Research Paper: Comparing Log-based and Exponent-based Functions to Predict Human Height by Foot Length

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ABSTRACT

Background: Human height estimation is critical in medicolegal cases. This anthropometric measurement not only reveals racial differences but also aids police investigation to narrow down. Foot size varies in different races and ethnic groups, because of genetic influence on development height. The present study aimed to explore the relationship between foot size and the height of a person in a particular context. The current research also compared log-based function and exponent-based function to explore which best fits the relation between age, foot size, and height.

Methods: This cross-sectional study included foot measurements from 240 participants of 6 different age groups in the age range of 2-21 years. Foot length and height were recorded as per standard methods after obtaining ethical approval from the Institutional Review Board of COMSATs University Islamabad Pakistan and gaining consent from the study participants. Correlation and regression analyses were performed using SPSS V 23. In this study, two mathematical functions of log-based and exponent-based were compared to more accurately predict the behavior of two variables. The appropriateness of these candidate functions was evaluated using statistical parameters, including the Sum of Squared Errors (SSE), R^2, adjusted R^2, and Root Mean Square Error (RMSE).

Results: The mean height of male participants of the age group of 3-5 years was higher than that of the female participants. Among 6-10-year-olds and 11-15-year-olds, female participants presented a greater height than males. In the age groups of 16-20 and ≥21 years, males were taller than females. The average foot size of males and females of all age groups was 22.09 cm and 20.44 cm, respectively. The exponent-based candidate functions best fitted the relationship between age, foot size, and height, compared to the log-based candidate function.

Conclusion: Foot size indicated the highest correlation with height and minimum standard error in the estimation of stature. Therefore, foot size provided the highest reliability and accuracy in estimating height.

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1. Introduction

The human body with all of its parts is distinctive. There is a unique relationship between the whole body and each part of it. Therefore, a collapsed body part can be estimated based on the ratio of the body part to the entire body [1]. The relationship between the height of an adult human and the length of phalanges and long bones of the body has always been an intriguing research area for forensic science [2, 3]. This science is used to identify decomposed and difficult-to-identify corpses resulting from fires, bomb blasts, airplane/railway accidents, and murders [4]. Height and foot size are also affected by other parameters, such as age, gender, race, heredity, nutritional status, lifestyle, and bone pathologies [5, 6].

Human body height, concerning the other body parts, can be estimated by anatomical and mathematical techniques [5]. In the anatomical technique, measuring various body parts (head circumference, the length of vertebral column, long bones, & phalanges) are used to calculate the height by applying the soft tissues correction factor [6, 7]. This technique yields accurate results; however, the inherent drawback of it is the unavailability of the precise measurements of all skeletal components. In the mathematical technique, body height is predicted from independent variables, such as long bone/phalange lengths and mathematical equations; they reflect the linear relationship between height and the independent variables [2, 8]. In forensic sciences, the anatomical technique is preferable to the mathematical technique only in the availability of a complete skeleton [9]. A linear regression equation provides a good estimate for individuals' height based on their foot size [5]. However, a formula devised for one population does not necessarily provide reliable results for another [5]. There is a lack of studies regarding the comparison of two different formulas and addressing the correlation between foot size and height in this particular context.

The current study aimed to discover the relationship between foot size and the height of an individual. We also aimed to derive a regression equation for estimating the height from the foot size of an individual from Rawalpindi City, Pakistan. The current research also compared two different functions (log-based & exponent-based) to explore the best one to fit the relation between age and foot size, age, and height.

2. Materials and Methods

This cross-sectional study was conducted using foot measurements of a random sample of 240 participants. The study subjects were enrolled at the Holy Family Hospital, Rawalpindi City, Pakistan. The required data were collected from March to August 2017. The sample size of the current study was calculated by considering the correlation coefficient of 0.58, alpha error of 5%, and the power of 80 [1, 10-12]. The male-to-female ratio for this study equaled 1:1. Moreover, the research subjects were divided into 6 groups as per their age and gender; each group included 20 male and 20 female participants. However, those with congenital bone deformity and a family history of congenital bone deformity (as they may harbor genetic variations) were excluded from this study.

All study participants were requested to wash their feet with soap and trim their nails after being explained about the procedure by data collectors. The study participants were requested to place their left foot on the osteometric board and foot measurements were recorded using an osteometric board composed of two plates on a measuring scale. The posterior plate was fixed where the heel was placed and the anterior plate was adjustable to place against the most projected point of the longest toe (Dynalon model; DYLO8551-3224) [1, 13]. Foot measurement per individual was conducted numerous times till achieving the concordant measurement. The height of all participants was measured 4 times until consistent values in centimeters were recorded using a stadiometer (Seca 213 model) [11]. The research participants' heights were measured by requesting them to stand upright barefooted, with the palms of the hands inward and head positioned in the Frankfort plane. For the quality control to eliminate diurnal variation and personal error in methodology, measuring all subjects was conducted at a fixed time and was performed by the same individual using the same instrument.

SPSS V 23 was used to analyze the collected data. The between-group differences were measured using a t-test with 95% CI. Candidate functions, like the mathematical test,s was used to check behavior between the relationship between the two different variables, such as age, and foot size. The appropriateness of these candidate functions was evaluated using statistical parameters, such as the Sum of Square Errors (SSE), R^2, adjusted R^2, and Root Mean Square Error (RMSE). Moreover, the Shapiro-Wilk test was performed to check data normality in this study.

Table 1. The Mean±SD length of foot and height of study cases concerning age groups (N: 240)

Age Groups (y)	Mean±SD			
	Height of Male Participants (cm)	Length of Male Foot (cm)	Height of Female Participants (cm)	Length of Female Foot (cm)
0-2	75.10±7.44	11.95±1.28	68.60±13.23	11.65±1.53
3-5	103.35±7.48	16.05±2.47	98.25±7.05	15.90±1.21
6-10	121.85±12.95	20.02±2.07	121.95±18.98	19.75±1.86
11-15	143.80±8.40	23.19±1.58	144.30±11.70	21.40±1.98
16-20	168.08±11.95	25.58±2.02	152.55±9.97	22.60±1.54
21	170.52±8.06	25.59±1.34	154.25±8.65	23.00±1.18

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3. Results

The gender-wise Mean±SD height and size of the left foot per age group are summarized in Table 1.

The mean value of the height and foot size ratio (except group 1) among males and females was 6.4 and 6.5 cm, respectively. The correlation coefficient was significant for all study groups and gender-based on regression equations for height (Y) on foot size (X). The correlation coefficient of the groups 2-6 was equal to 0.992-0.999 (P<0.001), i.e. highly significant with the degree of association between height and foot size. In group 6, the correlation coefficient for males and females was measured as 0.999 and 0.998, respectively; in group 5, it was calculated as 0.999. The correlation coefficients in all groups presented a highly-significant association (P<0.001) between height and foot size. Furthermore, the Mean±SD height of a human, either male or female was 6.5±1.68 times the length of his/her foot size in the study respondents. The Mean±SD length of the foot in the male samples was 20.40±5.37cm. In the female samples, the Mean±SD height was equal to 123.32±33.62 cm and the Mean±SD foot size was 19.05±2.36cm. The correlation coefficient for both genders was measured as r=0.998. The coefficient of determination (R^2), which reflected the strength of the linear connection between X and Y, the standard error of estimate, and the standard error of coefficient estimated the standard deviation of the coefficient. The regression between the height and foot size for males and females were 2,184,916.503 and 2,032,111.664, respectively (Table 2).

The collected data was used to create some relations between age and foot size, age and height, as well as foot size and height. The method of least square error was applied to find the relevant coefficients. The employed candidate functions included log-based and exponent-based as listed in Equations 1 and 2.

1.

$$Size_i = mag_i \times [\log (a_i \times x + \frac{b_i}{\mathbf{x}})]$$

2.

$$Size_i = mag_i \times (1 - a_i \times e^{-bi \times age} + bias_i)$$

Where age was an independent parameter and age ϵ [5…,80], sizei refers to the size of foot and height for the value of i=1,2 respectively; other variables were extracted using the method of least square error. The appropriateness of these candidate functions was evaluated

Table 2. Regression equation, correlation coefficient, and coefficient of determination between height (Y) and foot size (X)

Gender	No.	R	R^2	Std. Error of Estimate	Std. Error of Coefficient	Regression (Height) ŷ=βx
Male	120	0.998	0.995	8.747	0.038	2184916.503
Female	120	0.998	0.995	8.937	0.041	2032111.664

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Table 3. The constants of the mathematical model for foot size and height, extracted from the method of least square error

Function	$Size_i$	A	B	Mag	SSE	R^2	Adjusted R^2	RMSE
Log-based	Foot	26.02	-19.4	3.967	2370	0.6701	0.6677	2.889
	Height	3.491	-1.326	35.09	7.964×104	0.811	0.8097	16.75
Exponent-based	Foot	0.7499	0.1715	0.008652	26.76	1709	0.762	0.7604
	Height	0.9094	0.1293	0.02965	165.75	4.803×104	0.886	0.8852

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using statistical parameters, such as the Sum of Squared Errors (SSE), R^2, adjusted R^2, and Root Mean Square Error (RMSE). Finally, the optimal candidate function was announced based on these statistical parameters.

The first candidate function was selected as a log-based function (Equation 1) for the higher values of the independent axis. Other variables, such as mag_i, a_i, and b_i were extracted using least square error method. Accordingly, mag_i represents the final tapering value of the scale height, a_i, and b_i are constants to control the tapering of the function (Table 3).

Figure 1 shows the flow diagram illustrating the selection of the study participants in this study on the data of foot size as a growing function depending on the age. The height has larger values and cannot be expressed on the same scale; dividing the values of height by 5, rather than presenting original values suggests the height. Scaling the height enables to demonstrate the foot size and height with reasonable visibility.

The plot of age against foot size is shown in Figure 2. The smaller values of age have an increasing trend in the foot size and larger values of age lead to tapering off in the foot size. This natural phenomenon can be modeled using the method of least square error. The steady-state value of foot size is extracted from the collected data by taking the average value of >15 years of age. This threshold of age is selected by observing the foot size, as it almost remains constant after this age. The mean value of

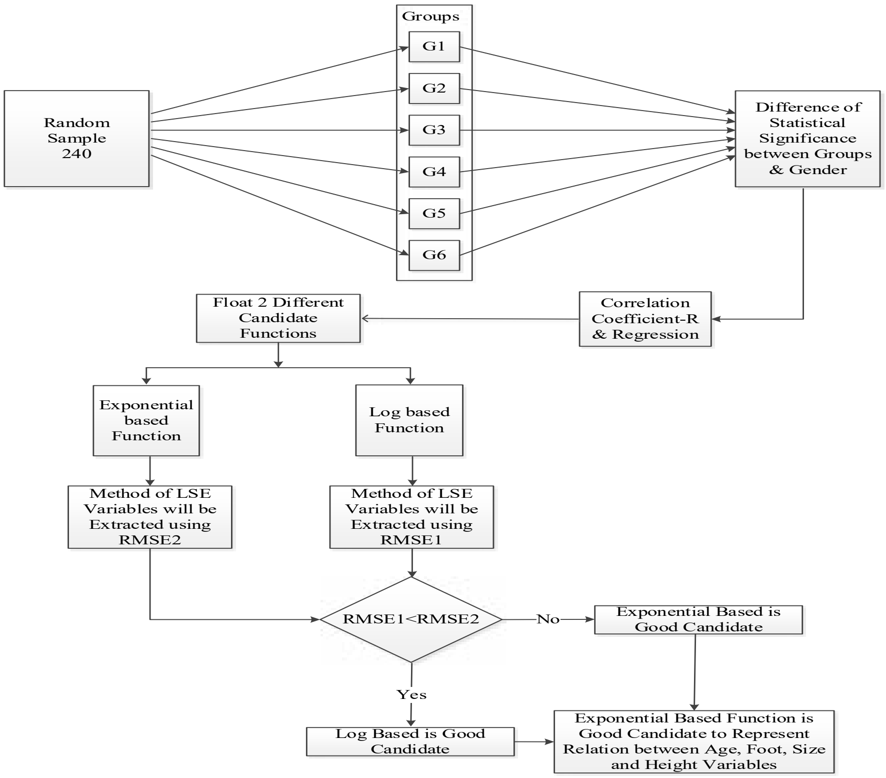

Figure 1. Flowchart showing the study methodology

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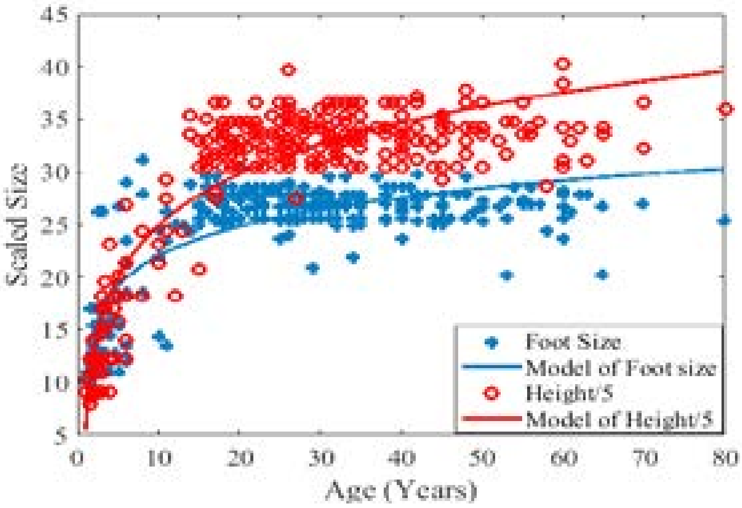

Figure 2. Comparing the collected data by the log-based mathematical model extracted from the method of least square error and presented in Equation 1

foot size was calculated to be 26.76 cm, which acts as a constant characteristic (mag_i) in the mathematical model.

The mathematical equation serving as tapered exponential was selected, as this equation seemed closer to the obtained data. The maximum value (mag_i) of tapered exponential was extracted from the mean values of foot size for >15 years of age as highlighted above. The equation used in the mathematical model was extracted using the method of least square error and illustrated in Equation 2. Foot size is plotted along with the mathematical model and shown in Figure 3.

Height has a different scale to the foot size; thus, a scaling number divides the value of height to be shown in the same window. The similarity in the values of decay constant factor b_i reflects similar trends for the increase in foot size and height. This similarity indicates the correlation between foot size and height. The values of model for the foot size and height are plotted against each other to illustrate this correlation. Figure 4 shows an almost linear correlation between foot size and height for the smaller values of foot size. The relatively increased values of height are observed for the larger foot size.

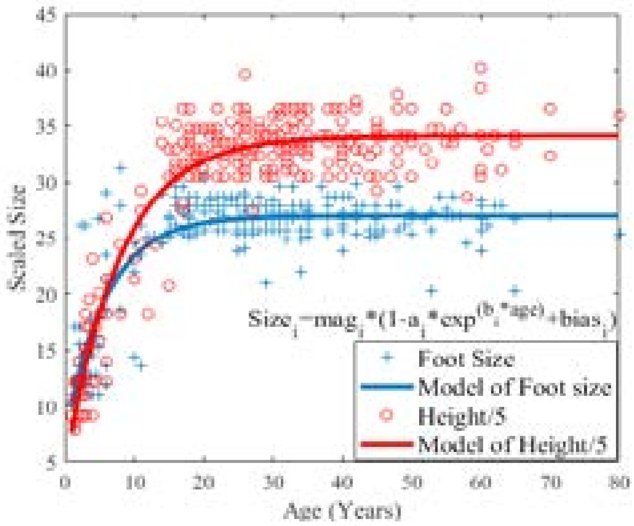

Figure 3. Comparing the collected data by the exponent-based mathematical model extracted from the method of least square error and shown in Equation 2

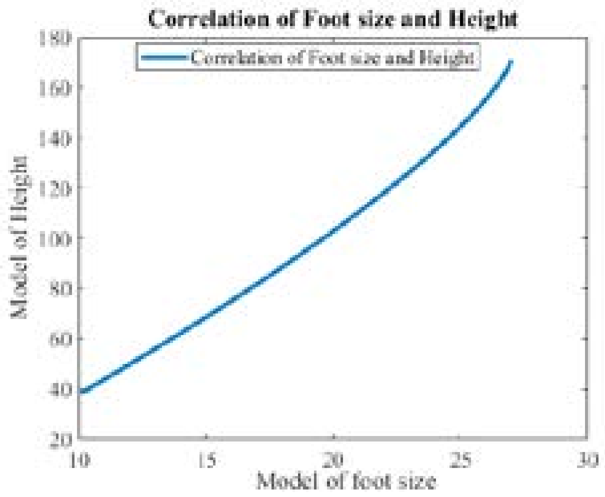

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Figure 4. The models of foot size and height are compared where an almost linear correlation is observed between foot size and height

4. Discussion

Our study, using regression analysis to correlate height with foot size, revealed that all coefficients were statistically significant; we indicated a linear relationship between the explored variables for both genders. The correlation coefficient provides the highest reliability and accuracy of data in estimating the height of an unknown individual. Physiologically, it is suggested that taller individuals require longer feet for the support and balance of the body [14]. Although numerous approaches are established to correlate this ratio, regression analysis is the easiest. Numerous characteristics, such as environmental, gender, health, and genetic in nature influence foot size and height. Trauma-induced abnormalities, disability, poor nutrition, and lifestyle choices (e.g. footwear type & use, athletic inclinations, etc.) can also affect the relationship between height and foot size [5, 6]. Our results were congruent with other studies [15] revealing that the correlation coefficients for all the age groups of African children of different ethnic origins were similar (0.90-0.98); such findings indicate a highly significant ($P<0.001$) degree of association between height and foot size. A similar study reported a significant correlation between height and foot size [16]. Another investigation predicted a regression equation for a North-Western Indian population [17]. Their correlation coefficient between foot size and height was measured as +0.69 in males and +0.70 in females. Other scholars found a strong significant relationship between foot size and height ($P<0.01$) [18]. Hands and foot lengths were compared to the height; accordingly, it was found that the relationship was stronger in males rather than in females.

Community surveys in general, however, are not concerned with individuals but with the group as a whole. Besides, in such surveys, estimating height from foot length may likely be more accurate than measuring height by an untrained observer. First, the accurate measurement of height in an uncooperative child is extremely difficult, if not impossible; foot length measurement by the described method can be simple and accurate. Secondly, the errors in the estimation of height from foot length tend to cancel out in a large number of individuals; however, in our experience, those of an observer measuring height is likely to be in the same direction. Intra groups' variance also exists in the model and is plotted in the scatter plot.

5. Conclusion

The present study results suggested that the height of an individual, either male or female was 6.5±1.68 times higher than the length of his/her foot in the study population. Foot size provides high reliability and accuracy in estimating height; thus, this can be of practical use in medico-legal inquiries and investigations in the region. The relationship between foot size and height depending on the age can be expressed with the exponent-based function due to the lower values of SSE, RMSE, and higher values of R^2 and adjusted R^2.

Ethical Considerations

Compliance with ethical guidelines

All respondents provided written informed consent to participate in this study. Besides, ethical approval was obtained from the institutional review board of COMSATs University of Islamabad, Pakistan. Consent for publication Not applicable.

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Author's contributions

Investigation: Fozia Anwar; Writing – original draft: Ramesh Kumar; Data collection, final approval: All authors; Data analysis: Khurram Saleem Alimgeerand Fozia Anwar; Writing – review & editing: Ratana Somrongthong.

Conflict of interest

The authors declared no conflicts of interest.

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