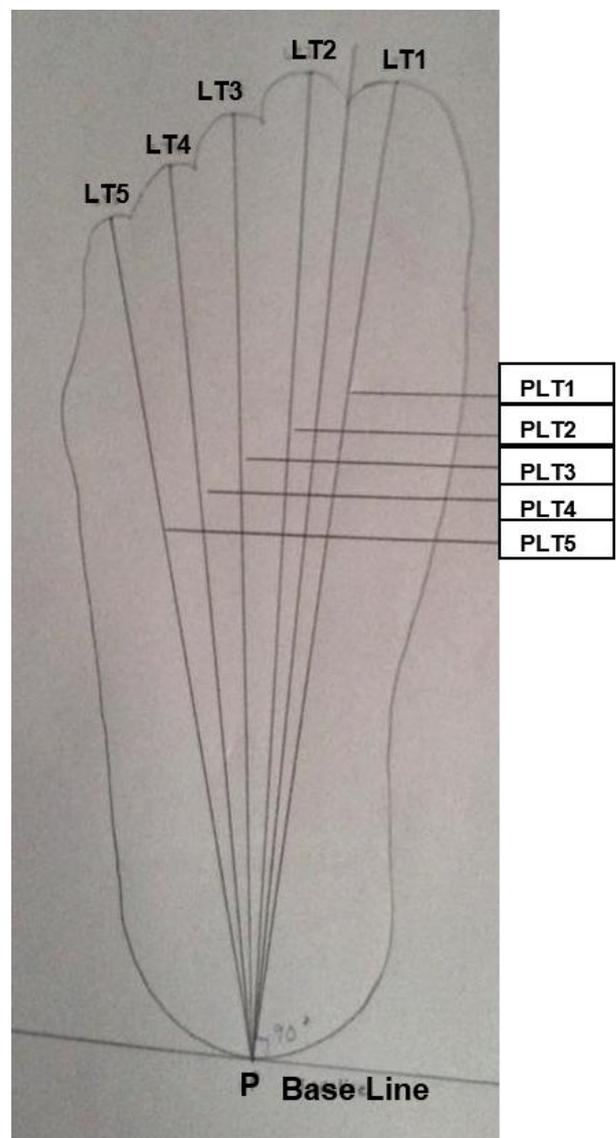

Figure 1: Landmarks and diagonal length measurements on left foot outline

Statistical analysis

The data were analyzed using SPSS software version 21. 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[27]. The standard error of estimation (SEE) was calculated to analyze the deviation of the estimated stature from the actual stature for foot outline measurements.

RESULTS

All 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 154.0 to 182.0 cm (mean 167.9cm) and in females, it ranges from 139.0 to 167.0 cm (mean 153.1 cm). In pooled sample, the stature ranges from 139.0 to 182.0 cm (mean 159.7). 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 Malaysian Malayalees (in centimeters).

	Min	Max	Mean	RD	SD
Male (N=50)	154.00	182.0	167.9	28.0	7.2
Female (N=60)	139.0	167.0	153.1	28.0	6.9
Pooled sample (N=110)	139.0	182.0	159.7	43.0	10.2

SD: standard deviation; RD: range difference; Min: minimum; Max: maximum;
Table 2 to 4 present the descriptive statistics of various foot outline lengths i.e. diagonal length between the rear heel end (P) and anterior points of each toe in both left (LT1-LT5) and right (RT1-RT5) of males, females and pooled sample. All the foot outline length measurements in males are found to be larger than females both in left and right feet.

Table 2: Descriptive statistics of foot outline length measurements in males in adult Malaysian Malayalees (in centimeters). N=50

Variables	Min	Max	Mean	RD	SD
PLT1	22.1	28.5	25.80	6.4	1.4
PLT2	21.6	27.8	25.27	6.2	1.4
PLT3	21.0	26.8	24.47	5.8	1.3
PLT4	20.0	25.1	23.18	5.1	1.2
PLT5	18.6	23.8	21.51	5.2	1.2
PRT1	22.1	28.1	25.54	6.0	1.4
PRT2	21.7	27.6	25.16	5.9	1.2
PRT3	21.2	26.8	24.46	5.6	1.2
PRT4	20.5	25.0	23.18	4.5	1.1
PRT5	19.1	23.8	21.59	4.7	1.0

Table 3: Descriptive statistics of foot outline length measurements in females in adult Malaysian Malayalees (in centimeters). N=60

Variables	Min	Max	Mean	RD	SD
PLT1	20.5	26.0	23.55	5.5	1.3
PLT2	20.4	25.4	23.02	5.0	1.3
PLT3	19.7	24.7	22.17	5.0	1.3
PLT4	18.3	23.7	20.99	5.4	1.2
PLT5	17.4	22.0	19.54	4.6	1.1
PRT1	21.1	25.5	23.47	4.4	1.2
PRT2	20.8	25.2	23.05	4.4	1.1
PRT3	20.1	24.7	22.30	4.6	1.1
PRT4	19.2	23.6	21.17	4.4	1.1
PRT5	18.3	21.7	19.73	3.4	0.9

Table 4: Descriptive statistics of foot outline length measurements in pooled sample in adult Malaysian Malayalees (in centimeters). N=110

Variables	Min	Max	Mean	RD	SD
PLT1	20.5	28.5	24.57	8.0	1.8
PLT2	20.4	27.8	24.04	7.4	1.7
PLT3	19.7	26.8	23.22	7.1	1.7
PLT4	18.3	25.1	21.99	6.8	1.6
PLT5	17.4	23.8	20.44	6.4	1.5
PRT1	21.1	28.1	24.41	7.0	1.6
PRT2	20.8	27.6	24.01	6.8	1.6
PRT3	20.1	26.8	23.29	6.7	1.6
PRT4	19.2	25.0	22.08	5.8	1.5
PRT5	18.3	23.8	20.57	5.5	1.4

A salient feature observed in the foot outline lengths is that the first toe-heel foot outline length in both left and right are found to be the longest in males and females in both genders. The left foot outline lengths are found to be larger than the right in both males and females showing the existence of bilateral asymmetry.

Table 5-7 depict the linear regression equations for stature estimation in adult males, females and the pooled sample through various foot outline length measurements and ANOVA.

Table 5: Linear regression equations for stature estimation through various foot outline length measurements and ANOVA in adult male Malaysian Malayalees (in centimeters). N=50

Varia-bles	Regression Equations	SEE	*R*	*R²*	Coefficient of t-test	ANOVA
PLT1	56.731 + 4.310PLT1	3.792	0.86	0.732	11.436	130.791(1,48);*p*<0.001
PLT2	60.116 + 4.267PLT2	4.362	0.80	0.645	9.334	87.129 (1,48);*p*<0.001
PLT3	59.598 + 4.427PLT3	4.495	0.79	0.623	8.901	79.232 (1,48);*p*<0.001
PLT4	60.249 + 4.647PLT4	4.589	0.78	0.607	8.607	74.081 (1,48);*p*<0.001
PLT5	66.924 + 4.696PLT5	4.860	0.75	0.559	7.801	60.853 (1,48);*p*<0.001
PRT1	59.707 + 4.237PRT1	4.404	0.80	0.638	9.195	84.556 (1,48);*p*<0.001
PRT2	57.332 + 4.396PRT2	4.783	0.76	0.573	8.025	64.394(1,48);*p*<0.001
PRT3	58.276 + 4.483PRT3	4.819	0.75	0.566	7.917	62.683 (1,48);*p*<0.001
PRT4	59.513 + 4.678PRT4	5.011	0.73	0.531	7.375	54.393 (1,48);*p*<0.001
PRT5	59.818 + 5.008PRT5	5.127	0.71	0.509	7.056	49.783 (1,48);*p*<0.001

PLT1 to PLT5: left lengths from anterior part of toes outline LT1- LT5 to outline mid-rear heel point P; PRT1 to PRT5: right lengths from anterior part   of toes outline RT1-RT5 to outline mid-rear heel point P; SEE: standard error of estimate; R: Correlation coefficient; R²: coefficient of determination.   p-value < 0.001 is significant

Table 6: Linear regression equations for stature estimation through various foot outline length measurements and ANOVA in adult female Malaysian Malayalees (in centimeters). N=60

Varia-bles	Regression Equations	SEE	*R*	*R²*	Coefficient of t-test	ANOVA
PLT1	68.600 + 3.590PLT1	5.053	0.68	0.468	7.140	50.980 (1,58);*p*<0.001
PLT2	68.827 + 3.662PLT2	5.103	0.68	0.457	6.992	48.885 (1,58);*p*<0.001
PLT3	77.127 + 3.428PLT3	5.228	0.66	0.430	6.618	43.804 (1,58);*p*<0.001
PLT4	74.370 + 3.752PLT4	5.105	0.68	0.457	6.984	48.780 (1,58);*p*<0.001
PLT5	63.983 + 4.562PLT5	4.882	0.71	0.503	7.666	58.765 (1,58);*p*<0.001
PRT1	60.438 + 3.950PRT1	5.178	0.66	0.441	6.766	45.776 (1,58);*p*<0.001
PRT2	57.231 + 4.161PRT2	4.992	0.69	0.481	7.327	53.691 (1,58);*p*<0.001
PRT3	61.899 + 4.091PRT3	5.111	0.68	0.456	6.966	48.526 (1,58);*p*<0.001
PRT4	60.150 + 4.392PRT4	4.929	0.70	0.494	7.521	56.567 (1,58);*p*<0.001
PRT5	51.776 + 5.139PRT5	4.952	0.70	0.489	7.449	55.489 (1,58);*p*<0.001

PLT1 to PLT5: left lengths from anterior part of toes outline LT1- LT5 to outline mid-rear heel point P; PRT1 to PRT5: right lengths from anterior part   of toes outline RT1-RT5 to outline mid-rear heel point P; SEE: standard error of estimate; R: Correlation coefficient; R²: coefficient of determination. p-value < 0.001 is significant

Table 7: Linear regression equations for stature estimation through various foot outline lengths measurements and ANOVA in pooled samples in Malaysian Malayalees (in centimeters). N=110

Varia-bles	Regression Equations	SEE	R	R^2	Coefficient of t-test	ANOVA
PLT1	36.625PLT1 + 5.016	5.057	0.87	0.756	18.307	335.157 (1,108);*p*<0.001
PLT2	37.858PLT2 + 5.074	5.256	0.86	0.737	17.386	302.259 (1,108);*p*<0.001
PLT3	43.716PLT3 + 5.002	5.387	0.85	0.723	16.810	282.565 (1,108);*p*<0.001
PLT4	42.909PLT4 + 5.320	5.319	0.86	0.730	17.104	292.554 (1,108);*p*<0.001
PLT5	39.071PLT5 + 5.911	5.277	0.86	0.735	17.292	299.012 (1,108);*p*<0.001
PRT1	29.483PRT1 + 5.341	5.380	0.85	0.724	16.840	283.602 (1,108);*p*<0.001
PRT2	28.221PRT2 + 5.483	5.313	0.86	0.731	17.131	293.471 (1,108);*p*<0.001
PRT3	32.526PRT3 + 5,469	5.346	0.85	0.728	16.986	288.517 (1,108);*p*<0.001
PRT4	31.532PRT4 + 5.811	5.363	0.85	0.726	16.913	286.050V(1,108);*p*<0.001
PRT5	27.382PRT5 + 6.439	5.349	0.85	0.727	16.974	288.117 (1,108);*p*<0.001

PLT1 to PLT5: left lengths from anterior part of toes outline LT1- LT5 to outline mid-rear heel point P; PRT1 to PRT5: right lengths from anterior part of toes outline RT1-RT5 to outline mid-rear heel point P; SEE: standard error of estimate; R: Correlation coefficient; R^2: coefficient of determination.
p-value < 0.001 is significant

Correlation coefficient (R) values are found to be higher in the pooled sample (0.85–0.87) when compared with males (0.71–0.86) and females (0.66–0.71) separately. The coefficient of determination (R^2), the predictive accuracy, is found to be higher in the pooled sample (0.723-0.756) when compared with males (0.509-0.732) and females (0.430-0.494) and all measurements are found to be positive and statistically significant (<0.001) for stature estimation.
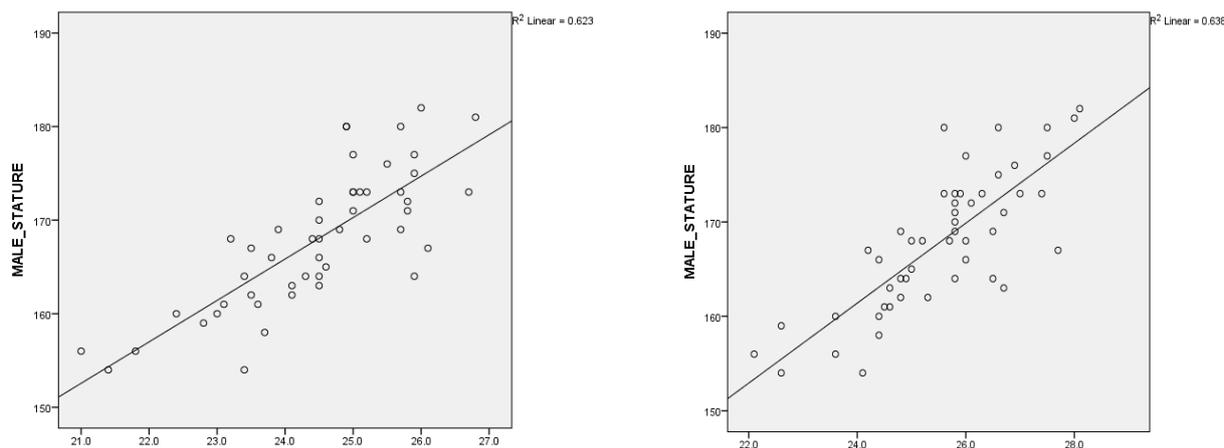

Figure 2: Illustrative examples of scatter graphs showing the relationship between foot outline lengths (left and right) and stature in adult male Malaysian Malayalees.
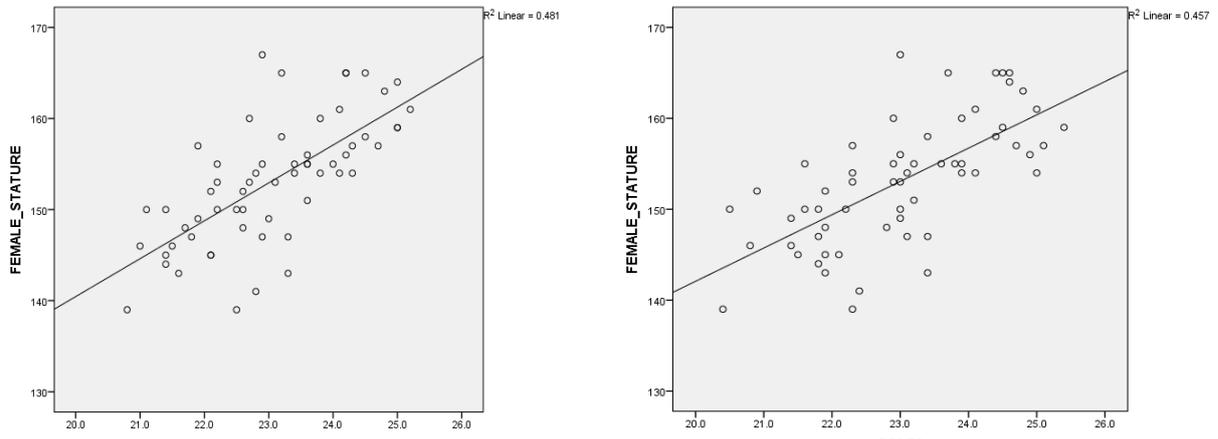
Figure 3: Illustrative examples of scatter graphs showing the relationship between foot outline lengths (left and right) and stature in adult female Malaysian Malayalees.
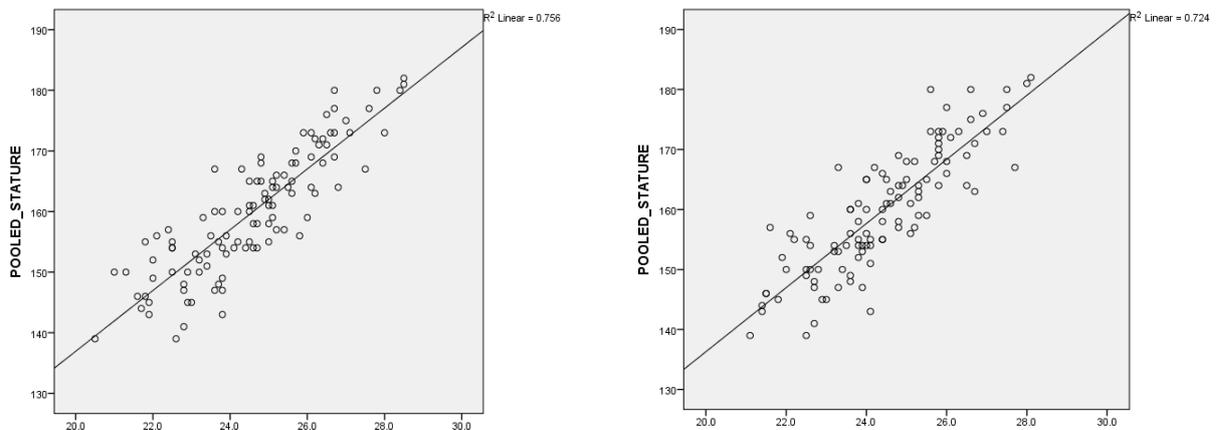

Figure 4: Illustrative examples of scatter graphs showing the relationship between foot outline lengths (left and right) and stature in pooled samples of Malaysian Malayalees.

A few illustrative examples of graphs with fitted lines for foot outline and stature in males (Figure 2), females (Figure 3) and the pooled sample (Figure 4) are presented. All graphs show positive correlaton between staure and foot outline length measurements.

DISCUSSION

Stature is found to be larger in males than females, showing the existance of a statistically significant gender difference in Malaysian Malayalees. This may be attributed general male-female differences and natural size in both sexes. This finding is in accordance with the previous studies [22-28]. The foot outline provided the size parameters of the fleshed bare foot and also represents the boundaries of the foot's impression in soft soil surfaces that produces a 3D footprint impression. The investigation revealed that the left foot outline measurements are found to be larger in both sexes and hence the existence of left-sided asymmetry. Similar observations were noted in Malaysian Malays[9], male Gujjars of North India[10], male Egyptian[17,] Indian[29] and male Jat Sikh in North Indian[30]. Researchers[31] suggested that in majority of both left and right handed persons, the left foot is more used than the right.

The age of the subjects is above 18 years and considered appropriate since average length of the adult's foot is attained by the age of 16 years in male and 14 years in females[32]. The researchers concluded that to estimate stature, irrespective of ethnics, toe-to-heel length measurements are more reliable and accurate than from any other measurements such as breadth measurements etc.[9-10, 21-22]. The result of the study indicated that the correlation coefficient (R) between stature and foot outline length measurements is higher in pooled sample compared to male and female individually. Hence the regression equations derived for pooled samples can be used to estimate stature since the sex of the 3D foot impression is unknown in real crime scenes. The standard error of estimate (SEE) is a measure of accuracy of predictions. Researchers shown that regression equations can be derived for stature estimation using foot and hand measurements with a great accuracy in both males and females show high reliability and accuracy with low SEE. The SEE values are found to be low in the present study.

CONCLUSION

The result of this research provided linear regression equations for stature estimation from foot outline (3D foot impression) anthropometry in Malaysian Malayalee ethnics. The findings of the study will be applicable to complete and even partial foot impressions found in soft soil or mud. The research shows that the regression equation without gender indicators perform significantly better that do models with sex indications, as in real crime scenarios.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

ACKNOWLEDGMENT

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