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FORENSIC ESTIMATION OF STATURE FROM STERNAL MORPHOMETRY IN THE INDIAN POPULATION: AN AUTOPSY-BASED ANTHROPOMETRIC STUDY

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ABSTRACT

Background: Stature estimation is a key component of forensic identification, particularly in cases involving decomposed or partial human remains. The sternum, due to its resistance to decomposition and ease of extraction, presents a reliable alternative for stature estimation. This study aimed to formulate regression equations for estimating stature based on sternal morphometry in the Indian population. **Aim:** To derive regression equations for stature estimation based on sternal morphometric measurements in the Indian population, and to evaluate the reliability of the sternum as a forensic tool in cases of partial or decomposed remains. **Methods:** This observational cross-sectional study was conducted on 110 autopsied Indian cadavers aged 10–70 years at a tertiary care Center in New Delhi. Six sternal parameters-including the lengths and breadths of the manubrium and body, total sternal length, and the sternal index-were measured from macerated sternal bones. Statistical analysis included Pearson/Spearman correlation and linear regression to derive stature prediction models. **Results:** The mean stature of the study population was 163.29 ± 8.16 cm. Among all parameters, the length of the body of the sternum showed the highest correlation with stature (R^2 = 16.42%). Multivariate regression combining the lengths of the manubrium, sternal body, and total sternum improved the coefficient of determination to 17.4%. Gender-specific analysis revealed that stature could be estimated more reliably in males using the length of the sternal body (R^2 = 7.45%), though overall significance was limited. **Conclusion:** The study concludes that the length of the sternal body is the most reliable parameter for stature estimation, especially in males. While the predictive power remains modest, the developed regression models can serve as valuable tools in forensic contexts where alternative methods are unavailable.

INTRODUCTION

The process of identification involves establishing the unique identity of an individual, whether living or deceased. In the field of medico-legal investigations, the analysis of human skeletal remains plays a critical role in aiding this identification process (1,2). In forensic medicine, specialists often rely heavily on skeletal remains to determine key aspects of an individual's identity, particularly in cases involving dismembered bodies or isolated bones. Estimations of sex, age, and stature are fundamental components of this identification process. Additionally, other distinguishing features—such as racial characteristics, moles, scars, occupational marks, and skin complexion—can also serve as valuable indicators, especially when they exhibit permanence throughout an individual's life (3).

In India, identifying deceased individuals can be particularly difficult due to rapid decomposition in hot climates or damage by wild animals, especially in rural areas. Accurate identification is essential in murder trials, as confirmation of corpus delicti is required before sentencing and decomposed or partial remains may be misused to support false accusations. Stature estimation plays a key role in this process and is influenced by genetic, nutritional, environmental, and

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psychological factors. While it is straightforward when the full body or skeleton is available in cases involving only partial remains, forensic experts apply specific osteometric formulae based on the proportional relationship between individual bones and overall body length (4).

The aim of the study was to develop regression equations for estimating an individual's stature using measurements of the sternum—a superficial bone that often remains intact even in advanced stages of decomposition. Additionally, the sternum can be easily retrieved from cadavers during routine autopsies without causing any significant damage, making it a practical and reliable element for forensic analysis.

METHODOLOGY

Study Design and Participants

This study is an prospective Observational Cross-Sectional study carried out in the Department of Forensic Medicine and Toxicology, Vardhman Mahavir Medical College & Safdarjung Hospital, New Delhi, from Jan 2020 to June 2021 after obtaining hospital ethical committee approval (**IEC/ VMMC/SJH/Thesis/2019-10/157**). Dead bodies of Indian population brought for autopsy to the Mortuary wing were the source population.

Sample Size

In the study of **Goksin Nilufer Yonguc et al (4)**., observed that correlation coefficient of total sternal length and stature was 0.806. Taking this value as reference, the minimum required sample size with 80% power of study and 5% level of significance is 10 study subjects. Also, sensitivity and specificity of total sternal length for predicting gender was 89.2% and 80% respectively. Taking this value as reference, the minimum required sample size with desired precision of 10%, 80% power of study, and 5% level of significance is 108 study subjects. To reduce margin of error, total sample size taken is 110.

Inclusion & Exclusion Criteria

Cases of both sexes where identity is known and Age greater than 10 years and less than 70 years were included in the study. Whereas, fracture of sternum, Unclaimed dead bodies, Skeletal deformities, Diseased or deformed bones, and any disease or deformity or deficiency that effects the stature were excluded from the study.

Procedure and technique for the Removal of the Sternum

After obtaining informed consent from the deceased's relative, the body was placed in the supine position with arms by the sides, and an I-shaped incision was made from the chin to the symphysis pubis. The chest muscles were dissected with the knife directed inward toward the ribs, extending laterally to the mid-axillary line and over the clavicles. The chest cavity was opened by cutting the costal cartilages close to the costochondral junctions, starting from the second cartilage. The sternoclavicular joint was identified by shoulder movement, and its capsule was divided using a vertical, circular motion of the knife. The sternum was detached from the diaphragm and removed completely, with each specimen labelled. Maceration of soft tissues was performed by boiling the sternum in a solution of 7–8 grams of sodium hydroxide per litre of water, using 2 litres of solution in an aluminium vessel for 60–75 minutes. The specimens were monitored to prevent over-boiling and achieve optimal maceration. After boiling, the specimens were thoroughly rinsed, and residual soft tissue was removed using forceps and a soft brush. The cleaned bones were dried on a clean cloth for 2–3 days and then sealed in airtight zip-lock bags for preservation as shown in Figure 1.

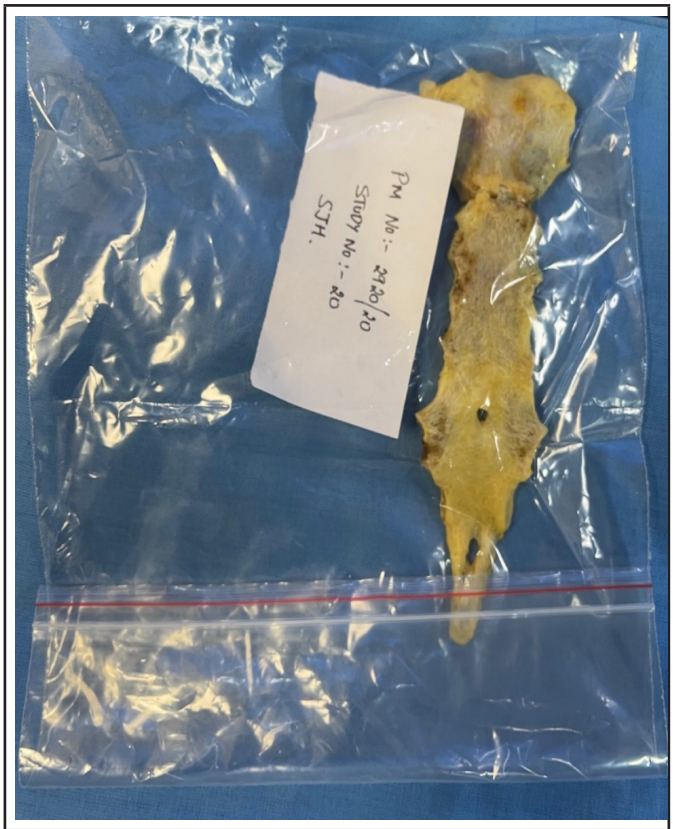

Fig.1. Labelling and packing each sterna in an airtight zip locker

Osteometric Parameters Used for Analysis

Measurements were taken using vernier callipers as shown in Figure 2,

1. Total length of sternum: Straight distance from the deepest point of the suprasternal notch to the point on the lower margin of the corpus Sterna in the mid-sagittal plane. When the sternum was not united as a single piece due to lack of fusion, individual segments were measured independently, and the total length is calculated by adding all.
2. Length of body of sternum: Straight distance from the point on the lower margin of manubrium to the point on the lower margin of the body in the mid-sagittal plane.
3. Length of manubrium: Straight distance from the suprasternal notch to the point on the lower margin of the manubrium in the mid-sagittal plane.
4. Breadth of manubrium: Straight distance between the most laterally placed points on the lateral margins of the manubrium, taken at right angles to the length of the manubrium.

5. Breadth of body of sternum: The straight distance between the most laterally placed points on the lateral margins of the body taken at right angles to the length of the body.
6. Sternal index:

$$\frac{\text{Length of manubrium}}{\text{Length of body}} \times 100$$

Fig.2. Osteometric Measurements by Vernier Callipers

Statistical Analysis

Categorical variables will be presented in number and percentage (%) and continuous variables will be presented as mean ± SD and median.Normality of data will be tested by Kolmogorov-Smirnov test. If the normality is rejected, then nonparametric test will be used. Pearson correlation coefficient/Spearman Rank correlation coefficient (when the data sets are not normally distributed) will be used to correlate quantitative parameters. Univariate and multivariate linear regression will be used to predict stature. A p value of less than 0.05 will be considered as significant. The data will be entered in MS EXCEL spreadsheet and analysis will be done using Statistical Package for Social Sciences (SPSS) version 21.0.

RESULTS AND OBSERVATIONS

In present study, 26.36% of patients belonged to age group 31-40 years followed by 21-30 years (23.64%), 41-50 years (21.82%), 51-60 years (12.73%) and 11-20 years (8.18%). Age group was 61-70 years of only 8 out of 110 patients (7.27%). Mean value of age (years) of study subjects was 38.22 ± 13.7 with median (25th-75th percentile) of 35.5(29-47.75) as shown in Figure 3.

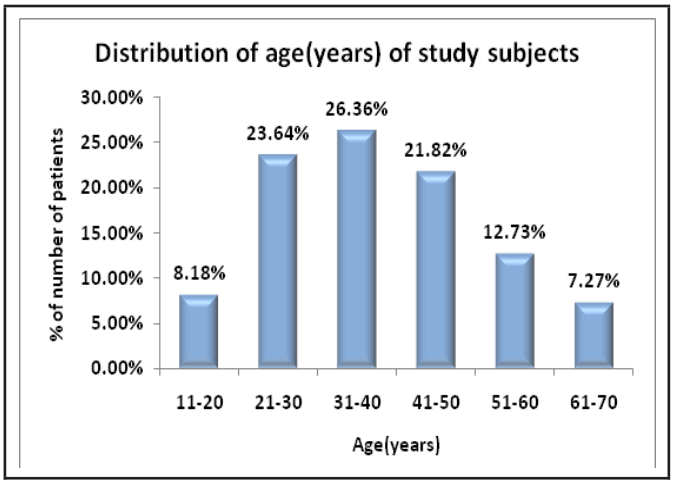

Fig. 3. Distribution of age (years) of study subjects.

Mean value of stature (cm), length of manubrium (mm), length of body of sternum (mm), length of total sternum (mm), breadth of manubrium (mm), breadth of body of sternum (mm) and sternal index of study subjects was 163.29 ± 8.16, 51.43 ± 5.19, 90.99 ± 11.77, 166.46 ± 19.24, 57.37 ± 7.25, 37.24 ± 6.47 and 57.49 ± 8.07 with median (25th-75th percentile) of 163(158-169), 51(48-54.95), 91.85(84.5-99.375), 167.5(154-180.375), 57(52-61), 37(32-42) and 57.06(52.65-62.092) respectively as shown in Table 1.

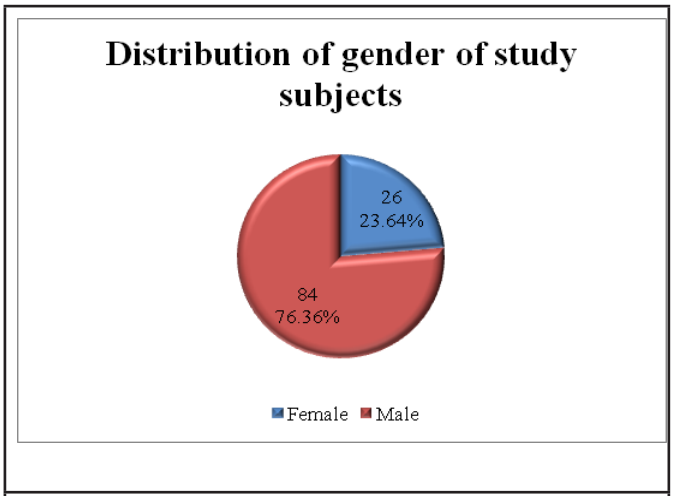

Fig 4. Distribution of gender of study subjects.

In total study subjects, regression analysis revealed that stature can be calculated with the highest coefficient of determination of 16.42% from length of body spectrum. On performing multivariate linear regression on length of manubrium, body of sternum and total sternum, coefficient of determination increased to 17.4% with obtained equation as 127.16363+0.35164*Length of manubrium (mm)+0.35779*Length of body of sternum (mm)-0.08717*Length of total sternum (mm).

In females, regression analysis revealed that stature can be calculated with the highest coefficient of determination of 4.80% from length of body of sternum but the estimation by all measurements were non-significant.

In males, regression analysis revealed that stature can be significantly calculated with the highest coefficient of determination of 7.45% from length of body of sternum and estimation by other measurements were non-significant as shown in table 2.

Table 1. Descriptive statistics of measurements of study subjects.			
Measurements	**Mean ± SD**	**Median (25th-75th percentile)**	**Range**
Stature (cm)	163.29 ± 8.16	163(158-169)	144-188
Length of manubrium (mm)	51.43 ± 5.19	51(48-54.95)	37.5-67.5
Length of body of sternum (mm)	90.99 ± 11.77	91.85(84.5-99.375)	66-119
Length of total sternum (mm)	166.46 ± 19.24	167.5(154-180.375)	115.5-216
Breadth of manubrium (mm)	57.37 ± 7.25	57(52-61)	40-83.5
Breadth of body of sternum (mm)	37.24 ± 6.47	37(32-42)	24-56
Sternal index	57.49 ± 8.07	57.06(52.65-62.092)	39.61-85.07

Table 2 Univariate linear regression to predict stature

Variable	Total study subjects			Male			Female		
	Standard error	**Equation**	**R^2**	**Standard error**	**Equation**	**R^2**	**Standard error**	**Equation**	**R^2**
Length of manubrium (mm)	0.147	143.229+0.39* Length of manubrium (mm)	6.15%	0.165	154.156+0.208* Length of manubrium (mm)	1.91%	0.356	150.37+0.149* Length of manubrium (mm)	0.72%
Length of body of sternum (mm)	0.061	137.701+0.281* Length of body of sternum (mm)	16.42%	0.088	148.153+0.178* Length of body of sternum (mm)	4.80%	0.146	141.691+0.202* Length of body of sternum (mm)	7.45%
Length of total sternum (mm)	0.039	139.852+0.141* Length of total sternum (mm)	11.00%	0.054	155.321+0.056* Length of total sternum (mm)	1.30%	0.085	143.085+0.099* Length of total sternum (mm)	5.30%

Table 3. Comparison of Observations of the Present Study with Previous Studies

	Menezes et al (n = 40)	**SinghJ et al (n = 91)**	**Yonguc(n = 30)**	**Chandrakant et al (n = 50)**	**Gupta el al (n = 34)**	**In present study (n = 110)**
Study Population	Mangalore, South India	North-western, India	Turkey	Mysuru, SouthIndia	Delhi,NorthIndia	Indian population
Range of stature	146-168	136-177	-	140-181	140-165	144-188
Meanstature(SD)	155.88 (5.27)	156 (6.98)	160.2 (6.7)	155.7 (8.1)	150.32 (7.20)	163.29 (8.16)
SternalLength (SL)						
Mean (SD)	14.12 (1.07)	14.3 91.245)	17.92 (1.6)	12.24 (1.62)	11.88(0.88)	16.64 (1.92)
Regression model	111.59+3.316(SL)	130.82+0.18(SL)	110.783+0.27(SL)	140.315+0.167(SL)	131.62+1.574(SL)	139.852+0.141*SL
SEE	4.11	6.66	0.059	9.26	7.181	0.039
R^2	–	0.100	0.438	0.103	0.037	0.11
Length of Manubrium (M)						
Mean (SD)	–	4.72 (0.517)	4.83 (0.54)	4.37 (0.42)	3.73 (0.141)	5.14 (0.51)
Regression model	–	141.17+0.32(M)	120.276+0.827(M)	138.129+0.519(M)	30.445+32.15(M)	143.229+0.39 *M(mm)
SEE	–	6.82	0.173	9.21	0.567	0.147
R^2	–	0.06	0.448	0.144	0.398	0.06

DISCUSSION

Estimation of stature from long bones has been carried out by various researchers and they have succeeded in that by finding various mathematical solutions. But as far as other flat bones are concerned, it is still incomplete. Previous studies by Menezes et al., and Gupta et al., (5, 6) focused on developing regression equations for stature estimation based solely on the length of the sternum in female individuals. In contrast, researchers such as Singh J. et al.,Yonguc et al., and Chandrakant et al., (4, 7, 8) conducted their investigations on both male and female sterna, aligning more closely with the methodology of the present study. Notably, all these studies were conducted on dry, macerated sternal bones. Marinho et al., and Tumram et al., (9, 10) however, utilized fresh sternal bones for stature estimation, although their research excluded female subjects. In the current study, the relationship between various sternal

parameters—including the length of the manubrium, length of the sternal body, total sternal length, and the breadths of both the manubrium and body—were analysed in relation to stature using dry sternal bones. Unlike some earlier studies, such as those by Singh et al., Yonguc et al., and Chandrakant et al., (4, 7, 8) which did not assess the breadth measurements, this study incorporated a more comprehensive set of variables. The findings have been systematically compared with results from previous research to evaluate consistency and variations across populations and methodologies as shown in Table 3.

The range of stature observed in the present study was comparable to that reported by Menezes et al.,(5) while it was slightly lower than the ranges noted in the studies conducted by Singh et al., Chandrakant et al., and Gupta et al (6, 7, 8). Interestingly, the mean sternal length recorded in this study exceeded the mean values reported in all previously referenced studies. Additionally, the coefficient of determination (R^2) for the total sternal length in the present research closely aligned with the findings of Singh et al. and Chandrakant et al.,(7, 8) indicating consistency in the predictive value of this parameter for stature estimation.

In this study, in males, regression analysis revealed that stature can be calculated with the highest coefficient of determination of 4.80% from length of body of sternum but the estimation by all measurements were not significant. In females, regression analysis revealed that stature can be significantly calculated with the highest coefficient of determination of 7.45% from length of body of sternum and estimation by other measurements were not significant. A study conducted by Hu Peiru & Zhao Zhiyuan (11), in the year 1987 to estimate stature from sternum of adults in North China, included 28 adult cadavers and concluded that the relationship between stature and total length of sternum reveals a higher coefficient of correlation and a lower standard error of estimation, as compared to that between stature and length of the manubrium sterni and that between stature and length of the body of the sternum which was not in agreement with our study as it was the length of body of sternum.

In our study, estimation of stature in both sexes from length of body and total length are more reliable than from length of manubrium. On performing multivariate linear regression on length of manubrium, body of sternum and total sternum, coefficient of determination (R2) increased to 17.4% with obtained equation as 127.163+0.351*Length of manubrium (mm)+0.357*Length of body of sternum (mm)-0.087*Length of total sternum (mm) and it is explicit that the length of body of sternum is the more reliable parameter in determination of stature of an individual. However, the confidence interval by using the standard error that is derived from this study is only 68%. So, these regression formulae can be used for estimation of stature where there are no other suitable alternative methods. This observation is agreed by many authors like Dwight et al., Trotteret al., Vyas et al., and Singh et al (12,13, 14, 15).

CONCLUSION

The study concluded that in males, the length of the sternal body is a more reliable parameter for estimating stature. In females, however, stature estimation was not feasible due to the limited sample size, which stands as a notable limitation of the research. In cases where the sex of the individual is unknown, both the length of the sternal body and the manubrium can be utilized for stature estimation. The regression equations developed through this study offer a valuable tool for estimating stature from the sternum, particularly within the Indian population, and are especially useful when other anatomical references are unavailable.

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Ethical clearance: A prior approval was obtained from the Institutional ethics committee (**IEC/VMMC/SJH/ Thesis/2019-10/157**).

Conflict of interest: None to declare.

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