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Original Article

Estimation of Stature from Footprint Anthropometry Using Regression Analysis: A Study on the Bidayuh Population of East Malaysia

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Abstract

The human foot has been studied for a variety of reasons, i.e., for forensic as well as non-forensic purposes by anatomists, forensic scientists, anthropologists, physicians, podiatrists, and numerous other groups. 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. The present study, conducted during 2013-2014, aimed to derive population specific regression equations to estimate stature from the footprint anthropometry of indigenous adult Bidayuhs in the east of Malaysia. The study sample consisted of 480 bilateral footprints collected using a footprint kit from 240 Bidayuhs (120 males and 120 females), who consented to taking part in the study. Their ages ranged from 18 to 70 years. Stature was measured using a portable body meter device (SECA model 206. The data were analyzed using PASW Statistics version 20. In this investigation, better results were obtained in terms of correlation coefficient (R) between stature and various footprint measurements and regression analysis in estimating the stature. The (R) values showed a positive and statistically significant ($p < 0.001$) relationship between the two parameters. The correlation coefficients in the pooled sample (0.861–0.882) were comparatively higher than those of an individual male (0.762-0.795) and female (0.722-0.765). This study provided regression equations to estimate stature from footprints in the Bidayuh population. The result showed that the regression equations without sex indicators performed significantly better than models with gender indications. The regression equations derived for a pooled sample can be used to estimate stature, even when the sex of the footprint is unknown, as in real crime scenes.

Key words: Forensic Science, Forensic Anthropology, Stature Estimation, Footprint, Bidayu Population, East Malaysia

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تقدير طول القامة بواسطة بصمة القدم (الأنثروبومترية) باستخدام تحليل معامل الانحدار: دراسة على سكان البيدايوه (Bi-dayuh) في شرق ماليزيا

لقد دُرست قدم الإنسان بواسطة المختصين لمجموعة متنوعة من الأسباب منها ما هو جنائي بالإضافة إلى أسباب أخرى غير جنائية، مثل دراستها من قبل علماء التشريح، وعلماء الطب الشرعي، وعلماء الأنثروبولوجيا، والأطباء، وأطباء الأطفال، والعديد من المجموعات الأخرى من المختصين. جانب من جوانب الهوية البشرية التي تلقى اهتماما ضئيلا من علماء الانثروبولوجيا الشرعي هو دراسة أقدام

الإنسان، وآثار الأقدام التي تصنعها القدمين. أجريت هذه الدراسة خلال الفترة ما بين 2014-2013، وهدفت إلى استخلاص معادلات انحدار محددة للسكان، وذلك لتقدير قامة الشخص بواسطة بصمة القدم الخاصة به، وقد أُجريت الدراسة على سكان بيدايوه Bida-yuhs الأصليين البالغين في شرق ماليزيا. و تكونت عينة الدراسة من 480 زوج من الأقدام، والتي جُمعت باستخدام أطقم كشف بصمة القدم من 240 شخص من سكان بيدايوه، (120 ذكور، و 120 إناث)، كانوا قد أعطوا موافقة مسبقة على المشاركة في الدراسة. وتراوحت أعمار المشاركين ما بين 70-18 عاما. وقد تم قياس القامة باستخدام جهاز متر الجسم المحمول (نموذج SECA 206). وقد تم تحليل البيانات باستخدام برنامج الحزمة الإحصائية PASW النسخة 20. في هذا الدراسة، تم الحصول على أفضل النتائج فيما يتعلق بمعامل الارتباط (R) بين طول القامة وقياسات بصمة القدم المختلفة، وتقدير طول القامة باستخدام تحليل الانحدار. أظهرت قيم (R) وجود علاقة إيجابية ذات دلالة إحصائية ($P<0.001$) بين معيارَي الدراسة. وكانت معاملات الارتباط في العينة المجمعة (0.882-0.861) أعلى نسبيا من تلك التي كانت من الذكور فقط (0.795-0.762)، أو من الإناث فقط (0.765-0.722). قدمت هذه الدراسة معادلات الانحدار لتقدير قامة الشخص من آثار أقدامه في عدد من سكان بيدايوه، وأظهرت النتيجة أن معادلات الانحدار كانت تعطي نتائج أفضل بكثير من دون ادراج البيانات الخاصة بجنس المشارك. معادلات الانحدار المشتقة من العينة المجمعة يمكن استخدامها لتقدير القامة حتى عندما يكون جنس القدم المطبوعة غير معروف، كما هو الحال في سيناريوهات الجريمة الحقيقية.

Introduction

Every part of the body is different in its own way, not only within a particular body, but also from one body to another. 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 [1]. The human foot has been studied for a variety of reasons, for forensic as well as non-forensic purposes by anatomists, forensic scientists, anthropologists, physicians, podiatrists, and numerous other groups. An aspect of human identification that has received scant attention from forensic anthropologists is the study of human feet and the prints made by the feet [2]. An individual's footprint may represent his or her identity. Person identification using footprints is an emerging biometric technique [3]. 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 the crime scene [4]. Examination of barefoot impressions is important, especially in Asian countries like India, Malaysia, Thailand, and Indonesia where the majority of the rural population walk barefoot. This is largely due to socioeconomic and climatic conditions. Partial or complete footprints can be found on rain covered surfaces, newly waxed floors, freshly cemented surfaces, moistened surfaces, in dust, mud, sand, oil, paint and can be left in blood at murder scenes as well [5-7].

Researchers have conducted stature estimation studies by analyzing feet [8-11] and footprints [12-15] because of the existence of a strong correlation between stature and foot size [16]. Many of these studies were conducted using feet and footprints from mixed populations. The researchers have cautioned that people from different regions of a country bear different morphological features depending upon their geographical distribution and primary racial characteristics; therefore, a single formula cannot represent all parts of that country [7, 13-15]. For the stature estimation from foot/footprint parameters, the researchers concluded that toes-to-heel length measurements in a foot/footprint are more reliable and accurate than any other measurements like breadth at ball/heel, big toe breadth/length etc.[7, 14-18].

The present study aimed to estimate stature from all toes-to-heel length measurements in a footprint so that the findings of the study could be applicable to partial and complete footprints of Bidayuhs, an indigenous population group residing in Sarawak, a state in the east of Malaysia. The study used regression analysis since the reliability and prediction of stature estimation is more accurate and reliable with the regression analysis method [19].

Materials and Methods

Study area and Subjects

The study was conducted in Sarawak, a state in the east of Malaysia in the north west of the Island of Borneo (Fig.1). The subjects were from colleges, universities and the general public. The Bidayuhs are an indigenous ethnic group, native to the east of Malaysia. Most Bidayuhs reside in Sarawak, one of the two states (Sabah and Sarawak) in the east of Malaysia, and speak the Ban Bidayuh language. The Bidayuhs were traditionally longhouse dwellers who made

Figure 1- *Map of Malaysia showing the sampling area, Sarawak state, East Malaysia*
Source: *http://nice.easibook.com/Destinations/malaysia.aspx*

their living by farming or fishing.

Sample collection

Before starting the research, permission for sample collection was obtained from Sarawak Chief Minister vide No. JKM.P/DEV/16/005/12(44), for sample collection. Informed consent was obtained from each participant and the ethical standards of Universiti Sains Malaysia Human Research Ethic Committee were strictly followed. The present study aimed to estimate stature in a sample of 480 bilateral footprints collected from 240 (120 males, 120 females) adult Bidayuhs, between 18 and 70 years old. Subjects with any apparent foot-related disease, pregnancy, orthopedic deformity, physical impairment, injury, or any other anatomical disorders were excluded from the study. Just prior to participation in the study, subjects were advised to wash their feet with soap and water.

The stature of each subject was measured without any head and/or footwear using a portable body meter measuring device (SECA model 206, Germany) following the standard procedure [7, 15]. The body height measuring meter was suspended upright against the wall and measurements were taken to the nearest 0.5 cm. The subject was advised to stand still under the body meter with his/her heels together and weight evenly distributed between both feet. Stature was measured in cm as the vertical distance between the vertex

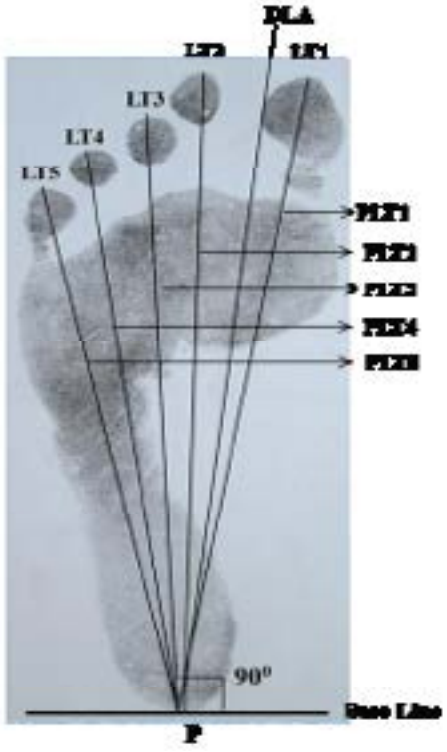

Figure 2 - *Landmarks and diagonal length measurements on left footprint PLT1-PLT5, measurements were taken from the mid-rear heel point, pternion (P) to the most anterior point of toes LT1-LT5 on left footprint. DLA (designated longitudinal axis)*

and the sole of the foot when the individual was standing still and barefoot with head held in the Frankfurt horizontal plane with eyes looking forward. The measurements were repeated until concordant values were achieved. Considering the diurnal variation in stature, the height of the subjects was measured approximately at a fixed time in the afternoon. The diurnal change in the height of a person has been reported and confirmed by researchers [20, 21].

A cleaned plain glass plate of 8 mm thickness was uniformly smeared with "Kores quick drying black duplicating ink 4746" with the help of a footprint roller. The subject was asked to step on the inked glass plate and put his/her left foot down with minimal pressure. Then the inked foot was placed on an A4 plain white paper kept aside on a solid uniform surface and thus the left footprint was transferred. The right footprint was also obtained following the same procedure. Before lifting the sole from the paper, anatomical land marks of the feet were marked on the papers close to the footprints which included mid-rear heel point (P) and the most anterior point of all toes (L1-L5 in left footprint and R1-R5 in right footprint), as shown in Figure 2.

The designated longitudinal axis (DLA) and the base lines (BL) were drawn on the footprints according to the procedure described by Krishan [7] and Nataraja Moorthy [15]. The DLA was drawn from the pternion (P) landmark at the mid-rear heel margin to the lateral side of the toe 1 pad margin, the axial line touching the rim of the pad margin as it passed forward beyond the length of foot. The base line (BL) was drawn at the rear edge of the foot and perpendicular to the DLA. The base line extended from the landmark P at the rear of the heel in both medial lateral directions while maintaining its perpendicular alignment with the DLA. Its axis could be determined as marked on the footprint using the protractor. With the 90° mark on the footprint placed on the DLA, and the midpoint of the protractor base at pternion, one automatically has the perpendicular BL by drawing a line through pternion along the base of the protractor. Then five diagonal footprint length measurements were taken from the mid-rear heel point (P) to the most anterior point of each left toe (LT1, LT2, LT3, LT4, and LT5). The left footprint length measurements were designated as PLT1, PLT2, PLT3, PLT4, and PLT5. The procedure was repeated for the right footprint and the right footprint length measurements were designated as PRT1, PRT2, PRT3, PRT4, and PRT5. The landmarks and diagonal length measurements on the right footprint are shown in Figure 2. All footprints and information relating to participants were coded with a sample ID for anonymity.

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 a one-sample t-test. Pearson's correlation coefficient (R) between various footprint lengths and stature was obtained. The linear regression analysis method was employed to derive regression equations for stature estimation from various footprint lengths since stature estimation from foot outline length is more accurate and reliable with regression analysis [19].

Results

Table 1 presents the descriptive statistics of stature in males, females and a pooled sample. All footprint lengths exhibited a statistically positive significant correlation with stature. In males, the stature ranged from 147.0 to 184.5 cm (mean 165.3 cm) and in females the stature ranged from 139.0 to 169.5 cm (mean 153.6 cm). According to our results, the mean stature was found to be significantly higher in males than females. Table-2 shows the descriptive statistics of various footprint lengths i.e. diagonal length between the

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

Variable	Male (n=120)					Female (n=120)					Pooled sample (n=240)				
	Min	Max	Range	Mean	SD	Min	Max	Range	Mean	SD	Min	Max	Range	Mean	SD
Stature	147.0	184.5	37.50	165.3	6.6	139.0	169.5	30.5	153.6	5.5	139.0	184.5	45.5	159.5	8.4

Table 2- ***Descriptive statistics of footprint length measurements (in cm) in males, females and a pooled sample of adult Bidayuhs in East Malaysia***

Variables	Male						Female						Pooled sample					
	n	Range	Min	Max	Mean	SD	n	Range	Min	Max	Mean	SD	n	Range	Min	Max	Mean	SD
PLT1	120	7.0	20.5	27.5	23.3	1.1	120	5.1	19.2	24.3	21.6	0.9	240	8.3	19.2	27.5	22.4	1.3
PLT2	120	7.5	20.0	27.5	23.5	1.2	120	5.2	19.3	24.5	21.6	1.0	240	8.2	19.3	27.5	22.6	1.4
PLT3	120	7.1	19.3	26.4	22.7	1.2	120	5.4	18.5	23.9	20.9	0.9	240	7.9	18.5	26.4	21.8	1.4
PLT4	120	7.0	18.2	25.2	21.5	1.1	120	5.0	17.5	22.5	19.7	0.9	240	7.7	17.5	25.2	20.6	1.3
PLT5	120	6.5	16.5	23.0	19.7	1.0	*118	4.5	16.0	20.5	18.2	0.8	*238	7.0	16.0	23.0	19.0	1.2
PLT1	120	5.7	20.5	26.2	23.3	1.1	120	4.4	19.5	23.9	21.6	0.9	240	6.7	19.5	26.2	22.4	1.3
PLT2	120	6.6	20.2	26.8	23.5	1.2	120	5.1	19.3	24.4	21.6	1.0	240	7.5	19.3	26.8	22.6	1.4
PLT3	120	6.8	19.3	26.1	22.7	1.1	120	5.4	18.5	23.9	20.9	0.9	240	7.6	18.5	26.1	21.8	1.4
PLT4	120	6.3	18.4	24.7	21.5	1.1	120	4.9	17.5	22.4	19.7	0.9	240	7.2	17.5	24.7	20.6	1.3
PLT5	120	5.9	16.8	22.7	19.7	1.0	120	4.1	16.1	20.2	18.1	0.8	240	6.6	16.1	22.7	18.9	1.2

Min - minimum; Max - maximum; PLT1 to PLT5- left footprint lengths from anterior part of toes LT1- T5 to mid-rear heel point P; PRT1 to PRT5- right footprint lengths from anterior part of toes RT1-RT5 to mid-real heel point P; SD- standard deviation; n: sample size. *n - Samples leaving missing toes in two female subjects during footprint development process.

rear heel end (P) and anterior points of each toe in both left (LT1– LT5) and right (RT1–RT5) footprints of males, females and the pooled sample. All the footprint length measurements in males were found to be larger than females both in left and right feet. The notable feature was that the mean second toe-heel footprint lengths in both left and right (PLT2, PRT2) were found to be the longest in males, whereas in females the mean first and second toe-heel footprint lengths in both right and left feet were found to be the same. The investigations revealed the nonexistence of significant bilateral asymmetry in both the genders (Table 3).

Tables 4-5 present the linear regression equations for the estimation of stature in adult males, females and the pooled sample through various footprint length measurements. The standard error of estimate (SEE) in the case of females (3.547-3.764) is comparatively lower than that of males (4.000-4.277) and the pooled sample (3.980-4.288). The tables also show the correlation coefficient (R) between the stature and various footprint lengths among males, females and the pooled sample, and the R value is statistically significant (<0.001). Correlation coefficient values were found to be more in the pooled sample (0.861-882) when compared with males (0.762-0.795) and females (0.722-0.765). The coefficient of determination (R^2), a statistical measure of how well the regression line approximates the real data points, was found to be statistically significant for stature estimation. Hence, statistically significant correlation coefficients exist between stature and all footprint length measurements in Bidayuhs of East Malaysia.

The result of this pilot footprint study in the east of Malaysia (the Island of Borneo) provided regression formulae

Table 3 - ***One-sample t-test of bilateral differences (left–right) in footprint length measurements among males and females in adult Bidayuhs of East Malaysia***

Variables	Male (n = 120)				Female (n = 120)			
	Mean difference (left-right)	SD	t-Value	P-Value	Mean difference (left-right)	SD	t-Value	P-Value
T-1 (PLT1 – PRT1)	0.0508	0.41	1.35	0.178	-0.0267	0.41	-0.72	0.475
T-2 (PLT2 – PRT2)	0.0217	0.36	0.65	0.515	0.0075	0.37	0.22	0.825
T-3 (PLT3 – PRT3)	0.0325	0.34	1.05	0.295	0.0367	0.36	1.11	0.267
T-4 (PLT4 – PRT4)	0.0033	0.32	0.11	0.909	0.0392	0.35	1.23	0.221
T-5 (PLT5 – PRT5)	0.0275	0.32	0.95	0.342	0.0559	0.35	1.76	0.081

Table 4- ***Linear regression equations for stature estimation (in cm) from different footprint length measurements on left and right sides among adult male and female Bidayuhs in East Malaysia***

		Male (n= 120)			
Variables	**Regression Equations**	**SEE**	**R**	**R^2**	**Adj,R^2**
PLT1	56.476 + 4.668PLT1	4.198	0.772	0.595	0.592
PLT2	66.003 + 4.221PLT2	4.249	0.765	0.586	0.582
PLT3	67.408 + 4.306PLT3	4.277	0.762	0.580	0.576
PLT4	63.911 + 4.724PLT4	4.073	0.787	0.619	0.616
PLT5	61.999 + 5.236PLT5	4.12	0.780	0.609	0.605
PRT1	49.669 + 4.971PRT1	4.000	0.795	0.633	0.630
PRT2	61.622 + 4.412PRT2	4.168	0.775	0.601	0.598
PRT3	61.304 + 4.581PRT3	4.132	0.780	0.608	0.605
PRT4	62.423 + 4.794PRT4	4.121	0.781	0.610	0.607
PRT5	57.481 + 5.473PRT5	4.027	0.792	0.62	0.625

Table 4- ***countinued***

Variables	Regression Equations	Female (n = 120) SEE	R	R^2	Adj,R^2
PLT1	60.549 + 4.319PLT1	3.736	0.735	0.540	0.537
PLT2	64.225 + 4.130PLT2	3.764	0.730	0.534	0.530
PLT3	66.018 + 4.193PLT3	3.811	0.722	0.522	0.518
PLT4	61.323 + 4.675PLT4	3.676	0.745	0.555	0.551
PLT5	64.198 + 4.916PLT5	3.703	0.729	0.532	0.528
PRT1	49.817 + 4.811PRT1	3.547	0.765	0.586	0.582
PRT2	61.026 + 4.280PRT2	3.696	0.742	0.550	0.547
PRT3	64.967 + 4.250PRT3	3.795	0.725	0.526	0.522
PRT4	56.569 + 4.925PRT4	3.553	0.765	0.585	0.581
PRT5	58.468 + 5.253PRT5	3.711	0.739	0.547	0.543

PLT1 to PLT5- left lengths from anterior part of toes LT1- T5 to mid-rear heel point P; PRT1 to PRT5- right lengths from anterior part of toes RT1-RT5 to mid-rear heel point P; SEE- standard error of estimate; R^2 -coefficient of determination. Adj, R^2-Adjusted R^2. p-value< 0.001 significant

Table 5- ***Linear regression equations for stature estimation (in cm) from different footprint measurements on left and right sides among pooled samples in adult Bidayuhs in East Malaysia (n=240).***

Variables	Regression Equations	SEE	R	R^2	Adj,R^2
PLT1	37.641 + 5.431PLT1	4.202	0.867	0.751	0.750
PLT2	45.237 +5.058PLT2	4.251	0.863	0.746	0.745
PLT3	46.865 + 5.162PLT3	4.288	0.861	0.741	0.740
PLT4	43.950 + 5.606PLT4	4.096	0.874	0.764	0.763
PLT5	42.495 + 6.170PLT5	4.166	0.870	0.757	0.756
PRT1	29.793 + 5.784PRT1	3.980	0.882	0.777	0.776
PRT2	42.221 + 5.195PRT2	4.144	0.871	0.758	0.757
PRT3	43.980 + 5.301PRT3	4.149	0.870	0.758	0.757
PRT4	42.844 + 5.666PRT4	4.009	0.880	0.774	0.773
PRT5	40.588 + 6.287PRT5	4.026	0.879	0.772	0.771

PLT1 to PLT5- left lengths from anterior part of toes LT1- T5 to mid-rear heel point P; PRT1 to PRT5- right lengths from anterior part of toes RT1-RT5 to mid-rear heel point P; SEE- standard error of estimate; R^2-coefficient of determination. Adj, R^2-Adjusted R^2 p-value< 0.001 significant

for the stature estimation from various bilateral footprint length measurements of indigenous Bidayuh when complete or even partial human footprints are available.

Discussion

Malaysia is a multi-racial, multi-ethnic and multi-cultural country. It consists of two similarly sized regions: Peninsular Malaysia (West Malaysia) and Malaysian Borneo (East Malaysia), separated by the South China sea. East Malaysia is less populated with a larger forest land mass. The indigenous ethnic groups of Sarawak include Iban, Bidayuh, Melanau, Orang Ulu and so on. Bidayuh is the third largest of Sarawak's ethnic groups. The Bidayuh speak the Bau Bidayuh language that is distinct from other Bornean languages. Farming is the main occupation of the Bidayuh followed by fishing. The age range of the subjects in this research is appropriate since stature at 18 years is accepted as adult [22, 23]. Some researchers indicated that the foot in a male grows to its adult size by 16 years [24, 25]. Hence the minimum age of participants in this study was fixed at 18 years old. The present investigation shows that statistically significant male–female differences exist in stature among the Bidayuh population. All the footprint length measurements in males are found to be larger than females both in left and right feet. This may be attributed to the general male-female differences and natural size in both sexes [26]. The result shows that the mean second toe–heel footprint lengths in both left and right (PLT2, PRT2) are found to be longest in males, whereas in females the mean first and second toe-heel footprint length in both right and left feet are found to be the same. The investigation reveals that no significant bilateral asymmetry is observed in both genders. This finding is concordant with Philip [1] and Robbins [27] who did not find significant bilateral asymmetry while working on US and south Indian populations. Some researchers have shown the existence of left sided asymmetry in their study populations [7, 14, 15].

For the stature estimation from foot/footprint parameters, the researchers concluded that toes to heel length measurements are more reliable and accurate than any other measurements like breadth at ball/heel and big toe breadth/length [7, 10, 17, 18, 28, 30]. The correlation coefficient (R) between the stature and various footprint lengths among males, females and a pooled sample is statistically significant (<0.001). It is interesting to note that the correlation coefficient (R) between stature and footprint 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. Hence statistically significant correlation coefficients exist between stature and all footprint length measurements in Bidayuhs of east Malaysia. This finding is consistent with earlier studies of Malay [4], Malaysian Chinese [14], and Indian populations [26]. Considering real crime scenarios where the sex of the perpetrator is unknown, it is suggested that a better regression equation for stature estimation is one without sex indicators. The standard error of estimate (SEE) is a measure of the accuracy of predictions. Researchers indicated that regression equations can be derived for stature estimation using foot and hand measurements with great accuracy and a small SEE i.e. about 2-6 cm [19]. Thus, the SEE calculated from footprint lengths in males, females and a pooled sample is smaller, and the stature can be estimated with better accuracy. Another important observation made during the development process of footprints is that the 5th toe of some female subjects was found missing i.e. did not contact with the ground and appeared as missing toes in footprints. The non-contact of the toes is an important valuable clue in crime scene investigation and perpetrator identification. Similar findings were observed and recorded in previous population studies [4, 7, 14, 26].

Conclusion

The present study concludes that footprint length measurements have a strong relationship to stature. This investigation revealed that the footprints of Bidayuhs are different from other populations in Malaysia and outside Malaysia. The result of this investigation provided regression equations for stature estimation from footprints in east Malaysian Bidayuhs. The regression equations derived for a pooled sample can be used to estimate stature when the sex of the footprint remains unknown, as in real crime scenarios. It is improper to utilize these population specific equations to estimate stature from footprints for any other populations either in Malaysia or elsewhere in the world.

Conflict of interest

The authors have no conflict of interest to declare.

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