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Original Research Article

Estimation of Height from Foot Dimensions

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ABSTRACT:

Introduction: Height determination by measuring various body parts is of value in medicolegal investigations as well as in anthropology. The current study was conducted to analyze interrelation between foot dimensions and stature, and to predict stature from foot dimensions. **Methods**: The study was done in medical students where stature, foot length, and foot breadth were quantified using standard instruments. We calculated correlations between variables with correlation test and predicted stature from foot length and foot breadth using linear regression. **Results**: The correlation between foot length and stature, and foot breadth and stature were statistically significant in both gender ($p < 0.05$). Greater correlation coefficient between foot length and stature than that for foot breadth and stature indicated stronger correlation between foot length and stature. Separate formulae were drawn for calculation of stature from foot breadth and foot length by regression analysis. **Conclusion**: Both foot breadth and foot length were correlated with stature. Foot length was found to be a better predictor of stature.

Keywords: anthropometry • foot • height • linear regression • stature

INTRODUCTION:

Ascertainment of an identity is crucial in medicolegal cases. Height is a key parameter of an individual person.[1] Resolving the personal identity from decomposed and dismembered body parts caused by natural and anthropogenic disasters is of prime prerequisite nowadays.[2] Retrieval of complete skeleton at the scene of crime is not possible many times and is a well-known fact for forensic experts. So, forensic scientists are left with no other option than to rely on calculative techniques to determine stature. This would be helpful even if body parts like hands or feet are obtainable at the scene of crime.[3]

Many researchers have made an effort to estimate height from measurement of a variety of long bones with a certain extent of success and have acquired their own equation for calculating height from long bones. However, not much endeavors to measure foot for this purpose have been made. Prediction of height was found to be equally consistent from foot measurements as well as from long bones.[4]

Epiphyseal fusion of bones in foot occurs earlier than the long bones, so height could be more precisely predicted from foot measurements as compared to that from long bones.[4] This study was conducted to find association between foot dimensions and stature, and to predict height from foot dimensions.

METHODS:

Present observational, cross-sectional, and analytical study was conducted in the Department of Forensic Medicine, Lumbini Medical College Teaching Hospital (LMCTH), Palpa, Nepal from 1st September 2017 to 30th November 2017. The study was approved by Institutional Review Committee (IRC) of the institute. Informed consent was taken from each participant.

Nepalese undergraduate medical students

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from all batches currently studying in the institute were included in the study. These students came from various regions of Nepal. We excluded the subjects with any defects of vertebral column or upper and lower limbs. Similarly, we excluded those who had chronic illnesses like anemia, heart disease, diarrhea, tuberculosis, or connective tissue disorders that would impair the growth of the individual. Students who did not consent to the study or were not available throughout the study period were also excluded. Female attendant was procured while taking measurements in female subjects.

Measurement of Height:

Height was calculated in upright position following the method outlined by Cameron et al.[5] Each subject was asked to stand on the board of a stadiometer taking off shoes and putting both feet in approximation, trunk supported by the vertical board and head oriented in Frankfort Horizontal plane. Measurement was done by sliding the horizontal bar to touch the vertex and the height was noted in centimeters (Figure 1).

Measurement of foot dimensions:

A straight distance between the most prominent part of the heel backwards (pterion) and the most distal part of the longest toe (acropodium) was taken as the foot length. The subject was instructed to stand on the ground slightly bending his/her right leg and drawing it backward to rest on left foot only, which was to be measured. Left foot was selected for measurements according to the recommendation of the international agreement for paired measurements.[6] Placement of the caliper was horizontal along the medial border of the foot. The immovable external jaw of the caliper was applied to the pterion and movable external jaw was slid to touch the acropodium. Foot breadth was measured from base of first metatarsal to the base of fifth metatarsal using sliding caliper on standing position.

Fig 1. Measurement of stature with a stadiometer

The same observer carried out all the measurements with the same instrument to minimize instrument and inter-observer errors. To get rid of disparity due to diurnal variation, we measured three times between 2:00 pm to 5:00 pm and calculated their mean for data analysis. Data were entered and analyzed using the Statistical Package for the Social Sciences (SPSS) version 16. Comparison of mean in two groups was done with *Independent t-test*. Linear relationship between two continuous variables was analyzed with *Pearson correlation test*. Prediction of stature from foot length or width was made with *linear regression*. *P* value less than 0.05 was considered as statistically significant.

RESULTS:

There were a total of 260 participants in this study (146 males and 114 females). Mean age of males was 21.36 years (*SD* = 1.17) and that of females was 20.56 years (*SD* = 1.47). Mean height in males was 167.82 cm (*SD* = 6.58) and that in females was 156.71 cm (*SD* = 5.31). This gender wise difference in mean height was statistically significant (t = -14.659, df = 258, $p < 0.001$). Thus, a male student was likely to be taller than a female student.

Mean foot length in males was 23.56 cm (*SD* = 1.18) and that in females was 21.78 cm (*SD* = 0.94). This gender wise difference in mean foot length was statistically significant (t = -13.17, df = 258, $p < 0.001$). Thus, the foot length of a male student was likely to be greater than that of a female student. Similarly, mean foot breadth in males was 7.96 cm (*SD* = 0.39) and that in females was 7.6 cm (*SD* = 0.35). This gender wise difference in mean

foot breadth was statistically significant (t = -7.48, df = 258, $p < 0.001$). Thus, the foot breadth of a male student was likely to be greater than that of a female student.

Relationship between stature and foot dimensions was studied with *Pearson correlation test*. There was a significant positive correlation between them for both gender (Table 1). Visual representation of those relationship is presented in Figure 2.

Equations derived from regression analysis for estimation of stature from foot length and foot breadth are presented separately in Table 2 and Table 3 respectively. Coefficient of determination (R^2) for prediction of height from foot length was much higher than that from foot breadth. Thus, foot length would be a better predictor of stature.

Table 1: Correlations between foot dimensions and stature

	Height			
	Male		Female	
	*r**	*p*	*r**	*p*
Foot length	0.78	< 0.001	0.57	< 0.001
Foot breadth	0.26	0.001	0.22	0.02

** correlation coefficient*

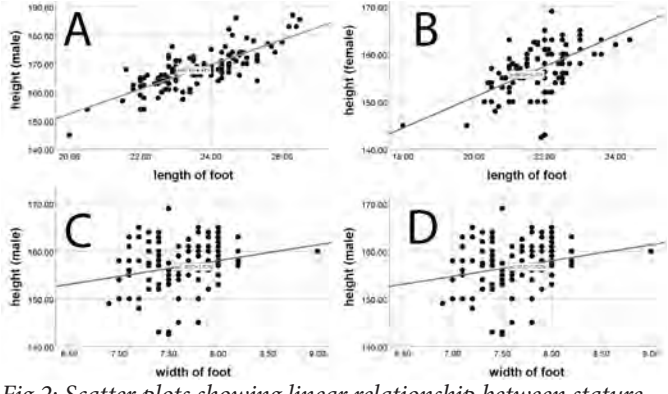

Fig 2: Scatter plots showing linear relationship between stature and foot dimensions

DISCUSSION:

In the present study, attempts have been made to analyze relationships between height and foot dimensions and to predict the height of a person from his/her foot dimensions. We found a positive correlation between stature and foot length as well as stature and foot breadth.

There was a positive statistically significant correlation between stature and foot dimensions. Moreover, the correlation was stronger between height and foot length than that between height and foot breadth. Again, the parameters were different for genders. These findings suggests that foot dimensions can be predictors of height of an individual and foot length would more preciously predict stature as compared to foot breadth. These findings can be of importance in calculation of height in medicolegal cases when whole body is not available. We attempted to formulate a regression equation to predict height from foot dimensions which we will discuss in a while. These finding are supported by various studies; Kanchan T et al. among Gujjars, a North Indian endogamous group,[7] Parekh U et al. among 200 medical students in Ahmedabad,[1] Rameswarapu SB et al. on 104 individuals from Secunderabad,[8] and Patel SM et al. among Gujarati population.[4] Study conducted on Nepalese population by Mansur DI et al.[2] also showed a strong positive correlation between height and foot length (r = 0.703, $p < 0.001$). Stronger correlation between foot length and stature than that between foot breadth and stature was also shown by Dhaneria V et al.[9] in population of Rajasthan,

Table 2: Regression equations for estimation of stature from foot length

	Male	Female	Pooled
Stature =	65.92 + 4.325 x Foot length (cm) [R^2 = 0.6, $p < 0.001$]	86.24 + 3.235 x Foot length (cm) [R^2 = 0.33, $p < 0.001$]	51.65 + 4.886 x Foot length (cm)

R^2 - Coefficient of determination

Table 3: Regression equations for estimation of stature from foot breadth

	Male	Female	Pooled
Stature =	133.048 + 4.37 x Foot breadth (cm) [R^2 = 0.068, p = 0.001]	131.488 + 3.316 x Foot Breadth (cm) [R^2 = .05, p = 0.017]	93.79 + 8.86 x Foot breadth (cm)

R^2 - Coefficient of determination

India. Foot dimensions, preferably foot length, may be used to predict stature in time of need. The values of correlation coefficients are different for the different gender and population. So, further studies are necessary to conclude a gender specific association between foot dimension and height in various geographical locations.

The present study revealed that the mean value of stature was significantly greater for males than that for females. Similar results were obtained for the mean values of foot length while comparing both genders. This may be due to the earlier fusion of bones in females allowing more time for bone growth in males. Another factor may be taller and narrower pelvis in males that makes them taller than females. So, further analysis with more stature data for multiple human societies are required as genetic, endocrine, nutritional factors, and ethnicity could have major impact on stature. These findings are in line to the study conducted by Ozdan H et al. in Turkish population,[10] Sanil SG et al.,[11] and Krishan K et al.[12] in North Indian population. Our study showed that males are likely to be taller as compared to females.

We developed regression equations for stature estimation from foot length and foot breadth. It is helpful in forecasting the height from the foot length and foot breadth when only these body parts are available. The coefficient of determination were low for foot breadth (0.017 and 0.068 respectively for female and male) but were high for foot length (0.33 for female and 0.6 for male) indicating that the foot length was a better predictor for stature. Inclusion of other variables would increase the value of coefficient of determination for better prediction. This knowledge gap would be appropriate for further research works. Genetics and environment are the major factors for variation in stature, so studies from different geographical locations are required in this context to derive simple and multiple regression equations. Tharmar N et al.[13] measured foot length from foot impression and derived a regression equation for stature estimation. Singh JP et al.[14], Parekh U et al.[1], and Rameswarapu SB et al.[8] have also derived regression equations for stature estimation from foot dimension. Mansur DI et al.[2] derived regression equation for stature estimation from foot length of Nepalese population. Our study has established a functional relationship between height and foot dimension with the help of which we can easily calculate the values of stature from known values of foot dimension.

Inclusion of medical students only to generalize the results in the Nepali population is a weakness of our study. These students were of age between 17 to 23 years and the age of epiphyseal fusion of tarsals and metatarsals are not established in Nepalese population. However, we hope that this age range covers the age at which fusion of foot bones occurs in population.[4] A wider age group of participants might have produced a different and a more accurate prediction of stature from foot dimensions. Similarly, we measured only the left foot as per the recommendation for paired measurements. A broader picture could have been obtained if both feet were measured and difference in the predicted stature from each was compared.

CONCLUSION:

The present study established a definite relationship between stature and foot length, and stature and foot breadth. Prediction of stature with foot length can be done with more precision than with the foot breadth.

ADDITIONAL INFO:

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Conflict of interest:
The authors declare that no competing interest exists.

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