



HEIGHT ESTIMATION BASED ON FOOTPRINT LENGTH AND FOOT LENGTH CORRELATION: A STUDY IN THE GOAN POPULATION

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Abstract : Estimating an individual's height is a vital aspect of forensic identification, especially in situations where only partial human remains or isolated evidence like footprints are recovered. Footprint and foot length are commonly used anthropometric indicators due to their ease of collection and notable association with stature. In forensic science, establishing accurate and reliable regression models to predict height from these parameters is crucial in aiding the identification process. However, factors such as sex, age, ethnicity, and regional differences can influence these relationships, highlighting the need for population-specific data. This research investigates height estimation based on footprint and foot length among individuals from Goa (North Goa and South Goa). Data were collected from participants (50 female and 50 male) within this region, and separate linear regression equations were formulated for males and females. The regression constants derived were used to estimate stature from both footprint and foot length. The performance of these equations was evaluated using statistical methods to determine their accuracy and reliability. Additionally, a correlation analysis was performed to explore the relationship between footprint length and foot length, aiming to determine how well one could predict the other. This study aims to establish a reliable, region-specific method for estimating stature from foot evidence, which can significantly support forensic investigations involving individuals from the Goan population. It also provides insight into the degree of correlation between footprint and foot length, enhancing the utility of either parameter when only one is available.

Keywords: Forensic Anthropology, stature estimation, footprint length, foot length, linear regression, Goan population: North Goans and South Goans

I. INTRODUCTION

Forensic anthropology is a specialized branch of forensic science that applies principles of physical anthropology to legal processes, particularly in identifying human remains and aiding in the reconstruction of biological profiles. Estimating stature (height), one of the most important aspects of creating a biological profile, is essential for determining an unknown person's identity. This is particularly crucial in situations where only fragmentary remains are frequently found, such as mass disasters,

criminal investigations, or missing person cases. In order to determine stature in the absence of a complete, forensic anthropologists create regression models based on the link between various body components and total body height [1],[7],[20].

The lower extremities- more especially, the foot- are crucial in these situations. The foot is a robust and solid structure that supports the weight of the body and permits movement. Anatomically, a person's height and size of their feet are proportionately and consistently related [3]. This relationship is based on biomechanics and biological growth patterns, where the foot's length normally maintains a specific ratio with stature. The distance from the heel to the end of the longest toe is known as the foot length and is recorded directly from the foot.

Footprints are the marks or impressions left by the foot on a surface, which can be formed by bare feet or feet covered by footwear. Footprints play a crucial role in forensic investigations by helping to determine the identity of a suspect. They are found as kind evidence at the crime site and the link between the crime and the perpetrator [1][8]. Footprints may appear on a variety of surfaces such as freshly waxed floors, newly cemented areas, damp surfaces, and can also be found in materials like dust, oil, or paint. At crime scenes, they may even be left in blood, especially in cases involving violent crimes.

Although both measurements may seem comparable, they are not the same, since one measures the foot itself, while the other measures the foot's impression on a surface. Both, however, have proven effective in predicting stature, especially when other body parts are unavailable. The analysis of foot and footprint measurements plays a crucial role in determining an individual's stature, as numerous studies have demonstrated a strong and consistent relationship between foot dimensions and a person's height [6],[7],[10]. Researchers have noted that the length from the toes to the heel in a footprint offers greater accuracy for predicting stature [4],[15].

The estimation of stature from various bodily components, such as the skull, long bones, handprints, and footprints, has been the attention of numerous scholars worldwide. The foot has drawn the most attention among these because of its consistent anatomical dimensions and the simplicity of taking measurements of it. According to studies, a person's foot length accounts for 15% of their height [3]. However, because of variations in genetics, diet, lifestyle, and environmental variables, this ratio may alter among populations. To ensure the accuracy and reliability of stature estimation, it is vital to construct regression equations that are specifically designed for the target population [7],[11],[19].

Regression analysis is a statistical method used to determine the relationship between one or more independent variables (such as footprint length and foot length) and a dependent variable (in this case, height). Linear regression equations are typically represented in the following form:

$$h = a + b \times (\text{footprint/foot length})$$

The regression coefficient, denoted by "b," and the intercept, denoted by "a," are both obtained using real sample data. The degree of correlation between the stature and the measured variable determines how reliable such calculations are. The equation can be used with confidence to estimate height in forensic investigations, according to a high association [11],[15],[20].

In the present study, Foot lengths and footprints were taken from a representative sample of both males and females living in Goa for the current study. Standardized circumstances were used for the measurements in order to minimize error and guarantee consistency. Given the importance of sexual dimorphism in anthropometry, the data was then statistically analyzed to produce distinct regression models for males and females. For greater precision, sex-specific equations are required because males often have larger and longer bones than females.

After regression formulas were developed, each subject's height was calculated using the length of their foot and footprint. The accuracy, reliability, and standard error of the projections were then assessed by comparing these estimations with the subjects' actual height.

In order to determine how closely footprint and foot length connect, this study also investigated their relationship. In forensic settings where only one kind of measurement is available, this is especially helpful. The scope and usefulness of the height estimation model are increased if a high correlation is discovered, as this allows for the accurate inference of the missing variable.

This effort adds to the expanding corpus of forensic anthropological research in India by determining a set of trustworthy regression equations and comprehending the connection between footprint and foot length in the Goan people. It improves the capacity of law enforcement and forensic experts to identify unidentified people with only incomplete foot evidence. Additionally, the study offers a scientific justification for the use of readily available, non-invasive anthropometric measurements in real-world forensic settings.

NEED OF THE STUDY.

In forensic investigations, especially those involving decomposed, fragmented, or partial human remains, determining a person's identity becomes a major challenge. Height estimation plays a critical role in constructing a biological profile and narrowing down potential matches. Traditional methods often rely on long bones or skull measurements, but these may not always be available at crime scenes. The foot, due to its durability and the frequent presence of footprints at crime scenes, serves as a reliable alternative

for stature estimation. However, the relationship between foot dimensions and height can vary across populations due to factors such as genetics, environment, and lifestyle. Therefore, it is essential to develop region-specific formulas for accurate results.

Goa, with its unique demographic and genetic makeup, lacks sufficient anthropometric data for forensic use. This study addresses that gap by generating population-specific regression equations for height estimation using foot and footprint measurements from Goan individuals. Such data is invaluable for forensic experts working in local investigations, making the identification process more accurate and effective.

3.1 Population and Sample

The present study focused on individuals belonging to North Goa and South Goa, specifically within the age range of 18 to 25 years. A total of 100 participants were selected through random sampling, which included an equal number of males (50) and females (50). This balanced representation was intended to assess the differences in anthropometric measurements between the sexes. All participants were permanent residents of Goa and participated voluntarily after providing informed consent.

3.2 Data and Sources of Data

The research relied entirely on primary data gathered from the selected participants. Measurements such as footprint length, foot length, and height were recorded using standardized tools under controlled conditions. Instruments like ink pads, A4 sheets, measuring tapes, and scales were used to collect the required anthropometric data. As the study was based on firsthand observations and fieldwork, no secondary or external data sources were used.

3.3 Theoretical framework

This study is based on forensic anthropological principles that suggest a proportional relationship between various human body dimensions. It explores the biomechanical and anatomical theory that certain body parts, such as the feet, maintain a consistent ratio with an individual's height. The statistical foundation of this research is built on linear regression analysis, which helps establish predictive equations for estimating stature from measurable parameters like foot and footprint length. The influence of sexual dimorphism is also considered, prompting the development of separate equations for males and females to improve accuracy in height estimation.

RESEARCH METHODOLOGY

Materials required:

1. Personal Information sheet
2. Ink tube
3. Ink pad
4. Ink roller
5. A4 size sheet
6. Measuring tape
7. Scale
8. Stationary

Procedure:

1. Before data collection, all participants were informed about the objectives and details of the study.
2. Participants were asked to fill out a personal information form.
3. They were later requested to remove their shoes, socks, and any foot accessories.
4. Clear instructions about the process were given to all participants.
5. A scale was used to measure foot size for both male and female participants.
6. After that participants were instructed to press their foot onto an ink pad and then place the foot on A4 sheet to take the footprint
7. The dimensions of the footprints were then measured using a scale
8. A standard measuring tape was used to record the height in centimeters of both male and female participants.
9. All the collected data was arranged systematically and entered into table for analysis.

Exclusion Criteria:

1. Subjects with foot diseases and deformities were not selected.
2. Observational errors, due to parallax and approximations, were avoided to the maximum extent.
3. Subjects who did not consent were excluded from the study.

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3.4 Regression Analysis

To derive regression constants A and B To find B:

$$B = \frac{N \cdot \sum XY - \sum X \cdot \sum Y}{N \cdot \sum X^2 - (\sum X)^2}$$

To find A:

$$A = \bar{Y} - B \bar{X}$$

1. For male samples (Footprint) the constant values are:

$$A = 63.63 \quad B=4.41$$

2. For male samples (Foot length) the constant values are:

$$A = 58.26 \quad B=4.45$$

3. For female samples (Footprint) the constant values are:

$$A = 62.76 \quad B=4.30$$

4. For female samples (Foot length) the constant values are:

$$A = 58.47 \quad B=4.30$$

IV. RESULTS AND DISCUSSION

4.1 Results

Table 4.1: height wise classification of male participants with associated footprint and foot length ranges

Height in cm	No. of participants	Footprint range (cm)	Foot length range (cm)
151-155	2(4%)	22	23
156-160	1(2%)	22.5	23.5
161-165	6(12%)	22-24	23-25
166-170	21(42%)	22.5-24.5	23.5-25.5
171-175	13(26%)	23.5-25	24.5-26
176-180	3(6%)	25.5-26	26.5-27
181-185	3(6%)	26.5-27	27.5-28
186-190	1(2%)	28	29
Total	50(100%)		

Table 4.1 In this study, a total of 50 male participants were selected, categorized based on their height ranges. The majority of participants (42%) were within the 166-170cm height group, having footprint length range of 22.5-24.5cm and foot length range of 23.5-25.5cm. The second most common height category was 171-175cm having 26% of the participants, with footprint lengths between 23.5-25cm and foot lengths ranging between 24.5-26cm. Around 12% of the participants were in the 161-165cm height range, with footprints and foot length ranges of 22-24cm and 23-25cm. Smaller proportions were observed in the extreme height groups: 6% each in the 176-180cm and 181-185cm categories, with footprint ranges of 25.5-26cm and 26.5-27cm, and corresponding foot lengths of 26.5-27cm and 27.5-28cm and 4% of the participants in the 151-155cm having footprint length 22cm and foot length 23cm. In the 156-160cm and 186-190cm height range, lowest frequency was observed, there were only 2% of the participants in each, having footprint length 22.5cm and 28cm, and corresponding foot lengths of 23.5cm and 29cm. Overall, a gradual increase was observed in both footprint and foot length with increasing height, suggesting a positive correlation among the variables measured.

Research Through Innovation

Table 4.2: height wise classification of female participants with associated footprint and foot length ranges

Height in cm	No. of participants	Footprint range (cm)	Foot length range (cm)
141-145	1(2%)	19.5	20.5
146-150	2(4%)	20-20.5	21-21.5
151-155	15(30%)	21-22.5	22-23.5
156-160	10(20%)	20.5-23	21.5-24
161-165	13(26%)	22-23.5	23-24.5
166-170	8(16%)	24-25	25-26
171-175	1(2%)	25.5	26.5
Total	50(100%)		

Table 4.2 In this study, a total of 50 female participants were selected, categorized based on their height range, ranging from 141-175cm. The largest proportion of individuals (30%) fell within the 151-155cm height range, having footprint lengths between 21-22.5cm and foot lengths from 22-23.5cm. The second most common group was 161-165cm range, having 26% of the participants, with footprint lengths between 22-23.5cm and foot lengths between 23-24.5cm. Around 20% of the participants with heights between 156-160cm showed footprint ranges of 20.5-23cm and foot lengths between 21.5-24cm. 16% of the participants in the 166-170cm height group exhibited footprint lengths ranging from 24-25cm and foot lengths between 25-26cm. In the 146-150cm height group there were 4% of the participants with shorter footprint and foot length ranging from 20-20.5 and 21-21.5cm. Lowest frequency was observed in the height ranges of 141-145cm and 171-175cm, each having 2% of the participants, with the smallest and largest recorded foot print and foot length that is footprint length: 19.5cm and 25.5cm with corresponding foot length of 20.5cm to 26.5cm. Overall, the data indicated a gradual increase in footprint and foot length measurements with increase in height, supporting a positive correlation among the variables measured.

4.2 Discussion:

The present study aimed to investigate the relationship between footprint length, foot length, and stature estimation among male and female participants from the Goan population. A total of 100 participants were studied: 50 males and 50 females and were grouped into various height ranges to observe the variation in foot dimension with respect to height. The objective was to develop valid regression equation constants that can be used to estimate a person's height based on footprint length and foot length.

The findings from this study gave a strong positive correlation between both footprint length and foot length with a person's height. This shows that as the footprint and foot length increases, there is a proportional increase in height. This study reveals that both the measurements serve as a valuable indicator for estimating stature.

In males, the majority of participants (42%) fell within the 166-170cm height range having footprint lengths ranged from 22.5-24.5cm and foot lengths ranged from 23.5-25.5cm. The tallest height group: 176-190cm, though comprised of only 7 participants, showed the longest foot measurements, supporting the idea that foot size is linked to stature. However, few height groups: 156-160cm and 186-190cm with only 2% participants may limit statistical significance for these ranges.

In females, the most common height category was 151-155 cm with 30% participants having footprint lengths ranged from 21-22.5cm and foot lengths ranged from 22-23.5cm followed by 26% participants in the 161-165cm height group having footprint lengths ranged from 22-23.5cm and foot lengths ranged from 23-24.5cm. Similar with male data, a positive correlation between

height and foot dimensions were observed. The shortest group (141-145cm) had the smallest footprint and foot length 19.5cm and 20.5cm, and the tallest group 171-175cm had the highest values 25.5cm and 26.5cm.

After combining, both the male and female data showed a statistically observable trend: individuals with greater heights have larger footprint and foot length values. This supports existing research, which indicates that stature is positively correlated with foot size. The developed regression equation constants can serve as practical resources for crime scene investigations for estimating stature. It was observed that certain height groups exhibited overlapping footprint sizes, especially within the mid-range, which could pose challenges in forensic contexts requiring precise height estimation.

In females, the ratio of footprint to height was 14.06% and the ratio of foot length to height was 14.69%. In males, the ratio of footprint to height was 14.19% and the ratio of foot length to height was 14.77% respectively. Thus the research hypothesis, that the foot to height ratio is not equal to 15% is accepted.

Separate linear regression equations were developed for males and females to predict height from footprint length and foot length.

For the male participants, the regression constants were:

For footprint: $A=63.63$ & $B=4.41$ (Table 1)

For foot length: $A=58.26$ & $B=4.45$ (Table 2)

For the female participants, the regression constants were:

For footprint: $A=62.76$ & $B=4.30$ (Table 3)

For foot length: $A=58.76$ & $B=4.30$ (Table 4)

In both male and female samples, a difference of approximately 1cm was observed between the footprint length and foot length. However, this variation did not have any significant impact on the height estimation. When the regression formulas were applied using either footprint length or foot length, the calculated height values remained consistent, indicating that the slight difference between the two measurements did not influence the final height estimation outcome.

Thus the hypothesis, footprint length or foot length does not cause any significant difference in the height values is proved.

Therefore, both footprint length and foot length are reliable indicators for estimating stature is proved.

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