MULTIPLE REGRESSION ANALYSIS TO ESTIMATE HEIGHT FROM DYNAMIC FOOTPRINT ANTHROPOMETRY IN MALAYSIA INDIAN SUB-ETHNIC GROUP

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ABSTRACT

Human beings are social animals. The uniqueness human body size would become the basis of what Bertillon would term anthropometry, a system of personal identification based on the theory that no two people were identical in their body measurements. Person identification is a key element in forensic investigation. Footprint is a valuable item of physical evidence encountered in crime scenes that can be used to determine the stature of an individual for the purpose of identification. There is a strong correlation exists between footprint and stature. Researchers have proved that contemporary population specific standards should be used to formulate the accurate biological profile. The present study aimed to derive multiple regression equations to estimate height from dynamic footprints among one of the Malaysian Indian subethnic group, Malayalees living in Malaysia. The study subject consists of 50 males and 60 females from Malaysian Malayalee population living in Malaysia. The footprints and heights were recorded following the standard procedure and derived multiple regression equation to estimate height from footprints for forensic application.

Key words: Forensic science, height, footprint, Malaysian Malayalee

INTRODUCTION

Human beings are social animals. The uniqueness human body size would become the basis of what Bertillon would term anthropometry, a system of personal identification based on the theory that no two people are identical in their body measurements. Height estimation is one of important factors contributing to human identification. Human stature determination is possible using the measurements of different body parts (Ozaslan *et al.,* 2013; Zverev, 2003; Sanli *et al*., 2005; Nataraja Moorthy & Nurain, 2014a). Alphonse Bertillon was a French police officer who introduced anthropological technique to law enforcement creating an identification system based on physical measurements (Kennedy, 2000). The stature prediction occupies relatively a key position in the anthropometric research (Waghmare, 2010). Studies have been conducted on stature estimation from hand (Nataraja Moorthy *et al.,* 2014c; Jianpin, *et al.,* 2012; Nur *et al.,* 2012), handprint (Nur *et al.,* 2012; Melad, 2015), foot (Agnihotri *et al*., 2007; Jaydip & Ghosh, 2008), footprint (Nataraja Moorthy *et al.,* 2014a,b; Hairunnisa & Nataraja, 2015) and foot outline (Hairunnisa & Nataraja, 2013a,b,c). Two-dimensional (2D) bare footprints are recovered more often at crime scenes of house breaking, sexual assault, decoity, suspicious death or homicide, and are more prevalent at crime scenes in countries of a warmer climate (Qamra, 1980; Sharma, 1970). Anthropological study have shown that static footprints are being used for stature estimation. However, the offenders mostly left their dynamic footprints during their crime operations and then the field criminalists used to visit the crime scenes and collect two dimensional dynamic bare footprints for stature determination. Studies showed that parameters calculated from dynamic footprints were found to be significantly differ from those calculated from static prints (Mathieson *et al.,* 1999). Earlier anthropological studies for stature estimation from

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foot prints were conducted on mixed population (Nur *et al.,* 2012; Melad, 2015; Davesh *et al.,* 2006). But anthropological researchers cautioned for sample populations to be separated into their ethnic groups before applying meaningful analysis (Agnihotri *et al*., 2007; Jaydip & Ghosh, 2008). Hence the present investigation aimed to derive multiple regression equations to determine height from footprints of Malaysia Indian sub-ethnics, Malayalees living in peninsular Malaysia.

MATERIALS AND METHODS

Sample collection area

The research was conducted in Peninsular Malaysia, wherein most of the Malayalee have settled. The Malaysian Malayalees have ancestral origins in the modern day state of Kerala, on south west coast of India with their mother tongue 'Malayalam'. The study sample of volunteering subjects comprised 110 adult Malaysian Malayalees (50 males, 60 females) considered to be representative of the population in Malaysia. The subjects 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.

Methodology

Before sample collection, the feet of the subjects were washed to ensure they were free from adhesive dusts and height of the subjects were recorded following the standard procedure (Robbins, 1986; Nataraja Moorthy *et al.,* 2011a,b). Stature of each subject was measured using a portable body meter measuring device (SECA model 206). The stature of an individual is the vertical distance from floor to vertex when the individual is standing barefoot with head in the Frankfort plane. The height of the subjects was measured at a fixed time in the evening because of diurnal variation in stature (Krishan & Abihilasha, 2007b; Nataraja Moorthy *et al*., 2014a, b). Other information, such as name, age, sex, place of origin were also recorded. The dynamic footprints were collected following the standard procedure (Nataraja Moorthy & Rina, 2008; Reel *et al.,* 2012). The subject was requested to step on the footprint plate smeared uniformly with black footprint ink. Then the subject was asked to walk on a long white paper spread before the individual, leaving 3 to 5 dynamic footprints. The third or fourth footprint was chosen as dynamic footprint (left and right print). The anatomical landmarks on the right footprint, namely mid-rear heel point (pternion, P) in the base line BL and most anterior points of all toes (RT1–RT5) were marked as shown in Figure 1. Similar anatomical landmarks were marked in left dynamic footprint. The procedure was repeated for all other subjects. All foot print samples and information relating to participants were coded with sample ID for anonymity. The right footprint length measurements were designated as PRT1, PRT2, PRT3, PRT4, and PRT5. Similarly the left footprint length measurements were designated as PLT1, PLT2, PLT3, PLT4 and PLT5.

STATISTICAL ANALYSIS

The data were analyzed using SPSS software version 21. Pearson's correlation coefficient (R) between various dynamic footprint lengths and stature were obtained. The multiple regression analysis method was employed to derive regression equations for

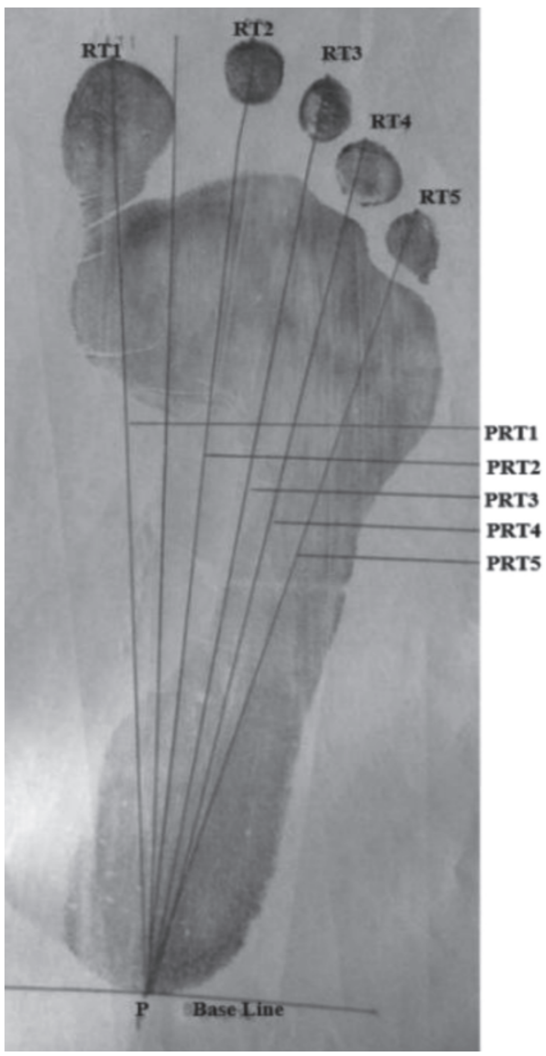

Fig. 1. Landmarks and diagonal length measurements on right dynamic footprint PRT1-PRT5, measurements taken from the mid-rear heel point, pternion (P) to the most anterior point of right toes RT1-RT5 on footprint.

stature determination from various footprint lengths since stature estimation from footprint length is more accurate and reliable with regression analysis (Nataraja Moorthy *et al.,* 2014b). The standard error of estimation (SEE) was calculated to analyze the deviation of the estimated stature from the actual stature for footprint measurements.

RESULTS

All footprint measurements exhibit statistically positive significant correlation with stature. Table 1 presents 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 167.9 cm) 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 2 to 4 present the descriptive statistics of footprint 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 footprint length measurements in males are found to be larger than females both in left and right foot prints. Another

Table 1. Descriptive statistics of stature in males, females and pooled sample in adult Malaysia Indian sub-ethnic, Malayalees (in centimeters)

Variable	Min	Max	RD	Mean	SD
Male (N=50)	154.0	182.0	28.0	167.9	7.2
Female (N=60)	139.0	167.0	28.0	153.1	6.9
Pooled sample (N=110)	139.0	182.0	43.0	159.7	10.2

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

Table 2. Descriptive statistics of dynamic footprint length measurements of males in adult Malaysia Indian sub-ethnic, Malayalees (in centimeters)

Variables	N	Range	Min	Max	Mean	SD
PLT1	50	6.4	20.3	26.7	23.76	1.3
PLT2	50	6.2	20.0	26.2	23.80	1.3
PLT3	50	5.7	19.6	25.3	23.07	1.2
PLT4	50	4.7	18.9	23.6	21.78	1.1
PLT5	48	4.6	17.4	22.0	19.98	1.1
PRT1	50	5.4	20.4	25.8	23.56	1.3
PRT2	50	5.4	20.5	25.9	23.65	1.2
PRT3	50	5.3	20.0	25.3	22.94	1.2
PRT4	50	4.7	18.9	23.6	21.66	1.1
PRT5	45	4.4	17.4	21.8	19.95	1.0

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

Table 3. Descriptive statistics of footprint length measurements of females in adult Malaysia Indian sub-ethnic, Malayalees (in centimeters)

Variables	N	Range	Min	Max	Mean	SD
PLT1	60	4.8	19.3	24.1	21.97	1.1
PLT2	60	4.7	19.5	24.2	21.88	1.1
PLT3	59	4.3	19.1	23.4	21.14	1.1
PLT4	60	4.8	17.6	22.4	19.93	1.1
PLT5	56	3.4	16.8	20.2	18.44	1.0
PRT1	60	4.1	19.7	23.8	21.80	1.0
PRT2	60	4.2	19.5	23.7	21.78	1.1
PRT3	60	4.5	18.9	23.4	21.06	1.1
PRT4	59	4.2	18.0	22.2	19.92	1.0
PRT5	57	3.1	17.0	20.1	18.43	0.9

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

Table 4. Descriptive statistics of footprint length measurements of pooled sample in adult Malaysia Indian sub-ethnic, Malayalees (in centimeters)

Variables	N	Range	Min	Max	Mean	SD
PLT1	110	7.4	19.3	26.7	22.78	1.5
PLT2	110	6.7	19.5	26.2	22.75	1.5
PLT3	109	6.2	19.1	25.3	22.02	1.5
PLT4	110	6.0	17.6	23.6	20.77	1.4
PLT5	104	5.2	16.8	22.0	19.15	1.3
PRT1	110	6.1	19.7	25.8	22.60	1.5
PRT2	110	6.4	19.5	25.9	22.60	1.5
PRT3	110	6.4	18.9	25.3	21.91	1.5
PRT4	109	5.6	18.0	23.6	20.72	1.4
PRT5	96	4.8	17.0	21.8	19.14	1.2

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

Table 5. Multiple regression equations for height estimation from various dynamic footprint length measurements and ANOVA in Malaysia Indian sub-ethnics, Malayalees

Gender	Side	Multiple regression equations	R	R^2	SEE	ANOVA
Male (N=50)	Left	H = 57.418 + 3.082(PLT1) + 0.733(PLT2) − 0.460(PLT3) + 2.969(PLT4) − 1.720(PLT5)	0.86	0.731	3.928	22.826 (5,44); *p*<0.001
	Right	H = 56.416 + 1.990(PRT1) + 2.772(PRT2) + 0.824(PRT3) + 0.703(PRT4) − 1.759(PRT5)	0.82	0.673	4.511	16.060 (5,44); *p*<0.001
Female (N=60)	Left	H = 52.617 − 0.884(PLT1) + 0.548(PLT2) − 0.061(PLT3) + 0.640(PLT4) + 5.220(PLT5)	0.78	0.600	4.521	14.715 (5,54); *p*<0.001
	Right	H = 48.516 + 0.374(PRT1) + 0.722(PRT2) − 1.860(PRT3) + 4.441(PRT4) + 1.694(PRT5)	0.73	0.532	4.996	9.989 (5,54); *p*<0.001
Pooled Sample (N=110)	Left	H = 26.807 + 1.720(PLT1) − 0.332(PLT2) + 0.187(PLT3) + 4.049(PLT4) + 0.714(PLT5)	0.87	0.748	5.345	52.823 (5,104); *p*<0.001
	Right	H = 20.889 + 0.970(PRT1) + 2.024(PRT2) + 0.332(PRT3) + 3.113 (PRT4) − 0.036(PRT5)	0.88	0.772	4.956	65.814 (5,104); *p*<0.001

PLT1–PLT5: left footprint lengths from anterior point of toes LT1–LT5 to mid-rear heel point P; PRT1–PRT5: right footprint lengths from anterior point of toes RT1–RT5 to mid-real heel point P; SEE, standard error of estimate. R: Pearson's correlation coefficient; R^2: coefficient of determination.

notable feature is that the second toe-heel footprint lengths in both left and right (PLT2, PRT2) are found to be the longest in males (highlighted in yellow color in Table 2 and 3) but the finding is opposite in females wherein the first toe-heel footprint lengths in both left and right (PLT1, PRT1) are found to be the longest. Thus the investigation revealed the existence of significant bilateral asymmetry in males and females. Also an interesting feature observed in footprints is the missing of toes in some footprints, i.e. PLT3, PLT5, PRT4 and PRT5 (highlighted in green color in Table 4). Even though the subjects have all toes, this missing of impression occurred because these toes did not make contact with the ground during the footprint development process. Similar observations were made in other footprint studies (Nataraja Moorthy *et al.,* 2011b; 2014b; Hairunnisa & Nataraja, 2015).

Table 5 presents the multiple regression equations for stature determination in adult males, females and the pooled sample through various dynamic footprint length measurements with ANOVA. The tables also depict Karl Pearson's correlation coefficients (R) of bilateral dynamic footprint length measurements with height for males, females and pooled sample. The R value is statistically significant (<0.001) and all the R values have shown strong positive correlation in terms of the relationship between footprint length and stature. Correlation coefficient values were found to be comparatively higher in the pooled sample (0.87-0.88) than males (0.82-0.86) and females (0.73-0.78). Hence, statistically significant correlation coefficients exist between height and all footprint length measurements.

DISCUSSION

The mean height of male was found to be larger than females, showing the existance of a statistically significant gender difference in Malaysia Indian sub-ethnics, Malayalees. This may be attributed general male-female differences and natural size in both sexes (Kanchan *et al.,* 2012). This finding is in accordance with the previous studies (Nataraja Moorthy *et al.,* 2014b,c; Hairunnisa & Nataraja, 2013a,b,c; 2014). Similarly the mean footprint length measurements in males are found to be larger than females both in left and right footprints, but there are small male and large female footprints. The age range of the subject in this research is appropriate since stature at 18 years is accepted as adult since average length of the adult's foot is attained by the age of 16 years in male and 14 years in females (Krishan & Vij, 2007a). The researchers concluded that height estimation irrespective of ethnics, toe-to-heel length measurements are more reliable and accurate than from any other measurements such as breadth measurements etc. (Nataraja Moorthy *et al.,* 2014a,b; Hairunnisa & Nataraja, 2013a,b; 2015). The result of the study indicated that the correlation coefficient (R) between stature and footprint length measurements is higher in pooled sample compared to male and female individually and hence the multiple regression equations derived for pooled samples can be used to determine stature since the sex of the footprint is unknown in real crime scenes. The standard error of estimate (SEE) is also shown in the Table 5. Findings indicated that regression equations can be used for stature determination using foot and hand measurements with a great accuracy and a small SEE, i.e. about 2-6 (Krishan *et al.,* 2012). The SEE values are found to be low in the present study. The coefficient of determination (R^2), the predictive accuracy, is found to be higher in the pooled sample when compared with males and females and all measurements are positive and statistically significant (<0.001) for stature determination.

CONCLUSION

The results of the investigation provided multiple regression equations for height estimation from footprints in Malaysia Indian sub-ethnics, Malayalee. The multiple regression equations derived for the pooled sample can be used to estimate stature even when the sex of the footprint's owner remains unknown, as in real crime scenarios. It is erroneous to utilize these population specific equations to estimate height from footprint either in Malaysia or any other populations in the world.

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