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Research Article

Regression Analysis to Determine Body Weight from Foot-Outline (3D) Anthropometry among Bidayuhs: An Indigenius Ethnic Group in Malaysian Borneo

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Abstract

Human identification is an absolutely paramount in any forensic investigation. Scientific methods are employed both in forensic laboratory and crime scenes to achieve identification and subsequent testimony in court. Physical evidence is a key element for forensic identification. One such evidence left unintentionally by the perpetrator is foot-impression. Anthropologists assist in identification by constructing a biological profile. Human foot-impressions have been used to determine stature, gender, body weight, age and race. Foot-impression is classified into Two Dimensional (2D) and Three Dimensional /foot-outline (3D) that are lifted through different techniques for forensic examination. One way of lifting a 3D foot-impression is by the tracing technique. Because feet bear body weight, the foot-impressions are likely to correlate with weight. The utility of foot-impression as an indicator of body mass has been less explored. It is mandatory that racial and cultural aspects of foot morphology must be considered in determination of height, body weight, gender and race. The present study's aim is to determine living body weight from foot-outline (3D) anthropometry of indigenous Bidayuhs, residing in Malaysian Borneo. The foot-outlines and body weights from the consented subjects have been collected following the standard procedure. The data obtained was computed with PASW 20 computer software and derived population specific regression equations to determine living body weight from foot-outline length measurements. The result shows that all foot-outline lengths exhibit statistically significant positive correlations with body weight. It is concluded with caution that it is erroneous to utilize these derived equations to any populations either in Malaysia or any populations in the world for body weight determination.

Introduction

Identifying a human individual through scientific means is a key component of forensic investigation. Every part of the human body is unique in itself. It is important to realize there is variability among the part of the body to the same part in another body. There is a relationship between each part of the body and the whole body [1]. Alphonse Bertillon was a French police officer who introduced anthropological technique of anthropometry to law enforcement creating an identification system based on physical measurements [2,3]. The human foot has been studied for forensic and non-forensic purposes by anatomists, forensic scientists, anthropologists, physicians, podiatrists, and numerous other groups [4]. Foot-impression forms important valuable physical evidence unintentionally left by the perpetrator or suspect in the scenes of crime that can help to link the crime and criminal. In some Asian countries, people prefer to walk barefooted because of their spiritual thoughts, religion, socio-culture, climatic condition, and socio-economic reasons, increasing the importance of bare foot-impression in the Asiatic crime scenes [5].

Foot-impressions are often found at crime scenes since some offenders remove their foot wears, either to avoid noise or to gain a better grip in climbing walls, etc., while entering or exiting [6]. Human foot morphology is greatly influenced by the combined effects of heredity and living style determinants that make the size and shape data of the feet/footprints unique to establish a human identity. Thus a keen examination of foot-impressions may provide fruitful information which can help in linking a suspect with the scene of crime. The foot-impression is useful source of physical evidence for person identity and in forensic science, forensic medicine, anthropology and in other research areas. The characteristic feature of a barefoot-impression found at the crime scenes can be either Two-Dimensional (2D) or Three-Dimensional (3D). When the foot's plantar surface actually touches the floor of hard surface, a 2D foot imprint is formed and is known as footprint. This footprint provides the dimension of foot size. However, when the foot plantar surface entered into the soft soil, or mud, a 3D impression is created and is known as foot-outline. Foot-outline is defined as the line tracing around the outer margins of the fleshed foot (Figure 1). The outline serves as a two-dimensional, intermediate foot form in going from the bare footprint to the shoe print.

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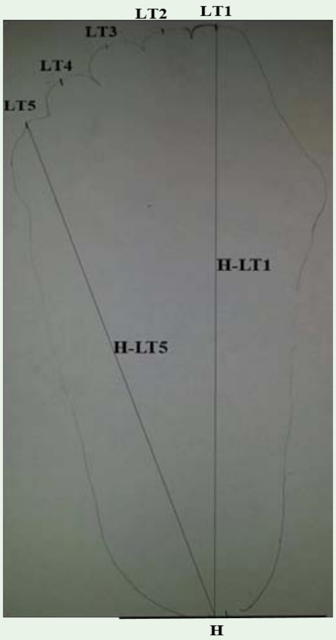

Figure 1: Illustrative example showing landmarks H- for the mid-rear heel point to the most anterior point of toes LT1-LT5 on left foot-outline (for example, foot-outline length measurements, H-LT1 and H-LT5 for toe1 and toe 5).

Both footprints and foot-outlines can provide promising information to establish the identity of suspect or perpetrator [7]. Stature has been estimated from foot [8-12], footprint [13-21], foot-outline [14,16,22-26] anthropometry, by considering the racial aspects during crime investigation.

Weight is a biometric trait which has been studied in both forensic and medical domains. In many practical situations, such as video surveillance, weight can provide useful information for re-identification purposes. Because feet bear body weight, the foot-impression is likely to correlate with weight. The utility of foot-impression as an indicator of body mass has been less explored [27]. In forensic perspective, the researchers have conducted population standard body weight determination from footprint for use in crime scene investigation [28-31]. But unfortunately, the literature review shows feeble number of studies recorded correlating foot-outline (3D) with living human body weight [32,33]. The present investigation aims are correlate the body weight and foot-outline length measurements of Bidayuhs, an indigenous ethnic group, mostly settled at Malaysian Borneo and developed regression formulae to determine body weight in forensic perspective.

Materials and Methods

Study area

The study area was Malaysian Borneo consisting of Sabah and Sarawak States. The study subjects were from colleges, universities and general public living in East Malaysia. The Bidayuhs are an indigenous ethnic group mostly residing in Sarawak State of East Malaysia.

Sample collection

Malaysian Borneo Island is a land inhabited by various indigenous populations with their characteristic culture and language. It is cumbersome to collect sample from indigenous groups in Malaysian Borneo Island. Hence appropriate permission was obtained from Sarawak State Chief Minister vide no. JKM.P/DEV/16/005/12 (44), as recommended by the Police Chief of Sarawak State. Informed consent was also obtained from the participants and followed the procedure in accordance with the ethical standards of the Universiti Sains Malaysia Human Research Ethic Committee. A sample of 400 bilateral foot-outlines were collected from 200 (100 males, 100 females) persons who underwent informed consent of Bidayuh ethnicity, ages ranging between 18 to 64 years. Subjects with any apparent foot-related disease, pregnancy, injury, disorders or under the age of 18 years were excluded from the study. Following the standard procedure, the weight of the subjects was measured and recorded [29].

Similarly, the foot-outlines were collected and recorded following standard procedure [22-26]. The five diagonal foot-outline length measurements were taken from the mid-rear heel point (H) to most anterior point of each left toes (LT1, LT2, LT3, LT4, and LT5). The left foot-outline length measurements were designated as H-LT1, H-LT2, H-LT3, H-LT4, and H-LT5. The procedure was repeated for the right foot-outline length measurements and was designated as H-RT1, H-RT2, H-RT3, H-RT4, and H-RT5. The left foot-outline length measurement between mid-rear heel point (H) and first toe end (T1) and fifth toe end (T5) are shown in Figure 1. All foot-outlines, body weights, and information relating to participants were coded with sample ID's for anonymity.

Statistical analysis

The collected data was analyzed by using SPSS statistics software package, version 20. Pearson's correlation coefficient (R) between various foot-outline lengths and body weight was obtained. The linear regression analysis method was employed to derive regression equations to determine body weight from various foot-outline length measurements.

Results

Table 1 presents the descriptive statistics of body weights in males, females and pooled sample (combined male and female subjects) of Bidayuh subjects. In males, the body weight ranges from 50.2 kg to 88.0 kg (mean 63.9 kg) while in females the range is from 44.2 kg to 66.0 kg (mean 54.6 kg). The table shows that the mean body weight of male is found to be comparatively higher (63.9 kg) than the body weight of female (54.6 kg).

Table 2 shows the descriptive statistics of various foot-outline lengths between the mid rear heel end (H) and anterior points of each toe in left (LT1 to LT5) and right (RT1to RT5) foot-outlines of

Table 1: Descriptive statistics of body weight in adult males, females and pooled sample of Bidayuh ethnics of Malaysian Borneo (in kg).

Group	Min	Max	Mean	SD
Male (N=100)	50.2	88	63.9	9.5
Female (N=100)	44.2	66	54.6	6.1
Pooled sample (N=200)	44.2	88	58.4	7.8

Min: Minimum; Max: Maximum; kg: Kilogram; N: Sample size; SD: Standard Deviation

Table 2: Descriptive statistics of foot-outline length measurements in males, females and pooled sample of adult Bidayuh ethnics of Malaysian Borneo (in centimeters).

Variable	Male (N=100)				Female (N=100)				Pooled sample (N=200)			
	Min	Max	mean	SD	Min	Max	mean	SD	Min	Max	mean	SD
H-LT1	22.7	28.5	25.26	1.1	21.3	24.7	23.05	0.7	21.3	28.5	24.14	1.4
H-LT2	22.3	28.5	25.15	1.1	20.9	24.5	22.85	0.8	20.9	28.5	23.96	1.4
H-LT3	21.5	27.6	24.34	1.1	20.0	23.7	22.08	0.8	20.0	27.6	23.16	1.4
H-LT4	20.3	26.2	23.05	1.0	19.0	22.4	20.95	0.7	19.0	26.2	21.95	1.3
H-LT5	19.1	24.1	21.31	0.9	17.2	21.3	19.38	0.7	17.2	24.1	20.31	1.2
H-RT1	22.8	28.8	25.25	1.0	21.2	25.0	23.05	0.8	21.2	28.8	24.14	1.4
H-RT2	22.2	28.5	25.09	1.1	20.9	24.8	22.81	0.9	20.9	28.5	23.93	1.4
H-RT3	21.5	27.7	24.24	1.1	19.7	23.9	22.03	0.8	19.7	27.7	23.10	1.4
H-RT4	20.3	26.1	23.00	1.0	18.7	22.9	20.86	0.8	18.7	26.1	21.89	1.3
H-RT5	18.9	24.0	21.26	0.9	17.3	21.1	19.26	0.7	17.3	24.0	20.23	1.2

Min: Minimum; Max: Maximum; H-LT1 to H-LT5: left foot-outline lengths from anterior part of toes LT1- LT5 to mid-rear heel point H; H-RT1 to H-RT5: right foot-outline lengths from anterior part of toes RT1-RT5 to mid-real heel point H; SD: Standard Deviation; N: Sample size.

males, females and the pooled sample. Here pooled sample (N=200) represents the combination of both male (N=100) and female (N=100) participants. A range of variation can be observed in the measurements of variables. From the various foot-outline length measurements presented in table 2, it is seen that the mean foot-outline lengths of male are found to be larger than the mean foot-outline lengths of female in both sides.

It is seen that the mean first toe to heel foot-outline lengths in both left and right (H-LT1, H-RT1) are found to be the longest in both genders. The investigation reveals the existence of bilateral asymmetry in both the genders but statistically not significant. The standard deviation values are found to be very low.

Tables 3-5 show the linear regression equations derived from ten foot-outline length measurements in adult Bidayuh males, females and pooled sample and ANOVA. Regression equations have been computed for body weight determination for ten foot-outline length measurements on both sides. The tables present the correlation coefficient (R) and Standard Error of Estimation (SEE) also. The standard error of estimation is found to be comparatively lower in females than males and pooled sample. Also the correlation coefficient (R) between foot-outline length measurements and body weight in males is in a range of 0.042-0.125 while the female is 0.056-0.197. The R value for pooled sample is found to be comparatively higher (0.220-0.290) than the separate genders. All foot-outline length measurements exhibit statistically positive significant correlation coefficients with body weight in Bidayuhs of East Malaysian Borneo.

Figures 2 to 4 show the correlation between body weight and a) left foot-outline length for toe 1 (H-LT1) in males, b) left foot-outline length for toe 2 (H-LT2) in females, c) left foot-outline length for toe 1 (H-LT1) in pooled sample and d) left foot-outline length for toe 2 (H-LT2) for pooled sample in this ethnic group.

Figure 2 is the scatter dot graph shows positive correlation between body weight and left first toe foot-outline length (H-LT1) in males. All the dots did not fall along the line showing low correlation between body weight and foot-outline length in male. The body weight did not show steady increase as the foot-outline length increases since the correlation coefficient (R) is 0.121 as shown in table 3. This is characteristics to this particular ethnic group.

Table 3: Linear regression equations for body weight estimation from various foot-outline length measurements on left and right sides among adult male persons of Bidayuh ethnicity of Malaysian Borneo.

Variables (cm)	Regression Equations	SEE	R	ANOVA
H-LT1	37.099 + 1.064 H-LT1	9.519	0.121	1.449 (1, 98); p = 0.232
H-LT2	38.105 + 1.029 H-LT2	9.519	0.121	1.445 (1, 98); p = 0.232
H-LT3	41.361 + 0.929 H-LT3	9.535	0.106	1.105 (1, 98); p = 0.296
H-LT4	37.143 + 1.164 H-LT4	9.514	0.125	1.557 (1, 98); p = 0.215
H-LT5	51.598 + 0.581 H-LT5	9.576	0.053	0.275(1, 98); p = 0.601
H-RT1	41.598 + 0.886 H-RT1	9.546	0.094	0.876 (1, 98); p = 0.352
H-RT2	42.094 + 0.872 H-RT2	9.542	0.099	0.969 (1, 98); P = 0.327
H-RT3	42.310 + 0.894 H-RT3	9.542	0.098	0.958 (1, 98); p = 0.330
H-RT4	39.417 + 1.068 H-RT4	9.532	0.109	1.178 (1, 98); p = 0.280
H-RT5	54.079 + 0.466 H-RT5	9.580	0.042	0.176 (1, 98); p = 0.676

H-LT1 to H-LT5: left foot-outline lengths from anterior part of toes LT1- T5 to mid-rear heel point H; H-RT1 to H-RT5: right foot-outline lengths from anterior part of toes RT1-RT5 to mid-rear heel point H; cm: Centimeters; SEE: Standard Error of Estimate; R: Correlation Coefficient.

Table 4: Linear regression equations for body weight estimation from various foot-outline length measurements on left and right sides among female persons of Bidayuh ethnicity of Malaysian Borneo.

Variables (cm)	Regression Equations	SEE	R	ANOVA
H-LT1	20.712 + 1.470 H-LT1	6.027	0.180	3.288 (1, 98); p = 0.073
H-LT2	20.558 + 1.490 H-LT2	6.008	0.197	3.942 (1, 98); p = 0.050
H-LT3	22.642 + 1.447 H-LT3	6.016	0.190	3.665 (1, 98); p = 0.058
H-LT4	28.702 + 1.236 H-LT4	6.059	0.149	2.214 (1, 98); p = 0.140
H-LT5	26.794 + 1.435 H-LT5	6.047	0.161	2.614 (1, 98); p = 0.109
H-RT1	36.851 + 0.770 H-RT1	6.095	0.103	1.042 (1, 98); p = 0.310
H-RT2	39.170 + 0.676 H-RT2	6.099	0.096	0.906 (1, 98); p = 0.343
H-RT3	43.703 + 0.495 H-RT3	6.113	0.068	0.458 (1, 98); p = 0.500
H-RT4	45.507 + 0.436 H-RT4	6.118	0.056	0.306 (1, 98); p = 0.582
H-RT5	43.595 + 0.571 H-RT5	6.114	0.067	0.442 (1, 98); p = 0.508

H-LT1 to H-LT5: left foot-outline lengths from anterior part of toes LT1- T5 to mid-rear heel point H-; H-RT1 to H-RT5: right foot-outline lengths from anterior part of toes RT1-RT5 to mid-rear heel point H; cm: Centimeters; SEE- Standard Error of Estimate; R: Correlation Coefficient.

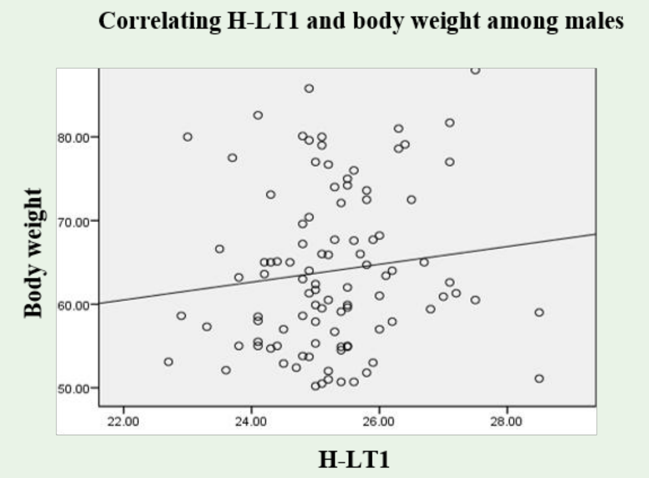

Figure 2: Illustrative example of scatter dot graph showing the relationship between body weight and left heel to toe 1 (H-LT1) length in male Bidayuhs.

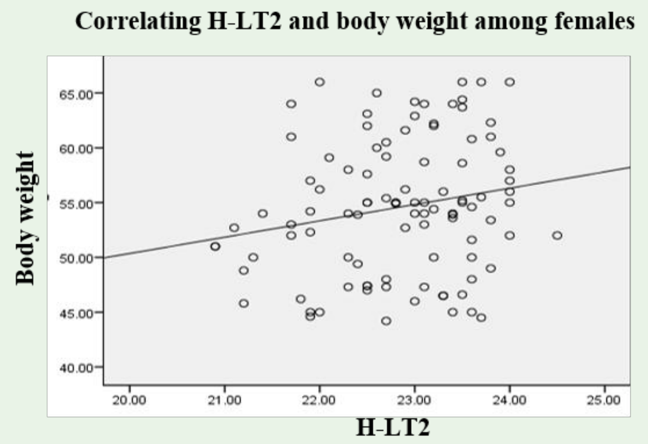

Figure 3: Illustrative example of scatter dot graph showing the relationship between body weight and left heel to toe 2 (H-LT2) length in female Bidayuh.

Table 5: Linear regression equations for body weight estimation from various foot-outline length measurements on left and right sides among adult persons of Bidayuh ethnicity pooled sample of Malaysian Borneo.

Variables (cm)	Regression Equations	SEE	R	ANOVA
H-LT1	18.030 + 1.672 H-LT1	7.476	0.29	18.204 (1, 198); p = 0.000
H-LT2	22.723 + 1.489 H-LT2	7.517	0.273	15.882 (1, 198); p = 0.000
H-LT3	24.028 + 1.483 H-LT3	7.532	0.265	15.013 (1, 198); p = 0.000
H-LT4	23.810 + 1.575 H-LT4	7.542	0.261	14.425 (1, 198); p = 0.000
H-LT5	24.498 + 1.668 H-LT5	7.554	0.255	13.745 (1, 198); p = 0.000
H-RT1	22.464 + 1.488 H-RT1	7.546	0.259	14.247 (1, 198); p = 0.000
H-RT2	28.373 + 1.254 H-RT2	7.603	0.23	11.072 (1, 198); p = 0.001
H-RT3	29.705 + 1.242 H-RT3	7.621	0.22	10.088 (1, 198); p = 0.002
H-RT4	27.556 + 1.409 H-RT4	7.59	0.237	11.769 (1, 198); p = 0.001
H-RT5	28.106 + 1.497 H-RT5	7.593	0.235	11.593 (1, 198); p = 0.001

H-LT1 to H-LT5: left foot-outline lengths from anterior part of toes LT1- T5 to mid-rear heel point H; H-RT1 to H-RT5: right foot-outline lengths from anterior part of toes RT1-RT5 to mid-rear heel point H; cm: Centimeters; SEE: Standard Error of Estimate; R: Correlation Coefficient.

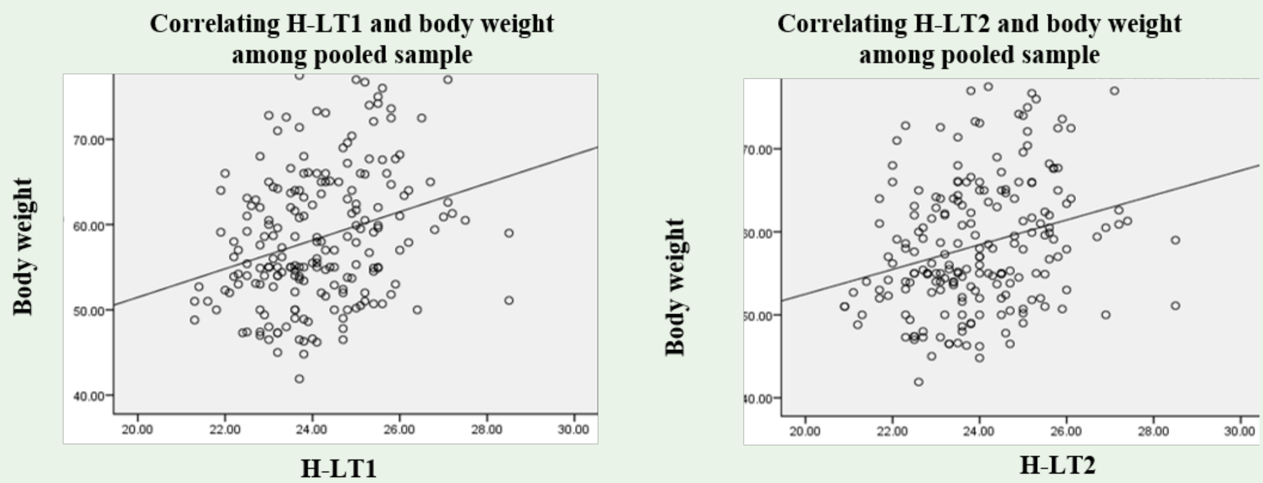

Figure 4: Illustrative example of scatter dot graph showing the relationship between body weight and left heel to toe 1 (H-LT1), left heel to toe 2 (H-LT2) lengths in pooled sample of Bidayuhs.

Figure 3 is the scatter dot graph showing positive correlation between body weight and left second toe foot-outline length (H-LT2) in females. The correlation between left second toe foot-outline length and body weight is comparatively higher (R=0.197) in female than male (0.121) showing the correlation variation among genders.

Figure 4 is the scatter dot graph showing positive correlation between body weight and left first & second toe foot-outline lengths (H-LT1 & H-LT2) in pooled sample. The interesting finding observed is that the correlation coefficient between body weight and foot-outline lengths are higher (R=0.290 & 0.273) than males and females separately. The linear trend lines in the pooled sample show better fit of the line to the data, i.e. the body weight is increasing at a steady rate with foot-out line length.

Discussion

The indigenous people of Sarawak State in Malaysian Borneo include Dayak, Iban, Bidayuh and Orang Ulu. Bidayuh is the second largest ethnic group in Sarawak State after Iban and people can be found in Sarawak and west Kalimantan [34]. This community constitutes 8.1% of Sarawak's population and less than 1% of Malaysia's population. Traditionally Bidayuhs live in longhouses on hills, and their main means of subsistence was shifting cultivation, planting hill rice. Some also rear animals like pigs and fowls. Bidayuh is an Austronesian language belonging to the Western Malayo-Polinesian branch [35].

The age range of the subjects in this research is appropriate since stature at 18 years is accepted as adult [36,37]. But some others researchers have informed that the foot in a male grows to its adult size by 16 years [38,39]. Thus the minimum age of study subjects was fixed as 18 years for sample collection. The study shows that statistically significant male–female differences exist in the foot-outline lengths in Bidayuh population. This may be attributed to the general male-female differences and natural size in both sexes [40]. This finding is in accordance with Malaysian Chinese [16], Melanaus [22], Kadasan Dusun [25] and Lun Bawang [26]. The foot-outline length measurements of the study population showed the existence of bilateral asymmetry but were not statistically significant. Similar findings were observed in Melanau [22] and Iban [24] populations. Correlation coefficient, R is regarded as a mathematical expression of the degree of association existing between paired measures. All the R values have shown positive correlation in terms of the relationship between foot-outline length and body weight. Based on foot-outline length and living body weight measurements, regression equations have been developed. Regression is a statistical tool, with the help of which we can estimate the unknown values of one variable from known values of another variable [6]. Here, the independent variable would be the foot-outline length while the dependent variable would be the body weight. In the present study, three types of regression equations have been developed for estimating body weight from foot-outline length viz. estimating the body weight of an individual regardless of sex (pooled sample), for males and females. The investigation revealed that the correlation coefficient (R), between foot-outline length and body weight for the pooled sample, gave a more significant result (0.220-0.290) than the correlations separately obtained for the males (0.042-0.125) and females (0.056-0.197). The standard error of estimate for female (6.008-6.118) is comparatively lower than male (9.514-9.580) and pooled sample (7.476-7.621).

Considering real crime scenarios, where the sex of the offenders' foot-outline is not known, it is suggested that a better model that can be used for body weight determination is the one without sex indicators/pooled sample. It has to be borne in mind that the limitation in applying foot-outline length for estimating body weight is that the regression equations provide only ranges and do not aid in arriving at the exact weight of an individual and hence has to be used with due caution during inclusion and exclusion of suspects [6].

Conclusion

It is an accepted fact that foot-impressions can provide more information than fingerprints during crime scene investigation. The study has successfully reported the relationship between living body weight and foot-outline length measurements. The investigation developed regression equations for body weight determination from foot-outline lengths of Bidayuhs of Malaysian Borneo by linear regression analysis. The equations can be well used in the crime scene investigation for the purpose of inclusion, exclusion of a suspect or for final identification. It would be incorrect to utilize these population standard equations to any other populations either in Malaysia or any other population in the world.

Acknowledgement

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