Original Article

Morphological and Morphometric Characteristics of the Adult Human Sternum: A Cross-Sectional Anatomical Study

Adabala N. V. V. Veerraju[1]

[1]Professor, Department of Anatomy, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, Andhra Pradesh, India

Abstract

Background: The sternum is a flat bone in the anterior thoracic skeleton. Its clinical importance relates to median sternotomy, the main approach for cardiac operations. The sternum is crucial in CPR, where compressions can cause fractures leading to heart injuries. Dwight and Hyrtl found that in females, the manubrium exceeds half the body length, whereas in males, the body is twice the length of the manubrium. Paterson found the male sternum longer and narrower. Ashley showed that the sternum indicates age, sex, and height in populations. This study aimed to standardize the sternum using morphometric analysis and to establish sex- and dimension-specific ranges. **Material and Methods:** In total, 50 adult sternum (30 male and 20 female) were examined in this study. Morphological and morphometric features, including the shape, length, width, and thickness of the manubrium, body of the sternum, and xiphoid process, were observed and recorded. The total sternal length and sternal angle were measured. The manubrium index, body of the sternum index, and sternal index were calculated and recorded. Measurements were performed using digital Vernier calipers and protractors. **Results:** The predominant shape of the manubrium was trapezoidal, the body of the sternum was longitudinally oval, and the xiphoid process was pointed. The manubrium index measured in male and female sternum was 121.98±4.80 and 117.49±5.06, respectively. The body of the sternum index measured in male and female sterna were 32.47±3.14 and 32.12±3.04 mm, respectively. The sternal index (manubrio-corpus index) measured in male and female sterna were 52.06±2.58 and 59.80±1.92, respectively. **Conclusion:** The standard dimensions of female and male sternum aid in standardizing research on sutures and materials used in median sternotomy. The morphometric findings provide a basis for exploring sternal biomechanics and assist in surgical planning and assessment of suture dehiscence risk. Morphometric standards vary among populations, necessitating specific guidelines for each ethnic group.

Keywords: Mesosternum, Morphometric analysis, Median sternotomy, Sex determination, Sternal index, Sternal Puncture.

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Introduction

The sternum, or breastbone, is a flat bone positioned vertically in the median and anterior parts of the thoracic skeleton. It consists of cancellous bone, which remains filled with hematopoietic bone marrow throughout a person's life.[1] The manubrium is attached to the body of the sternum at its lower border through a symphyseal joint, whereas its upper border, called the jugular notch, is concave and unattached. The manubrium has facets on its sides for the articulation of the first rib and part of the second rib. The body of the sternum is attached to the manubrium at the upper border and to the xiphoid process at the lower border. The lateral borders have facets for the articulation of the second to sixth or seventh ribs.[2]

The sternum has considerable clinical relevance, particularly because median sternotomy remains the most common surgical access for cardiac procedures. In this approach, the bone is divided longitudinally from the jugular notch to the xiphoid process to expose the anterior mediastinum, including the heart and great vessels.[1] Although generally safe, this technique may be complicated by sternal dehiscence, where the two halves of the sternum separate after closure, and by deep mediastinitis. Reported rates range from 0.5% to 2.5%, with some series documenting incidences as high as 8%. The risk of suture line failure is influenced by the closure method, bone quality (including osteoporosis), sex, associated comorbidities, and several perioperative and postoperative factors.[2]

The sternum also plays a central role during cardiopulmonary resuscitation. In active compression–decompression CPR (ACD-CPR), sternal fractures are a well-known complication and may lead to serious cardiac injury and even death.[3] Cadaveric work has shown that these fractures occur more often in women older than 50 years.[4] Osteoporosis is one explanation, but not the only one. The female sternum is generally thinner than the male sternum, which further increases its tendency to fracture.[5] Given the wide person-to-person variation in sternal size and shape, departures from a "standard sternum" are likely to modify the risk of postoperative sternal dehiscence and the likelihood of fracture during resuscitation.

Address for correspondence: Dr. Adabala N. V. V. Veerraju, Professor, Department of Anatomy, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, Andhra Pradesh, India
E-mail: adabalaveerraju23@gmail.com

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While the morphometry of various organs and skeletal parts is well documented, data on sternum morphology and morphometry are limited. These insights are crucial for anthropological research. The most extensive series examining sternal morphometric analysis, variations, and anomalies relied on the macroscopic and radiographic appearances of the sternum in autopsy populations.[6] Wenzel was the first to describe sexual dimorphism of the sternum.[7] The proportion between the lengths of the manubrium and mesosternum varies between sexes.[8] Dwight,[9] and Hyrtl,[10] conducted similar studies and identified a 1:2 pattern in females and a 2:1 pattern in males. In females, the manubrium of the sternum is longer than half the length of the body of the sternum, whereas in males, the body of the sternum is at least twice the length of the manubrium.[9] Paterson,[11] noted that the sternal body is longer and narrower in males than in females.

Ashley,[12] extensively demonstrated that the sternum serves as an indicator of an individual's age, sex, and height, with its measurements affecting the determination of sex and age in European and African populations. Dwight,[9] proposed that the male sternum is significantly longer than the female sternum. He also confirmed that the combined length of the manubrium and mesosternum, along with the total sternal length, is a reliable indicator of an individual's height. Similarly, Macaluso,[13] and Osunwoke,[14] examined sex differentiation in the human sternum by analyzing morphometric measurements across populations. In India, several researchers have conducted studies on sex determination using the sternum. This study aimed to standardize the sternum by size, shape, and sex through complex morphometric analysis and to establish ranges for the standard sternum by sex and individual dimensions.

Materials and Methods

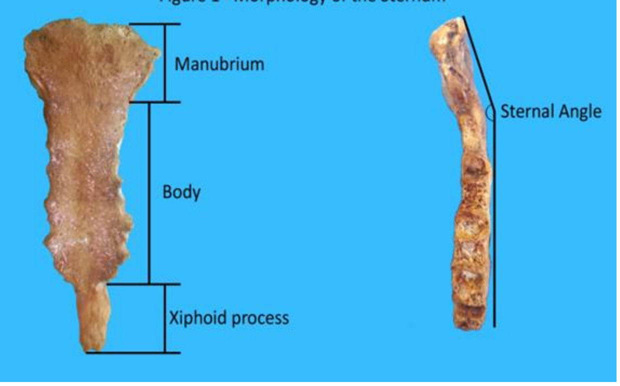
Study design and rationale: This investigation adopted a cross-sectional, descriptive-anatomical design with both qualitative (morphological) and quantitative (morphometric) components. Such a design is particularly suitable for osteological research because it allows the simultaneous documentation of structural variations and precise metric data within a defined series of dry bones, without any intervention or follow-up. By examining all eligible specimens within the study period, the design facilitated the generation of baseline normative values for adult sternal dimensions and shapes relevant to anatomy teaching, forensic anthropology, and thoracic procedures.

Study setting and time frame: The study was conducted in the Department of Anatomy, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, Andhra Pradesh, India. All procedures were performed in the departmental osteology laboratory, which maintains a curated bone bank of human skeletal material for teaching and research. Data collection was conducted over approximately six months in 2024, during which all available eligible sterns were systematically examined. The controlled laboratory environment ensured stable lighting, minimal handling artifacts, and consistent bone positioning during measurements.

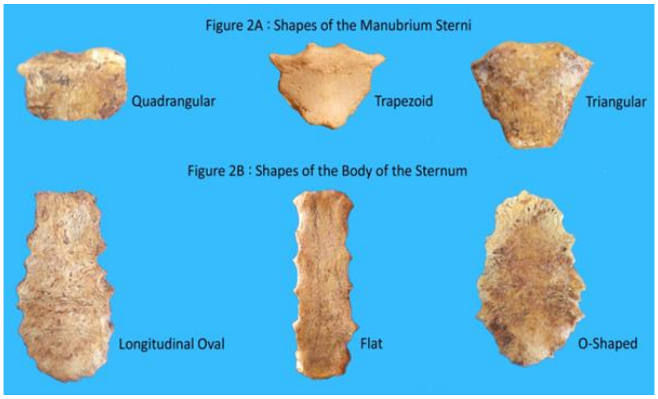
Specimen selection and eligibility criteria: The material for this study consisted of 50 adult human dry sternum: 30 male and 20 female. Sex and adult status were already documented in the departmental osteology register, based on donor records and earlier cataloguing. Only bones that were complete and showed clearly recognisable anatomical landmarks were included. Sterna with obvious damage, post-traumatic distortion, healed fractures, major congenital anomalies, or pathological changes such as destructive lesions or marked osteophytes were excluded, as these could alter measurements. Each accepted specimen received a unique identification code. Information on sex, catalogue number, and storage details was entered into a structured proforma to maintain traceability and reduce selection bias.

Morphometric measurements: Morphometric data were obtained using a digital Vernier caliper with a precision of 0.01 mm. The instrument was calibrated at the beginning of each session according to the manufacturer's instructions. Each sternum was placed on a firm, flat surface and oriented as close as possible to its anatomical position before measurements were taken. Linear parameters included total sternal length, manubrial length, body length, and selected transverse diameters at defined points on the manubrium and body. When a xiphoid process was present, its length and width were also measured. The sternal angle at the manubriosternal junction was recorded using a standard protractor, with its arms carefully aligned along the articular surfaces. All measurements were taken twice by the same observer. If the difference exceeded 0.5 mm, a third reading was added, and the mean of the two closest values was used for analysis to limit random error.

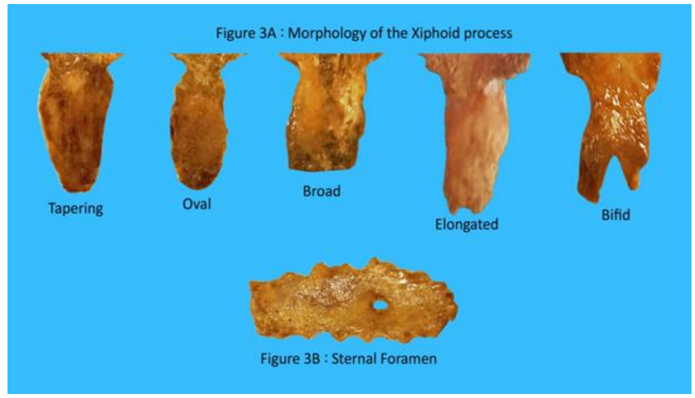
Figure 1 : Morphology of the Sternum



Morphological assessment: Morphological features were studied by careful visual inspection and palpation. Standard anatomical texts and earlier osteological classifications were used as references. The evaluation covered the overall outline of the sternum, the shape of the manubrium and body, the configuration of the xiphoid process, the presence of sternal foramina or accessory notches, and the pattern of fusion at the manubriosternal and xiphisternal junctions. Two anatomists independently recorded these qualitative features and remained blinded to each other's observations. Any disagreement was later discussed and resolved by consensus. After agreement, the different appearances were grouped into predefined morphological categories. Representative specimens are shown in [Figure 1–3], and the main parameters are summarised in [Table 1 and 2].



Data management and statistical analysis: All linear measurements were entered into a spreadsheet and carefully rechecked to detect and correct transcription errors. Descriptive statistics, including mean, standard deviation, and range, were calculated for all linear and angular measurements. A comparative analysis of male and female sternum was planned to use appropriate tests for continuous variables, with p-values < 0.05 considered statistically significant. Morphological categories were expressed as frequencies and percentages.



Ethical considerations: Institutional permission for the use of anonymous donated skeletal material was obtained from the head of the department and the Institutional Ethics Committee of Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram, Andhra Pradesh, in accordance with prevailing guidelines for research involving human tissues and cadaveric specimens. As only dry bones from previously donated bodies were used, issues of informed consent and confidentiality did not directly include living participants.

Results

The results obtained from the examination of the morphological and morphometric features of 50 dry sterna (30 male and 20 female) are recorded and shown in [Table 1 and 2].

Table 1: Morphological appearance of manubrium, body and xiphoid process of the sternum in the present study.

S. No	Part of the sternum	Shape	Number	Percentage
1	Manubrium	Trapezoid	34	68%
		Triangular	10	20%
		Quadrangular	6	12%
2	Body of the sternum	Longitudinally oval	35	70%
		Flat	8	16%
		O-shaped	7	14%
3	Xiphoid process	Tapering	20	40%
		Oval	7	14%
		Broad	7	14%
		Bifid	2	4%
		Elongated	4	8%
		Data not available	10	20%

Various shapes of the manubrium, body, and xiphoid processes of the sternum were observed. The most common shape observed in the manubrium was trapezoid. The manubrium was trapezoid in 34 specimens (68%), triangular in 10 (20%), and quadrilateral in 6 (12%). The most common shape observed in the sternum was an oval longitudinal shape. The body of the sternum was longitudinally oval in 35 specimens (70%), flat in 8 (16%), and O-shaped in 7 (14%). The most common shape observed for the xiphoid process was tapering. The xiphoid process was tapering in 20 specimens (40%), oval in 7 (14%), broad in 7 (14%), bifid in 2 (4%), and elongated in 4 (8%). In 10 specimens (20%), the data were not available as the xiphoid process was not intact (disarticulated). Two specimens (4%) exhibited a foramen in the body of the sternum. No foramina were observed in the manubrium or xiphoid process.

Table 2: Mean, standard deviation and p-value of various parameters of the sternum examined in the present study.

S. No	Parameter	Male Mean±SD (mm)	Female Mean±SD (mm)	P-value
1	Total sternum length	167.38±7.36	159.33±5.39	0.012
2	Manubrium length	47.22±4.23	43.12±3.77	0.027
3	Manubrium width	57.41±3.85	54.66±2.83	0.256
4	Manubrium thickness	12.43±1.82	12.31±1.34	0.789

5	Body length	90.90±7.89	82.02±4.53	0.001
6	Body width	29.21±2.94	26.22±2.00	0.001
7	Body thickness	9.94±1.30	9.54±1.16	0.264
8	Xiphoid process length	26.59±3.01	21.70±3.28	0.000
9	Xiphoid process thickness	6.64±1.62	6.02±1.39	0.000
10	Sternal angle	163.30±5.19	162.62±4.76	0.087
11	Manubrium index	121.98±4.80	117.49±5.06	0.019
12	Body of sternum index	32.47±3.14	32.12±3.04	0.763
13	Sternal index	52.06±2.58	59.80±1.92	0.000

The total sternum length measured in male and female sterna was 167.38±7.36 mm and 159.33±5.39 mm, respectively, with a p-value of 0.012, which was statistically significant. The length of the manubrium measured in male and female sterna was 47.22±4.23 mm and 43.12±3.77 mm, respectively, with a p-value of 0.027, which was statistically significant. The width of the manubrium measured in male and female sterna was 57.41±3.85 mm and 54.66±2.83 mm, respectively, with a p-value of 0.256, which was not statistically significant. The thickness of the manubrium measured in male and female sterna was 12.43±1.82 mm and 12.31±1.34 mm, respectively, with a p-value of 0.789, which was not statistically significant.

The length of the body of the sternum measured in male and female sterna was 90.90±7.89 mm and 82.02±4.53 mm, respectively, with a p-value of 0.001, which was statistically significant. The width of the body of the sternum measured in male and female sterna was 29.21±2.94 mm and 26.22±2.00 mm, respectively, with a p-value of 0.001, which was statistically significant. The thickness of the body of the sternum measured in male and female sterna was 9.94±1.30 mm and 9.54±1.16 mm, respectively, with a p-value of 0.264, which was not statistically significant.

The length of the xiphoid process measured in male and female sternum was 26.59±3.01 mm and 21.70±3.28 mm, respectively, with a p-value of 0.000, indicating a statistically significant difference. The thickness of the xiphoid process measured on male and female sternums was 6.64±1.62 mm and 6.02±1.39 mm, respectively, with a p-value of 0.000, indicating a statistically significant difference. The sternal angles measured in the male and female sterna were 163.30±5.19 mm and 162.62±4.76 mm, respectively, with a p-value of 0.087, which was not statistically significant.

Various indices used for sex determination of the sternum, such as the manubrial index, body of the sternum index, and sternal index (manubrio-corpus index), were calculated using the following formulas. The manubrium index measured in male and female sterna was 121.98±4.80 and 117.49±5.06, respectively, with a p-value of 0.019, indicating a statistically significant difference. The body of the sternum index measured in male and female sterna were 32.47±3.14 and 32.12±3.04 mm, respectively, with a p-value of 0.763, which was not statistically significant. The sternal index (manubrio-corpus index) measured in the male and female sterna were 52.06±2.58 and 59.80±1.92, respectively, with a p-value of 0.000, which was statistically significant. These observations suggest that the manubrium and sternal indices help determine the sex of an individual when only part of a skeleton is available.

Discussion

Heart surgeries often face complications due to suture dehiscence of the sternum and the onset of deep mediastinitis, which are linked to high mortality rates.[15,16] The findings indicate that the general structure of the sternum is similar in both sexes, although the absolute values of the measured parameters differ significantly between the sexes. Typically, the female sternum is shorter, narrower, and thinner than the male sternum. Previous research has suggested that female sex is an additional risk factor for suture dehiscence of the sternum.[17]

When the outlines of the sternum were standardised, a single "standard sternum" pattern was identified in over two-thirds of specimens in both males and females. The remaining third showed clear departures from this pattern, with values more than one standard deviation from the mean, but these atypical forms were relatively uncommon. This distribution is compatible with the functional setting of the sternum. It lies on the anterior thoracic wall, moves constantly with breathing, and is shaped within a truncated cone–like thoracic cage. These factors favour a longitudinally oval sternal body as the dominant or standard form. The measured variables as a whole support the presence of a single prevailing morphology, with a smaller group of atypical shapes representing modifications of this basic type.

The angle of Louis remains a crucial surface landmark for accurate rib counting in clinical practice. In the living subject, the sternal angle is usually visible and palpable, the second costal cartilage is easily located on either side, and the ribs are numbered downward from this level.[18] If the manubrium is abnormally long or short, the sternal angle may be displaced. This can lead to errors in identifying the intercostal spaces and increase the risk of incorrect needle placement during procedures such as thoracocentesis, potentially resulting in iatrogenic injury to mediastinal structures.[19] An unusually long xiphoid process may simulate an epigastric mass on palpation and cause discomfort, so clinicians should recognise this variant to avoid misinterpretation.[20] These observations also carry weight in forensic work. Although the pelvis and skull remain the preferred bones for sex estimation due to their high accuracy,[21] the sternum is a useful alternative when these bones are missing or damaged. In this study, the manubrial index and the manubrio–corpus (sternal) index proved to be reliable osteometric markers for determining sex in unidentified sternal remains.

The variation in the sternal index between males and females was statistically significant. This result aligns with the study by Macaluso et al,[22] who achieved an accuracy of 89.7% in sex identification when the entire sternum was available. Therefore, alternative skeletal elements need to be investigated as potential sex indicators.[23]

Numerous researchers have successfully determined height using long bones and developed various mathematical methods in the process.[24-26] However, the exploration of other flat bones remains incomplete. Height (Y) can be estimated from the manubrium length using the regression formula Y = 160.9 + (1.04 × length of the manubrium) and from the mesosternum length using the formula Y = 137.1 + (3.1 × length of the mesosternum).

In our study, we identified a sternal foramen in 2 specimens (4%), all located in the lower part of the sternal body. Moore et al,[27] reported 135 (6.6 %) sternal foramina in 2016 radiographs in an autopsy group. In the study by Yekeler et al,[28] the incidence of the sternal foramen was slightly higher (6.7%) than that reported in Stark's study (4.3%). In our study, no participant exhibited a foramen in the manubrium. Radiologists and pathologists must recognize these anatomical variations of the sternum and understand their imaging characteristics to avoid diagnostic errors. (28, 29). Sternal clefts may be misdiagnosed as traumatic fractures, whereas sternal foramina may be mistaken for osteolytic lesions.[29] Recognizing a sternal foramen is vital during sternal marrow aspiration because of the risk of heart injury.[28,29]

Conclusion

This study set out to describe the morphological patterns and sex-specific morphometry of the adult human sternum. We found that most manubria were trapezoid. The sternal body was usually longitudinally oval, and the xiphoid process showed wide variation, with tapering forms most frequent. Males had greater total sternal, manubrial, body, and xiphoid lengths, whereas females showed a higher sternal index, reflecting a relatively shorter and broader sternum. These data refine reference standards for thoracic surgery, prosthesis design, and forensic sex estimation. A modest sample size and a lack of age or radiological correlation limit the work. Larger, multi-centric and imaging-based studies are needed to test these patterns and integrate them into clinical and forensic practice.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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