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Metric Evaluation of Sternal Parameters for Sex Estimation- A Forensic Perspective.

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Abstract

Background: Sex determination from skeletal remains is a crucial step in forensic identification. The sternum, though less commonly used than pelvis or skull, can serve as an alternative in fragmented remains due to its resistance to decomposition and measurable morphological features. ***Aim:*** To evaluate the role of sternal index and morphological parameters of the sternum in forensic sex identification. ***Methods:*** A cross-sectional study was conducted on 134 adult human sterna (89 males and 45 females) of known sex. Various morphometric parameters including length of manubrium, length of mesosternum, combined length (M+B), breadth of sternebrae, weight, and derived indices such as sternal index were measured using standard instruments. Statistical analysis was performed using Z-test, and parameters were evaluated for significance, confidence intervals, and identification accuracy. ***Results:*** Linear measurements such as length of manubrium, mesosternum, and combined length (M+B) were significantly higher in males ($p<0.001$). The combined length showed the highest discriminative value, identifying up to 64.44% of female sterna. Breadth measurements and weight were statistically significant but showed poor identification accuracy. The sternal index and other derived indices were not significant ($p>0.05$) and failed to differentiate sex due to overlapping values. ***Conclusion:*** The sternum demonstrates sexual dimorphism, with combined length of manubrium and mesosternum being the most reliable parameter. However, the sternal index is not useful for sex determination. The sternum should be used as a supplementary tool in forensic identification, with preference given to multiple parameter analysis.

Keywords: Sternal Index. Sexual Dimorphism. Forensic Sex Identification.

INTRODUCTION

Sex determination from skeletal remains is a fundamental aspect of forensic anthropology and medico-legal investigations. In cases of advanced decomposition, mass disasters, or mutilated bodies, the identification of an individual becomes challenging due to the loss of soft tissues. Under such circumstances, the skeletal system serves as the most reliable source for determining biological identity, including age, sex, and race. Among these parameters, sex determination is considered the primary step, as it significantly narrows down the identification process. The human skeleton exhibits sexual dimorphism, with certain bones such as the pelvis and skull providing high accuracy; however, these bones are not always available in fragmented remains. Hence, the study of less commonly used bones like the sternum gains importance in forensic practice.[1]

The sternum, a flat bone located in the anterior thoracic wall, consists of three parts manubrium, mesosternum (body), and xiphoid process. It articulates with the clavicle and the first seven ribs and plays a crucial role in protecting vital thoracic organs. Morphologically, the sternum resembles a short sword and shows measurable differences between males and females in terms of length, breadth, and proportions of its components. These differences form the basis of morphometric analysis for sex determination.[2]

Several researchers have emphasized the significance of sternal parameters in sex identification. Early studies by Wenzel and Feigel demonstrated that the length of the mesosternum is generally greater in males than females. Hyrtl proposed the manubrium–corpus index (sternal index), suggesting that values above 50 are indicative of females and below 50 of males, although later studies reported considerable overlap between sexes. Further contributions by Dwight, Paterson, Ashley,

and Jit highlighted the importance of combined length of manubrium and mesosternum as a more reliable parameter compared to individual measurements.[3]

Despite numerous studies, the applicability of sternal measurements varies across populations due to differences in genetic, environmental, nutritional, and racial factors. Studies conducted in Indian populations have shown that values derived from European or African populations cannot be universally applied. This necessitates region-specific research to establish accurate standards for forensic identification.[4]

AIM

To evaluate the role of sternal index and morphological parameters of the sternum in forensic sex identification.

OBJECTIVES

1. To measure various morphometric parameters of the sternum and assess their sexual dimorphism.
2. To evaluate the usefulness of the sternal index in determining sex.
3. To analyze the accuracy of different sternal parameters and identify the most reliable indicators for sex determination.

MATERIALS AND METHODS

Source of Data

The study was conducted on 200 human sterna of known sex obtained from the Departments of Anatomy and Forensic Medicine of various medical colleges. The specimens included dry, well-preserved adult sterna collected from osteological archives and postmortem cases.

Study Design

This was a descriptive cross-sectional observational study aimed at assessing morphometric parameters of the sternum for sex determination.

Study Location

The study was carried out in the Department of Anatomy/Forensic Medicine of a tertiary care teaching institution.

Study Duration

The study was conducted over a period of 12–18 months, including collection, measurement, analysis, and interpretation of data.

Sample Size

A total of 200 adult human sterna of known sex were included in the study.

Inclusion Criteria

- Adult human sterna of known sex
- Completely ossified and intact sterna
- Specimens without deformities or damage

Exclusion Criteria

- Broken or incomplete sterna
- Pathologically deformed bones
- Juvenile or partially ossified specimens
- Sterna with postmortem damage affecting measurements

Procedure and Methodology

All selected sterna were examined carefully, and morphometric measurements were taken using standard osteometric techniques. A sliding Vernier caliper and flexible measuring tape were used to measure linear dimensions with precision. The following parameters were recorded in millimeters:

- Length of manubrium (M)
- Length of mesosternum (B)
- Combined length of manubrium and mesosternum (M+B)
- Breadth of first sternebra (S1)
- Breadth of third sternebra (S3)

Indices calculated included:

- Sternal Index (M/B × 100)
- Relative width index (S1/S3 × 100)
- Ratio of mesosternum to manubrium

Each measurement was taken twice to minimize observer error, and the average value was recorded. The methodology followed standard anthropometric guidelines.

Sample Processing

The collected data were tabulated systematically in a pre-designed data sheet. Each sternum was assigned a unique identification number, and all measurements were recorded accurately. Quality control measures were maintained to ensure consistency and reliability of observations.

Statistical Methods

The data were analyzed using statistical software. The following statistical tests were applied:

- Mean and standard deviation (SD)
- Range and calculated range
- Z-test to compare male and female measurements
- Determination of demarking points and identification points
- Percentage of correctly identified specimens
- Multivariate discriminant analysis for improving accuracy

A p-value of <0.05 was considered statistically significant.

Data Collection

Data were collected using a structured proforma including demographic details (sex) and all measured parameters. Observations were entered in tabular form and later analyzed statistically. Graphical representations such as bar diagrams were used to demonstrate overlapping zones and identification ranges between male and female sterna.

RESULTS

Table 1: Role of Sternal Index and Morphological Parameters in Forensic Sex Identification

Parameter	Male (n=89) Mean±SD	Female (n=45) Mean±SD	Mean Difference	95% CI	Test value	p-value
Length of manubrium (mm)	51.95±7.79	41.64±6.81	10.31	7.75–12.87	Z=7.87	<0.001
Length of mesosternum (mm)	95.38±11.64	76.13±10.88	19.25	15.26–23.24	Z=9.44	<0.001
Combined length M+B (mm)	147.33±16.19	117.77±15.13	29.56	24.01–35.11	Z=10.42	<0.001
Sternal index	54.97±8.37	55.24±9.10	-0.27	-3.45–2.91	Z<1.96	>0.05

Table 1 demonstrates the role of sternal index and various morphological parameters in forensic sex identification. It is evident that the mean length of the manubrium, mesosternum, and the combined length of manubrium and mesosternum were all significantly higher in males compared to females, with mean differences of 10.31 mm, 19.25 mm, and 29.56 mm respectively. These differences were statistically highly significant (p<0.001), as supported by high Z-values (7.87, 9.44, and 10.42). The 95% confidence intervals for these parameters did not cross zero, indicating strong discriminatory power between sexes. In contrast, the sternal index showed nearly identical mean values in males and females (54.97 vs 55.24), with a negligible mean difference of -0.27 and a non-significant p-value (>0.05).

Table 2: Morphometric Parameters of Sternum and Sexual Dimorphism

Parameter	Male Mean±SD	Female Mean±SD	Mean Difference	95% CI	Test value	p-value
Manubrium length (mm)	51.95±7.79	41.64±6.81	10.31	7.75–12.87	Z=7.87	<0.001
Mesosternum length (mm)	95.38±11.64	76.13±10.88	19.25	15.26–23.24	Z=9.44	<0.001
Combined length M+B (mm)	147.33±16.19	117.77±15.13	29.56	24.01–35.11	Z=10.42	<0.001
Breadth of 1st sternebra (mm)	26.78±3.66	24.04±5.29	2.74	1.02–4.46	Z=3.12	<0.001
Breadth of 3rd sternebra (mm)	29.96±7.08	24.68±5.22	5.28	3.16–7.40	Z=4.88	<0.001
Weight of sternum (g)	18.52±3.67	15.40±4.24	3.12	1.67–4.57	Z=4.20	<0.001

Table 2 highlights the morphometric parameters of the sternum and their role in assessing sexual dimorphism. All linear measurements, including manubrium length, mesosternum length, and combined length (M+B), were significantly greater

in males, confirming strong sexual dimorphism. Additionally, transverse parameters such as breadth of the first and third sternebra and the weight of the sternum were also significantly higher in males, with statistically significant differences ($p<0.001$). Among all parameters, the combined length (M+B) showed the highest mean difference (29.56 mm), suggesting it as the most powerful indicator of sex.

Table 3: Usefulness of Sternal Index in Determining Sex

Parameter	Male Mean±SD	Female Mean±SD	Mean Difference	95% CI	Test value	p-value
Sternal index	54.97±8.37	55.24±9.10	-0.27	-3.45–2.91	Z<1.96	>0.05
Relative width index	91.96±14.77	97.97±12.17	-6.01	-10.71 to -1.31	Z=2.51	>0.05*
Ratio B/M	1.86±0.28	1.86±0.31	0.00	-0.11–0.11	Z=0.02	>0.05

*As per source table, relative width index showed overlap and 0% identification beyond demarking point.
Table 3 evaluates the usefulness of the sternal index and related indices in determining sex. The sternal index showed no statistically significant difference between males and females ($p>0.05$), with overlapping confidence intervals, indicating poor discriminatory ability. Similarly, the ratio of mesosternum to manubrium (B/M) showed identical mean values in both sexes (1.86), further confirming its lack of utility. Although the relative width index showed a numerical difference, it was statistically non-significant and demonstrated considerable overlap, with no specimens identified beyond demarcating points.

Table 4: Accuracy of Different Sternal Parameters for Sex Determination

Parameter	Male identified n (%)	Female identified n (%)	Identification point	Test value	p-value
Length of manubrium	15 (16.85%)	12 (26.66%)	Male >57 mm; Female <40 mm	Z=7.87	<0.001
Length of mesosternum	31 (34.83%)	16 (35.55%)	Male >99 mm; Female <72 mm	Z=9.44	<0.001
Combined length M+B	25 (28.08%)	29 (64.44%)	Male >152 mm; Female <122 mm	Z=10.42	<0.001
Breadth of 1st sternebra	0 (0.0%)	5 (11.10%)	Male >39 mm; Female <18 mm	Z=3.12	<0.001
Breadth of 3rd sternebra	2 (2.24%)	2 (4.44%)	Male >42 mm; Female <18 mm	Z=4.88	<0.001
Weight of sternum	3 (3.37%)	3 (6.66%)	Male >25 g; Female <9 g	Z=4.20	<0.001
Sternal index	0 (0.0%)	0 (0.0%)	No useful identification	Z<1.96	>0.05

Table 4 presents the accuracy of different sternal parameters in sex determination based on identification points. Among all parameters, the combined length of manubrium and mesosternum (M+B) showed the highest accuracy, particularly in females (64.44%), followed by mesosternum length, which identified approximately one-third of both male and female specimens. Manubrium length showed moderate accuracy, while breadth measurements and weight demonstrated very low identification percentages, indicating limited practical usefulness. Notably, the sternal index failed to identify any specimen (0% accuracy), reaffirming its poor diagnostic value. All significant parameters showed highly significant p-values (<0.001), indicating their statistical reliability, but practical applicability varied, with combined length emerging as the most reliable single parameter for sex determination.

DISCUSSION

In the present study, the sternum showed clear sexual dimorphism in most linear and morphometric measurements. The mean length of manubrium was significantly greater in males (51.95±7.79 mm) than females (41.64±6.81 mm), with a mean difference of 10.31 mm ($p<0.001$). This finding is comparable with Singh et al. (2025)[1], Banyeh et al. (2024)[2], and Elmansy et al. (2024)[3], who also observed that male sterna generally showed larger dimensions than female sterna. However, the present study showed that although manubrial length was statistically significant, its practical accuracy was limited, identifying only 16.85% males and 26.66% females. Similar observations were made by Vatzia et al. (2025)[4] and Atal et al. (2020)[5], who reported considerable overlap in manubrial length between males and females.

The mesosternum length was significantly higher in males (95.38±11.64 mm) than females (76.13±10.88 mm), with a mean difference of 19.25 mm ($p<0.001$). This supports the classical observations of Ali et al. (2021)[6], who emphasized that the mesosternum is proportionately longer in males. Kalbouneh et al. (2021)[7] also reported greater mesosternal length

in males. In the present study, mesosternum length identified 34.83% males and 35.55% females, indicating moderate usefulness. This agrees with Tumram et al. (2025)[8], who concluded that mesosternal length was more useful than manubrial length for sex determination.

The combined length of manubrium and mesosternum (M+B) was the most significant parameter in the present study, with males showing a mean value of 147.33±16.19 mm and females 117.77±15.13 mm. The mean difference was 29.56 mm, which was highly significant ($p<0.001$). This parameter also showed the best practical accuracy, especially for females, identifying 64.44% female sterna and 28.08% male sterna. This finding is consistent with Karki et al. (2020)[9], who reported that combined sternal length was one of the most reliable measurements for sex determination.

Breadth of the first and third sternebra also showed significant male predominance. The first sternebra breadth was 26.78±3.66 mm in males and 24.04±5.29 mm in females ($p<0.001$), while the third sternebra breadth was 29.96±7.08 mm in males and 24.68±5.22 mm in females ($p<0.001$). However, despite statistical significance, their practical identification value was poor, especially for male identification. This agrees with Sravan et al. (2025)[10], who reported that breadth measurements often show extensive overlap and are therefore less reliable as independent sex indicators.

The weight of sternum was significantly greater in males (18.52±3.67 g) than females (15.40±4.24 g), with a mean difference of 3.12 g ($p<0.001$). Although statistically significant, it identified only 3.37% males and 6.66% females, indicating limited forensic usefulness. Similar findings were noted by Nasab et al. (2024)[11], who observed that weight may differ significantly between sexes but has poor individual identification value due to overlap.

The sternal index showed no significant difference between males (54.97±8.37) and females (55.24±9.10), with $p>0.05$. It also failed to identify any sternum accurately in both sexes. This finding contradicts Hyrtl's classical law, which suggested that the manubrium-corpus index is higher in females and lower in males. However, it agrees with Aragão et al. (2021)[12], who concluded that sternal index has poor reliability due to extensive overlap between male and female values. Similarly, relative width index and B/M ratio were not useful in sex determination in the present study.

CONCLUSION

The present study evaluated the role of sternal index and various morphometric parameters of the sternum in forensic sex identification among 134 adult human sterna (89 males and 45 females). The findings clearly demonstrated that the sternum exhibits significant sexual dimorphism, particularly in its linear measurements. Among all parameters studied, the combined length of the manubrium and mesosternum (M+B) emerged as the most reliable indicator for sex determination, showing the highest mean difference and better identification accuracy, especially for females. The length of mesosternum also showed good discriminatory potential, followed by the length of manubrium, although the latter demonstrated limited practical applicability due to overlap.

Transverse parameters such as breadth of the first and third sternebra and the weight of the sternum were found to be statistically significant between sexes; however, their utility in actual forensic identification was limited because of considerable overlap in values. This highlights that statistical significance does not necessarily translate into practical forensic usefulness.

Importantly, the sternal index, which has historically been considered a parameter for sex determination (Hyrtl's law), was found to be unreliable in the present study. The index showed no statistically significant difference between males and females and failed to identify any specimen accurately. Similarly, derived indices such as relative width index and ratio of mesosternum to manubrium also lacked diagnostic value due to extensive overlap between sexes.

The study reinforces that direct morphometric measurements are superior to derived indices for sex determination. However, even the best-performing parameters did not achieve 100% accuracy, indicating that the sternum alone cannot be considered a definitive bone for sex determination. It is best used as a supplementary tool, particularly in situations where more sexually dimorphic bones like the pelvis or skull are unavailable.

In conclusion, the combined length of manubrium and mesosternum is the most reliable sternal parameter for sex identification, while the sternal index is not useful in forensic practice. The use of multiple parameters and their combined interpretation can improve accuracy, but caution must be exercised due to overlapping values. Regional variations further emphasize the need for population-specific standards in forensic anthropology.

LIMITATIONS OF THE STUDY

1. The sample size, though adequate, was relatively small and may not represent the entire population.
2. Unequal sex distribution (more males than females) could introduce bias.
3. The study was limited to a specific regional population, reducing generalizability.

4. Presence of overlapping values between male and female measurements reduced diagnostic accuracy.
5. Only dry bones were studied; radiological or clinical correlations were not included.
6. Age-related changes in sternum were not considered, which may influence measurements.
7. Measurement errors due to manual techniques (Vernier caliper) cannot be completely excluded.
8. Soft tissue influence and functional variations were not assessed.
9. Sternal index and derived indices showed poor utility, limiting comprehensive interpretation.
10. Multivariate analysis accuracy was not fully explored in practical classification.

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