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Original Research Article

A study on the correlation between foot length and height of an individual and to derive regression formulae to estimate the height from foot length of an individual

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ABSTRACT

Background: To find out the correlation between foot length and height of an individual and to derive regression formulae to estimate the height from foot length of an individual.
Methods: This was a prospective comparative study. A total of 640 bilateral footprints collected from 320 adult volunteers of ages ranging between 25 and 50 years old. Foot Prints, foot length, Stature and height were recorded as per standard methods.
Results: The mean age (year) was 38.43±7.63, Stature (cm) mean of male and female was 162.75±6.03, Left Foot Breadth (cm) was 8.90±0.92, Right Foot Breadth (cm) was 8.88±0.82, Left Foot length (cm) was 23.70±2.41 and Right Foot length (cm) was 23.68±2.41. The stature-mean ranges from 20.21±1.25 to 23.70±2.1 cm. First toe-heel footprint length measurement (PLT1, PRT1) was found to be the longest in both right and left sides (23.70±2.1; 23.68±1.32) and Fifth toe-heel footprint length measurement (PLT5, PRT5) was found to be the shortest in both right and left sides (20.60±1.3; 20.21±1.25). For males, the highest correlation coefficient was noted for PLT5 (0.524) and the lowest correlation coefficient noted was for PLT1 (0.581) and for females the highest correlation coefficient was noted for PLT5 (0.585) and the lowest correlation coefficient noted was for PLT1 (0.611). Hence, statistically significant correlation coefficients exist between stature and all footprint length measurements. With regard to the coefficient of determination (R2), the predictive accuracy is found to be statistically significant for stature estimation.
Conclusions: Foot length in males and females shows highest correlation with stature and minimum standard error in the estimation of stature. So, the foot length provided the highest reliability and accuracy in estimating stature. The left foot length gives better prediction of stature than the right foot. The prediction of height is better in case of females in comparison to males.

Keywords: Foot length, Footprints, Height, Regression equation

INTRODUCTION

Every part of the human body is unique in itself. It is amazing to discover that every part of the body is different in its own way from a similar part in another body. There is also a relationship between each part of the body and the whole body. Estimation from dismembered body parts can be done based on the ratio of the body part concerned, in relation to the entire body.[1] The relationship between humerus, radius, ulna, femur, tibia, fibula and clavicle with the stature have been topics of research interest for decades.[1-5] Morphology of human feet is greatly influenced by the combined effects of heredity and living style of man that determines the size

and shape of the feet or footprints and thereby makes them unique data to establish human identity.[1,2] Clinicians, anthropologists, anatomists and forensic scientists have studied the various aspects of foot, over a long period of time.[2] Foot or shoe prints, if present at the scene of crime, may provide clue regarding the stature and sex of the person, which may help in establishing the partial identity of the suspect. Moreover, in an aircraft accident it is the feet, which are recovered more intact than other parts of the body, as they are often shoe clad. Hence, feet can be excellent clue regarding personal identity.[6]

Personal identification means determination of individuality of a person. It may be complete (absolute) or incomplete (partial). Complete identification means absolute fixation of individuality of a person. Partial identification implies ascertainment of only some facts about the identity of the person while others still remain unknown. Age, sex and stature are the primary characteristics of identification.[1]

Personal identification from foot and its segments becomes more important in cases of mass disasters, where there is always likelihood of recovering feet (often enclosed) in shoes separated from the body. Assessing the height of an individual, from measurements of different parts, has always been of immense interest to the anatomists, anthropologists and forensic medicine experts.[7]

Anthropology is the science of which deals with comparative study of Human, as a physical and culture being.[1] Anthropometry is one of the forensic investigation process and help in establishing identification of the individual. Anthropometry is being widely used in Forensic investigations for identification of an individual which is an important step in crime investigation. Various parameters used for identification are determination of age, sex, race etc.[8] When a complete dead body is found, stature determination is rather an easy task but in case where only some parts of the body are available, the determination of stature of an individual from skeleton material or from the mutilated or from amputed limbs or from parts of limbs, has obvious significant in the personal identification in the events of murders, accidents or natural disasters as required in forensic identification analysis.

The most of the workers on stature estimation have used the length of bones such as femur, tibia, humerus, radius etc.[1] Anthropology is the science of which deals with comparative study of Human, as a physical and culture being.[8]

Anthropometry is one of the forensic investigation process and help in establishing identification of the individual. Anthropometry is being widely used in Forensic investigations for identification of an individual which is an important step in crime investigation. Various parameters used for identification are determination of age, sex, race etc.[8]

The aim of the present study was to find out the correlation between foot length and height of an individual and to derive regression formulae to estimate the height from foot length of an individual.

METHODS

This prospective comparative study was carried out on patients of Department of Forensic Medicine & Toxicology, Hind Institrute of Forensic Sciences, Safedabad, Barabanki, U.P. on population around Barabanki, Uttar Pradesh. A total of 640 bilateral footprints collected from 320 adult volunteers of ages ranging between 25 and 50 years old between from July 2015 to December 2016. There were 160 Males and 160 Females were taken in study.

The subjects were confirmed to be descendants from three generations of Uttar Pradesh to ensure no genetic variation within races that can disrupt the results as stature can be affected by not only environment, but also genetic makeup. Those with any apparent disease, orthopedic deformity, injury or disorder were excluded from the study.

Method of collection of data

This study aimed to estimate stature in a sample of 640 bilateral footprints collected from 320 adult volunteers of ages ranging between 25 and 50 years old. There were 160 Males and 160 Females were taken in study. The research procedure followed was in accordance with the approved ethical standards. Before the sample collection, information such as subjects name, age, and place of origin was obtained and recorded. General physical examination was conducted to know the health status and rule out any deformities in the subjects.

Recording of foot prints

Just prior to research participation, the subjects were advised to wash their feet with soap and water. 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 with the left foot on an inked glass plate with minimal pressure. Then the inked foot was placed on an A4 plain white paper kept aside on a uniform surface and thus the left footprint was transferred. Before lifting the sole from the paper, anatomical landmarks of the feet were marked on the papers close to the footprints which are mid-rear heel point and most anterior point of all toes. Following Robbins[9] and Krishan[10], the designated longitudinal axis (DLA) and baseline (BL) were drawn on the footprints. The DLA is from the pternion (P) landmark at the mid-rear heel margin to the lateral side of the toe 1 pad margin, the axial line touches the rim of the

pad margin as it passes forward beyond the length of foot. Base line (BL) is drawn at the rear edge of the foot and perpendicular to the DLA.

The base line extends 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 can be determined as marked on the footprint using the pro-tractor. With the 90L 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 the 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.

Recording of foot length

The subject is made to place their left foot on Osteometric board with the fixed plate of the board touching the most posteriorly projecting point of the heel (pternion), the movable plate will be adjusted to measure the most anteriorly projected point (acropodian) of the first or second toe, whichever is longer, when the foot is stretched will be considered, and it will be measured in centimeters approximated to the nearest millimetre. Same thing will be repeated for the right foot.

Stature and height measurement

Stature of each subject was measured according to the standard procedures recommended by Weiner and Lourie[i] as follows: The subject should stand on a horizontal platform with his heels together, stretching upward to the fullest extent, aided by gentle traction by the measurer on the mastoid processes. The subject's back should be as straight as possible, which may be achieved by rounding or relaxing the shoulders and manipulating the posture. The marked Frankfurt plane must be horizontal. Either the horizontal arm of an anthropometer, or a counter weighted board, is brought down on to the subject's head. If an anthropometer is used, one measurer should hold the instrument vertical with the horizontal arm in contact with the subject's head, while another applies the gentle traction. The subject's heels must be watched to make sure they do not leave the ground. Each participant's stature was measured four times with the support of Forensic Assistant Directors. The first time the participant was invited to get into the stadiometer, the stature was noted by the main author. The participant was then requested to get down from the stadiometer. The subject was asked again to get into the stadiometer for recording the stature. Thus, the procedure was repeated four times and finally recorded the concordant stature value in centimeters.

Statistical analysis

Data was analyzed using Statistical Package for Social Sciences, version 20 (SPSS Inc., Chicago, IL). Bilateral asymmetry (difference between the measurements on left and right side within an individual) was calculated for each of the measurement taken on footprint and foot outline. The significance of bilateral asymmetry was tested by applying a paired t-test. Karl Pearson's correlation coefficients between various length/breadth measurements of the footprint and foot outline with stature were obtained separately. The level $p<0.05$ was considered as the cutoff value or significance.

RESULTS

The mean age (year) was 38.43±7.63, Stature (cm) mean of male and female was 162.75±6.03, Left Foot Breadth (cm) was 8.90±0.92, Right Foot Breadth (cm) was 8.88±0.82, Left Foot length (cm) was 23.70±2.41 and Right Foot length (cm) was 23.68±2.41 (Table 1).

Table 1: Overall demographic data (n=320).

	Mean±SD
Age (year)	38.43±7.63
Gender (Male : Female)	1:1
Stature (cm)	162.75±6.03
Left Foot Breadth (cm)	8.90±0.92
Right Foot Breadth(cm)	8.88±0.82
Left Foot length(cm)	23.70±2.41
Right Foot length(cm)	23.68±2.41

The stature-mean ranges from 20.21±1.25 to 23.70±2.1 cm. First toe-heel footprint length measurement (PLT1, PRT1) was found to be the longest in both right and left sides (23.70±2.1; 23.68±1.32) and Fifth toe-heel footprint length measurement (PLT5, PRT5) was found to be the shortest in both right and left sides (20.60±1.3; 20.21±1.25) (Table 2).

Table 2: Overall foot print in studied subjects (n=320).

Foot print	Mean±SD
PLT1(cm)	23.70±2.1
PLT2(cm)	23.21±1.09
PLT3(cm)	22.58±1.2
PLT4(cm)	21.1±1.13
PLT5(cm)	20.60±1.3
PRT1(cm)	23.68±1.32
PRT2(cm)	23.56±1.09
PRT3(cm)	22.51±1.2
PRT4(cm)	21.21±1.35
PRT5(cm)	20.21±1.25

For males, the highest correlation coefficient was noted for PLT5 (0.524) and the lowest correlation coefficient noted was for PLT1 (0.581) and for females the highest correlation coefficient was noted for PLT5 (0.585) and the lowest correlation coefficient noted was for PLT1 (0.611). Hence, statistically significant correlation coefficients exist between stature and all footprint length measurements. With regard to the coefficient of determination (R2), the predictive accuracy is found to be statistically significant for stature estimation (Table 3).

Table 3: Regression between stature and left and right footprints of male and female subjects.

Foot print	Male (n=160)			Female (n=160)		
	Regression equation	SE		Regression equation	SE	
PLT1	115.82+ 1.69	3.198	R = 0.581 R^2 = 0.311	114.62 + 18.51	2.898	R = 0.611 R^2 =0.288
PLT2	115.13 + 1.37	4.199	R = 0.580 R^2 =0.315	114.21 + 15.73	3.90	R = 0.605 R^2 =0.298
PLT3	116.56 + 1.70	3.198	R = 0.608 R^2 =0.298	115.82 + 21.28	3.89	R = 0.604 R^2 =0.302
PLT4	116.32 + 2.77	4.198	R = 0.603 R^2 =0.325	115.10 + 31.005	3.89	R = 0.601 R^2 =0.305
PLT5	117.63 + 0.018	4.199	R = 0.524 R^2 =0.350	116.32 + 22.16	3.89	R = 0.585 R^2 =0.310
PRT1	115.92 + 1.52	3.199	R = 0.687 R^2 =0.288	114.82 + 15.53	2.90	R = 0.605 R^2 =0.290
PRT2	115.56 + 0.833	3.199	R =0.614 R^2 =0.310	114.15 + 15.23	2.90	R = 0.595 R^2 =0.298
PRT3	116.63 + 0.350	4.199	R = 0.569 R^2 =0.315	115.63 + 18.34	3.89	R = 0.578 R^2 =0.285
PRT4	116.23 + 0.022	4.199	R = 0.514 R^2 =0.325	115.20 + 21.60	3.89	R = 0.584 R^2 =0.299
PRT5	117.33 + 0.025	4.199	R = 0.509 R^2 =0.335	116.40 + 25.03	3.89	R = 0.567 R^2 =0.305
Foot Breadth left	164.58 + 1.500	6.199	R = -0.025 R^2 =0.198	168.26 + 36.95	5.89	R = 0.005 R^2 =0.165
Foot Breadth right	164.29 + 0.740	6.199	R = -0.029 R^2 =0.185	168.09 + 34.39	5.89	R = 0.008 R^2 =0.160

DISCUSSION

To estimate stature in forensic sciences is quite important during the identity defining stage.[11] For better accuracy, stature estimation may be attempted only after the attainment of maturity.[12] Accurate estimation from known parameters is a fundamental aspect of science and is evident as emerging approach in the area of footprints and stature estimation; because foot length displays a biological correlation with stature that suggests the latter might be estimated from foot or shoe prints. [13,14]

In the present study mean age (year) was 38.43±7.63 ranging from 25-50 years. It indicates that one can successfully estimate stature from different parts of the footprints with a standard error of estimate using regression analysis. The reason for taking the adult sample ranging from 25 to 50 years may be due to the fact that generally stature at more than 18 years is accepted as adult although there are small increments in stature after this.[15] Some researchers indicated that the foot in a male grows to its adult size by 16 years of age.[16] Stature estimates are estimates, they are not exact and should always be expressed with range of error.

The investigation reveals that the left footprint length measurements are found to be larger than the right footprint length measurements. This result was similar to study as reported by Moorthy et al where left footprint length measurements are larger than the right footprint length measurements.[17]

The present study successfully derived linear regression equations for stature estimation from 10 diagonal axis footprint length measurements and the regression equations present lower SEE. The SEE values are found to be in between 2.89 and 4.19 cm. The foot length is the best parameter for estimating stature since stature can be estimated from an unknown person with great accuracy and a small SEE, i.e. about 2-6 cm as reported by Krishan et al.[12] The first left toe (LT-1) shows a lower SEE

(2.898) while the first left toe (LT2) (4.199) shows a higher SEE. Thus, the stature can very well be estimated from footprint lengths with low SEE. And in Table 05 shows correlation between stature and left and right footprints of male and female's subjects. All the values of stature and footprint for males and females were showing significant different relation ($p<0.001$) between each other except foot breadth left and foot breadth right were not significant ($p>0.001$). The highest correlations with stature for males were shown to be the T-1 length ($r = 0.687$, $p < 0.001$) for right and T-3 length ($r = 0.608$, $p < 0.001$) for left. For females the highest correlation with stature were shown to be the T-1 length for both feet ($r = 0.605$, $p < 0.001$) for right and ($r = 0.611$, $p < 0.001$) for left.

CONCLUSION

Foot length in males and females shows highest correlation with stature and minimum standard error in the estimation of stature. So, the foot length provided the highest reliability and accuracy in estimating stature. The left foot length gives better prediction of stature than the right foot. The prediction of height is better in case of females in comparison to males.

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