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ORIGINAL RESEARCH PAPER

An autopsy-based study of the estimation of height from the length of the sternum in an adult Indian population

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ABSTRACT

Background and aims: *Stature is a critical and consistent anthropometric parameter used in personal identification, particularly in forensic investigations involving unidentified remains from mass disasters, criminal incidents, or accidents. Accurate estimation of stature is essential in such contexts. A well-documented correlation exists between stature and various skeletal dimensions, especially those of long bones, which are commonly used to formulate regression models due to their high predictive reliability. Recently, the sternum – a centrally located, flat bone in the thoracic skeleton – has attracted forensic attention due to its robust nature and pronounced sexual dimorphism. Notably, sternal measurements have been shown to correlate positively with stature, providing an alternative method for estimating stature.* ***Methods:*** *This study analyses sternal measurements to estimate stature in a forensic context, using data from 200 medico-legal autopsy cases comprising 100 males and 100 females aged 21 to 80 years.* ***Results:*** *Findings indicate that males have significantly greater values in body length (LB), manubrium length (LM), and mesosternum length (LMS), with mean measurements of 158.14 cm, 4.38 cm, and 10.09 cm, respectively. Interestingly, total sternal length (TSL) was similar across genders, at 14.89 cm in males and 14.26 cm in females, highlighting potential differences in developmental biology. Moderate correlations were observed between each sternal parameter and stature, with the TSL exhibiting the strongest linear relationship in both sexes.* ***Conclusion:*** *The study confirms that sternal dimensions, particularly TSL, are reliable indicators of stature. Linear regression equations were derived for males, females, and combined datasets, thereby reinforcing the forensic applicability of the sternum.*

Keywords: *Stature; sternal bone measurements; linear regression equations.*

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INTRODUCTION

Stature, or standing height, is one of the most basic and stable anthropometric traits used to identify individuals. Defined as the vertical distance between the vertex of the skull and the heel in an upright posture, stature serves not only as a crucial individual characteristic but also reflects broader population traits, such as nutritional status, health, and heredity. In forensic investigations, accurately estimating stature is vital, especially in cases involving unidentified human remains recovered

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from mass disasters, criminal incidents, or accidents.[1]it is considered as a medical emergency and is seen among communities with the habit of hunting and cooking its wild variety. Amongst all identified species, poisoning caused by Amanita Phalloides is considered to be the fatal one because of onset of late symptoms with hepato-renal toxicity and persistence of toxins even after cooking or freezing. Symptoms appear usually after 6-8 hours of ingestion and by the time patient is brought to the emergency department, early hepatic complication already develops.", "container-title": "Journal of Indian Society of Toxicology", " DOI": "10.31736/jist/v15.i1.2019.48-53", "ISSN": "0973-3566, 0973-3558", "issue": "1", "language":"en", "page": "48","source": "DOI.org (Crossref

A well-established relationship exists between height and the measurements of various body parts, especially the long bones of the limbs, such as the femur, tibia, humerus, radius, and ulna. These bones have traditionally been used to develop regression models for estimating height because of their high predictive accuracy. However, the effectiveness of these models is largely population-specific, due to variations in skeletal dimensions influenced by genetic, environmental, and socioeconomic factors. As a result, height estimation equations created for one population often lack reliability when applied to another, emphasising the need for population-specific studies.[2]Pondicherry, India. A significant and positive correlation was observed between the stature of deceased (STAD

Two principal approaches are utilised in forensic anthropology to estimate stature: the anatomical method and the mathematical method. The anatomical method necessitates nearly complete skeletal remains, limiting its application in cases where the body is fragmented or partially decomposed. In contrast, the mathematical method relies on regression equations derived from specific skeletal measurements, making it more adaptable in forensic contexts involving incomplete remains. Although long bones are generally preferred for such analyses, their absence due to trauma or destruction in high-impact events demands alternative sources of measurement.[3]little previous work has been done on stature estimation among modern Thai people, despite a growing number of forensic cases in Thailand in recent years. The current study was carried out on a sample of 200 skeletons from a northern Thai population (132 males and 68 females

The sternum, a centrally located flat bone of the thoracic skeleton, has gained forensic relevance recently due to its structural resilience and marked sexual dimorphism. Composed of the manubrium, mesosternum (body), and xiphoid process, the sternum demonstrates a positive correlation with stature. Previous studies have shown that the combined length of the manubrium and body provides the highest correlation coefficients with stature across both sexes. Additionally, sternal measurements have shown promising results in sex estimation, with accuracies reaching up to 90% for specific dimensions. These attributes make the sternum a valuable alternative for stature estimation when long bones are unavailable.[4]but are observed as ranks or scores. In the present study, 8 nonmetric traits of sternum were examined from 343 sternums collected from the autopsy cases. More males, particularly older subjects, had a mesosternal foramen. The frequency of mesosternal foramen, arch-shaped prominence on the manubrium and radial strips on mesosternum significantly increased but that of lateral projection of manubrium decreased in the 30+ year age-group (older individuals

While molecular techniques, such as DNA analysis, are increasingly used in personal identification, they are not always feasible due to issues like sample degradation, contamination, a lack of antemortem reference data, and high costs. Thus, morphometric and metric methods remain indispensable tools in forensic anthropology, especially for adult skeletons.[5]

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Despite the growing relevance of sternal measurements in forensic science, data from the Indian population remains limited. Considering this, the present study, with ethical approval, aims to derive population-specific regression equations to estimate stature from sternal lengths in adult Indian individuals. This research aims to provide a reliable, practical tool for forensic experts in India, enhancing identification efforts in medico-legal investigations and mass-casualty scenarios.[6]aged between 25 and 40 years, obtained during medico-legal autopsies. Stature and four sternal lengths, length of the manubrium (LM

MATERIALS AND METHODS

Sample selection and data collection

The study was conducted on 200 medicolegal autopsy cases at a tertiary care centre between November 2022 and December 2023, comprising 100 male and 100 female cadavers aged between 21 and 80 years. Ethical clearance was obtained, and informed consent was obtained from the legal next of kin via signature or thumbprint. Only cases without any evident trauma or anomaly of the sternum were included. Cases involving individuals under 21 or over 80 years old and those with decomposed, mutilated, burned, or compressed bodies were excluded.

Anthropometric measurements

All measurements were recorded by the same investigator to reduce interobserver variability, under standardised lighting conditions, and at similar times to avoid diurnal variation. Stature (length of body) was measured from the vertex to the heel in a supine position using a steel tape and wooden blocks, as shown in Figure 1. Sternal measurements were taken using a sliding calliper and included:

- **Total Sternal Length (TSL)**: From the suprasternal notch to the xiphisternal joint, shown in **Figure 2.**
- **Length of Manubrium (LM)**: From the suprasternal notch to the manubriosternal joint, shown in **Figure 3.**
- **Length of Mesosternum (LMS)**: From the manubriosternal joint to the xiphisternal joint, shown in **Figure 4.** Each measurement was repeated three times for consistency and accuracy.

Figure 1 Measurement of the length of the body (LB)

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Figure 2 Measurement of total length of sternum (TSL) (excluding xiphisternum)

Figure 3 Measurement of the Length of Manubrium (LM)

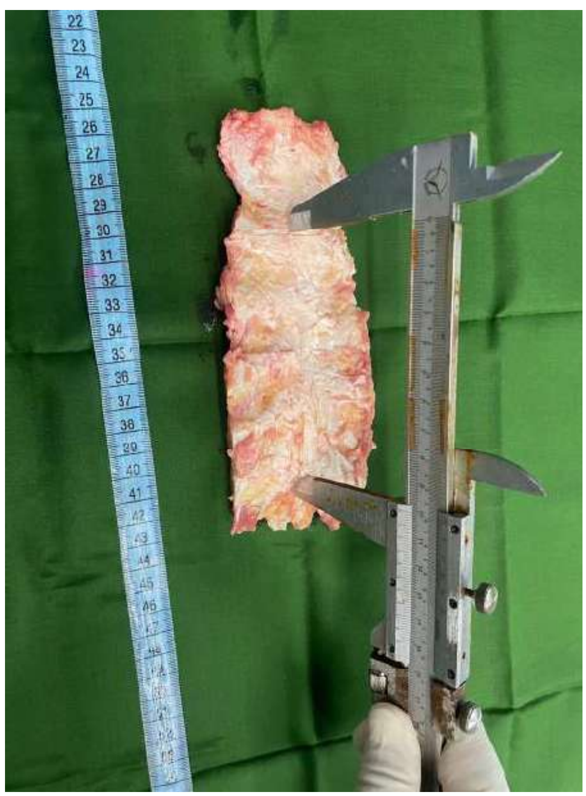

Figure 4 Measurement of Length of Mesosternum (LMS)

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Statistical analysis

Data were analysed using descriptive statistics, including arithmetic means, medians, and modes, to summarise the findings. Dispersion was assessed through range, standard deviation (SD), and coefficient of variation. To examine statistical differences between the sexes, independent-samples t-tests were used. Correlation between stature and sternal dimensions was assessed using Pearson's correlation coefficient (r).

Linear regression was used to derive sex-specific equations predicting stature based on sternal dimensions. The regression coefficients were used to calculate the rate of change in stature per unit change in sternal measurements. The standard error of estimate (SEE) was calculated to assess the accuracy of the predictive models.

RESULT

The study, as shown in **Table 1**, indicates that males have significantly greater measurements in Length of Body (LB), Length of Manubrium (LM), and Length of Mesosternum (LMS) compared to females, with means of 158.14, 4.38, and 10.09, respectively. In contrast, the total sternal length (TSL) is nearly equal for both genders, with males at 14.89 cm and females at 14.26 cm. These findings suggest biological differences in growth patterns between males and females. Overall, males exhibit larger body and sternal dimensions.

The study reveals a moderate correlation between all three variables and body length in the total sample, as well as a substantial linear relationship.

Table 1 Distribution of variables.

Variables	Males (N=100)		Females (N=100)		Total Sample (N=200)	
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
LB	182.50-149.50	162.28±6.24	177.5-138	154±5.76	182.50-138	158.14 ± 7.29
LM	6.34-3.13	4.51±0.71	5.51-2.89	4.25±0.69	6.34-2.89	4.38±0.71
LMS	11.89-7.25	10.17±0.91	11.94-8	10.01±0.87	11.89-8	10.09±0.89
TSL	17.24-12.01	14.68±1.30	16.76-12.2	14.26±1.08	17.24-12.2	14.47±1.21

LB – Length of Body, LM – Length of Manubrium, LMS – Length of Mesosternum, TSL – Total Sternal Length

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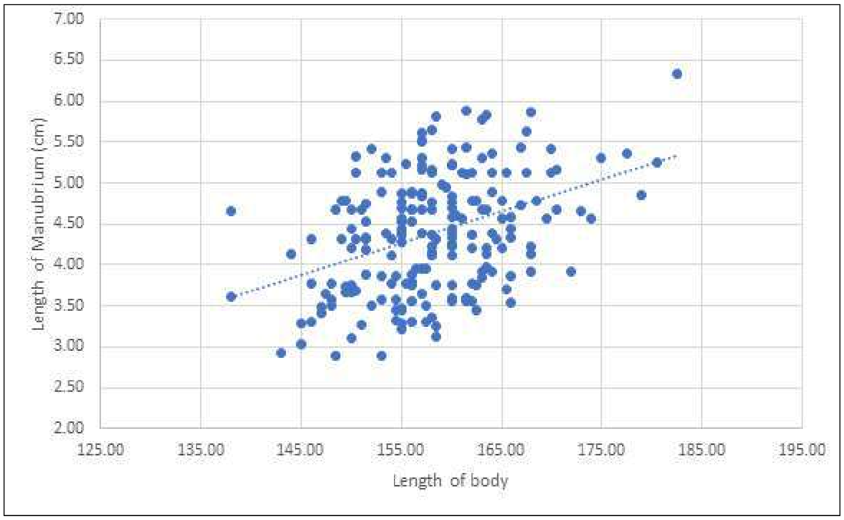

Figure 5 Correlation between length of body and length of manubrium (cm) in total sample (**N=200**)

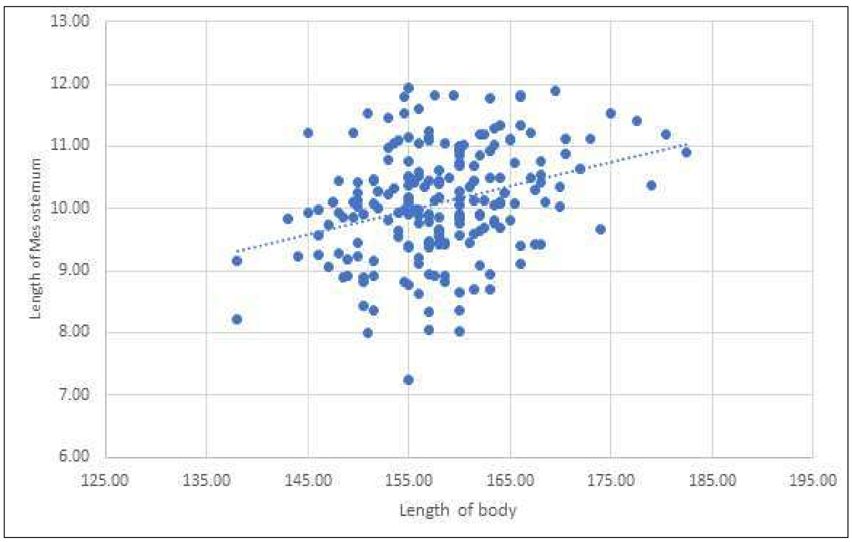

Figure 6 Correlation between length of body and length of mesosternum (cm) in total sample (**N=200**)

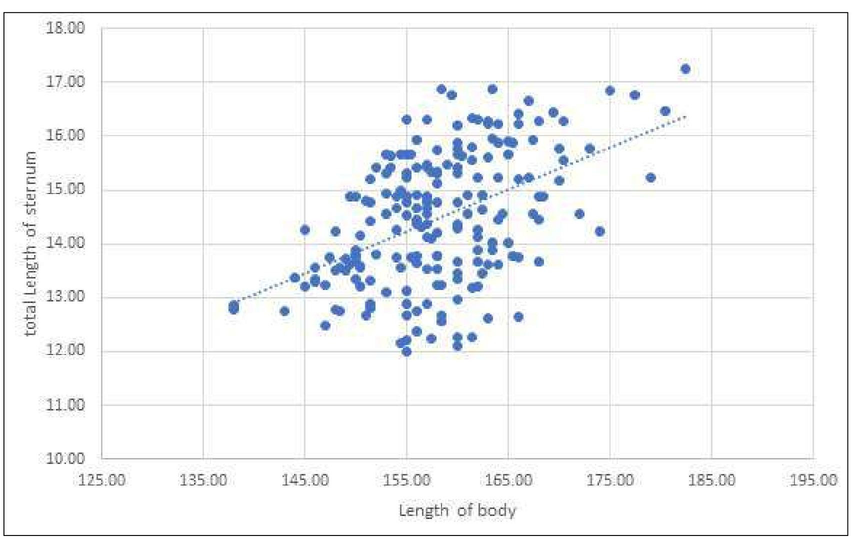

Figure 7 Correlation between length of body and total length of sternum (cm) in total sample (**N=200**)

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Table 2 Correlation and linear regression equation to estimate stature from different sternal lengths.

Sample & Variables	Pearson's correlation coefficient (R)	Variance (R^2)	P-value	Linear regression equation (Y = Stature)
Male (N=100) LM=X_1	0.34	0.11	0.0005	$Y = 3.007*X_1 + 148.7$
LMS=X_2	0.36	0.13	0.0002	$Y = 2.529*X_2 + 136.6$
TSL=X_3	0.44	0.19	< 0.0001	$Y = 2.127*X_3 + 131.0$
Female (N=100) LM=X_4	0.38	0.14	< 0.0001	$Y = 3.202*X_4 + 140.4$
LMS=X_5	0.27	0.07	0.0061	$Y = 1.799*X_5 + 136.0$
TSL=X_6	0.46	0.21	< 0.0001	$Y = 2.498*X_6 + 118.4$
Total (N=200) LM=X_7	0.39	0.15	< 0.0001	$Y = 4.070*X_7 + 140.3$
LMS=X_8	0.31	0.09	< 0.0001	$Y = 2.578*X_8 + 132.1$
TSL=X_9	0.46	0.22	< 0.0001	$Y = 2.806*X_9 + 117.5$

LB – Length of Body, LM – Length of Manubrium, LMS – Length of Mesosternum, TSL – Total Sternal Length

Table 3 Multiple linear regression equation to estimate stature.

	Variance (R^2)	Multiple Linear Regression Equation (Y = Stature)
Male (N=100)	0.20	Y = 131.38 + 2.03*TSL + 0.25*LM
Female (N=100)	0.24	Y = 119.99 + 1.97*TSL + 1.39*LM
Total (N=200)	0.23	Y = 119.69 + 2.20*TSL + 1.52*LM

LB – Length of Body, LM – Length of Manubrium, LMS – Length of Mesosternum, TSL – Total Sternal Length

The multiple linear regression shown in Table 3 suggests that the reliability and accuracy of predicting stature were high in males, total samples, and females, respectively, using total sternal length and the length of the manubrium. This study is also useful when sex is not known.

DISCUSSION

The present investigation was undertaken to evaluate the potential of sternal measurements for estimating stature in an adult Indian population, utilising a sample of 200 medico-legal autopsy cases (100 males and 100 females). The findings reinforce the applicability of sternum-based anthropometry in forensic identification, particularly in cases where long bones are absent, damaged, or otherwise unsuitable for analysis.

Statistical analysis revealed a moderate positive correlation between sternal dimensions and stature in both sexes. Pearson's correlation coefficients were calculated as 0.34

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for males and 0.46 for females, while the overall correlation for the combined sample was 0.44. These values suggest a consistent, albeit moderate, association between sternal length and stature, supporting the proposition that stature increases proportionately with sternal length (Table 2).

To enhance the predictive capacity of the model, sex-specific multiple linear regression equations were derived:

- For males: Stature (Y) = 131.38 + 2.03(LM) + 0.25(LMS)
- For females: Stature (Y) = 119.99 + 1.97(LMS) + 1.39(TSL)

These equations highlight the differential contributions of individual sternal components to stature estimation by sex. The coefficient of determination (R^2) for the total sample was 0.23, indicating that approximately 23% of the variability in stature could be attributed to sternal measurements. While this denotes moderate predictive power, it remains of considerable forensic significance, particularly in circumstances involving fragmented, charred, or decomposed remains where traditional long bones are inaccessible.

A comparative assessment with prior studies across diverse populations reveals substantial inter-populational variability. For instance, Tumram et al. reported a markedly higher correlation (r = 0.911 in males; r = 0.883 in females) in an Indian population, suggesting greater predictive validity within that cohort. Conversely, studies by Singh et al. in Northwest India reported weaker associations (ranging from 0.191 to 0.318 in males and 0.229 to 0.318 in females), thereby reflecting intra-national heterogeneity.[4,7]but are observed as ranks or scores. In the present study, 8 nonmetric traits of sternum were examined from 343 sternums collected from the autopsy cases. More males, particularly older subjects, had a mesosternal foramen. The frequency of mesosternal foramen, arch-shaped prominence on the manubrium and radial strips on mesosternum significantly increased but that of lateral projection of manubrium decreased in the 30+ year age-group (older individuals

Research from South India, including studies by Menezes et al. and Ranjith et al., demonstrated higher correlation values (up to r = 0.941 in males), reinforcing the notion of regional anatomical variation. Moderate correlations were reported in a study from Jodhpur by Saraf et al. (r = 0.737 for males; r = 0.707 for females), whereas Jeamornrat, et al. reported lower correlations in a Thai population (LM = 0.18–0.26; LMS = 0.35–0.39), suggesting limited generalizability of sternal-based stature estimation in Southeast Asian populations.[3,5,8]little previous work has been done on stature estimation among modern Thai people, despite a growing number of forensic cases in Thailand in recent years. The current study was carried out on a sample of 200 skeletons from a northern Thai population (132 males and 68 females

The Turkish study by Yonguc et al., showed strong correlations (r = 0.809 for males; r = 0.775 for females), comparable to findings from some Indian subpopulations. Likewise, Baraw et al. observed robust correlations in fresh sternal lengths within the Delhi population (r = 0.809 for males; r = 0.755 for females), although slightly diminished values were noted for dry sternal samples.[6]aged between 25 and 40 years, obtained during medico-legal autopsies. Stature and four sternal lengths, length of the manubrium (LM

These variations indicate the importance of developing population-specific regression equations to improve the accuracy of forensic stature estimation. Factors such as genetic diversity, environmental conditions, nutritional influences, and methodological disparities likely contribute to the observed differences in correlation strength. Thus, while sternal measurements present a valuable adjunct in forensic anthropological investigations, the application of a universal regression model is inadvisable.

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In summary, this study validates the utility of sternal morphometry as a reliable method for stature estimation within the Indian context, albeit with moderate predictive accuracy. The development of localised regression models tailored to specific populations is essential for enhancing forensic reliability. Future research involving larger, more heterogeneous samples is warranted to refine existing models and broaden the scope of application in forensic practice.

Table 4 Comparison results of stature estimation using the sternum with previous studies

Population	Author	Sternal lengths	Correlation coefficient	
			Male	Female
Indian (M=192)	Tumram et al.[7]	LM LMS TSL	0.44 0.25 0.55	
North West Indian (M=252, F=91)	Singh et al.[4]	LM LMS TSL	0.191 0.255 0.318	0.237 0.229 0.318
South Indian (M=35, F=40)	Menezes et al.[9]	Sternal Length	0.638	0.639
Jodhpur (N=100)	Saraf et al.[8]	LM LMS TSL	0.36 0.85 0.89	0.68 0.74 0.85
Thai (M=104, F=95)	Jeamamornrat et al.[10]	LM LMS	0.18 0.35	0.26 0.39
Turkish (M=65, F=30)	Yonguc et al.[6]	LM LMS TSL	0.65 0.74 0.85	0.67 0.37 0.74
Present Study (M=100, F=100)		LM LMS TSL	0.34 0.36 0.44	0.38 0.27 0.46

LIMITATIONS

The present study was conducted on postmortem cases aged 21 to 80 years. Accordingly, the regression equation formulated based on the collected data is considered most reliable when applied to individuals within this age bracket. Cases with congenital or acquired skeletal deformities were excluded, limiting the utility of the developed model in such populations. The sample size, although balanced by sex, may not be sufficiently large to represent the diverse genetic and environmental variability present within the Indian population. Furthermore, the data was collected from a specific geographic region, which may limit the generalisability of the results to other regions and ethnic groups in India. To enhance the accuracy and broader applicability of the regression model, future studies should aim to incorporate a larger sample size with greater demographic and age-specific representation. Additionally, the inclusion of other skeletal elements alongside sternal dimensions may facilitate more comprehensive and reliable stature estimation models. Investigating the influence of variables such as age, sex, and ethnicity on the relationship between sternal length and stature is also recommended to refine predictive algorithms and improve their forensic applicability.

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CONCLUSION

The present study establishes that sternal measurements, particularly in individuals aged 21-80 years, can serve as reliable indicators of stature in forensic contexts. Among the parameters examined, the total sternal length demonstrated the strongest correlation with stature in both males and females. This parameter also exhibited the lowest standard error of estimate, confirming its superior predictive accuracy and reliability for stature estimation.

Based on the collected data, a series of linear regression equations was developed for males, females, and the combined sample, shown in Tables 2 and 3, respectively.

These regression equations provide practical and statistically grounded tools for forensic practitioners, enabling stature estimation from sternal measurements with a reasonable degree of accuracy. Their application can be particularly beneficial in scenarios where conventional long bones are absent or unsuitable for measurement.

The findings underscore the forensic relevance of anthropometric methods, particularly for identifying individuals from skeletal remains. The study reinforces the necessity of thorough postmortem examination and precise anthropometric recording in cases involving decomposed, mutilated, or incomplete remains. Furthermore, these results add to the growing body of forensic anthropological literature and lay the foundation for future investigations aimed at refining stature-estimation techniques tailored to specific populations.

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Ethical clearance: The research has been approved by the institutional ethics committee.

Conflict of interest: All authors declare that they have no conflict of interest.

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Availability of data: Data is available in the record section of the Department of Forensic Medicine and Toxicology, GGMC and Sir JJH, Mumbai-08.

Contribution of authors: We declare that this work was done by the author named in this article, and the authors will bear all liabilities about claims relating to the content of this article.

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