Morphometric Study of the Sternum in Libyan People by CT Scan

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Abstract:
Introduction: The sternum, comprising the manubrium, mesosternum (body), and xiphoid process, varies in length due to biological factors such as age and sex. Understanding these variations is important in forensic, anatomical, and surgical contexts. This study focuses on the morphometric analysis of the sternum in a Libyan population using CT imaging.
Material and method: A cross-sectional anatomical study of 148 CT scan films was obtained from DAR ALSHIFA HOSPITAL (DSH). Individuals aged 20 to 60 were divided into 4 age groups for the sternal parameters, including measurements of the manubrium, mesosternum (body), xiphoid process, and total sternum length, as well as the presence of sternal foramen.
Results: The mean lengths of the sternal components were documented, with the manubrium measuring 4.2 cm in males and 3.8 cm in females. The sternal body length averaged 10 cm in males and 8.2 cm in females. The xiphoid process averaged 3.4 cm in males and 2.9 cm in females. The total sternal length averaged 17.7 cm in males and 14.7 cm in females. Sternal foramina were detected in 8.9% of the cases.
Conclusion: The total length of the sternum and its components significantly varies by sex and age. These findings are relevant for clinical practices involving thoracic anatomy and for forensic age and sex estimation. Further studies with larger populations are recommended to validate these observations.

Keywords: Sternum, computed tomography, morphometric, sternal foramina.

Abbreviations: CT: Computed tomography; DSH: Dar Alshifa Hospital; SPSS: Statistical Package for Social Sciences; SD: Standard deviation.

Introduction:

The sternum, or breastbone, is a flat, vertically oriented bone situated in the midline of the anterior thoracic cage. It is located anterior to the heart (1) and provides crucial protection for the heart and other vital intrathoracic organs, including the lungs and major blood vessels (2). The sternum forms the anterior boundary of the rib cage by articulating with the ribs via their costal cartilages. It is composed of three distinct segments: the manubrium, the body (mesosternum), and the xiphoid process (3). The manubrium is the superior, broad segment featuring a supra sternal notch. The body is the longest, central portion, and the xiphoid process constitutes the inferior, distal part [4]. The sternal angle, also known as the angle of Louis, is a significant anatomical landmark formed by the junction of the manubrium and the body. This angle corresponds anteriorly to the intervertebral disc between the fourth and fifth thoracic vertebrae [4]. The morphometric characteristics of the sternum, which vary based on factors such as sex, age, ethnicity, and congenital anomalies, are essential to evaluate. Precise knowledge of sternal anatomy is critical in various clinical contexts [5], including radiological imaging (e.g., X-rays, CT scans), chest surgery, bone biopsy procedures, and accurate acupuncture [6]. Furthermore, the sternum is a valuable tool in forensic anthropology for determining the sex and age of unidentified human remains. Since bones are the body's primary structural framework and are relatively resistant to post-mortem changes and minor trauma, the sternum's unique dimensions can be used for identification. For example, females typically possess a shorter and thinner sternum compared to males [7]. Computed tomography (CT) scans, particularly multi-detector CT, are the standard diagnostic tools for assessing sternal morphometric parameters. Multi-detector CT provides high-resolution, three-dimensional images that are particularly useful for identifying the presence of sternal foramina [8]. The sternum develops from a pair of vertical mesenchymal bands known as sternal bars, which are located in the ventral body wall. The chondrification process begins in the superior segments and progresses inferiorly, forming the cartilaginous precursors of the three sternal segments [9]. Failure of these sternal bars to completely fuse can result in sternal foramina, which are incomplete perforations that can occur in any sternal segment but are most common in the body [10]. Clinically, awareness of sternal foramina is crucial, as they can be mistaken for gunshot or stab wounds. Furthermore, a lack of awareness of these foramina can lead to iatrogenic complications during medical procedures like acupuncture or sternal biopsy, potentially causing severe cardiac damage and leading to conditions such as cardiac tamponade [2]. This study's primary objective was to measure the lengths of the manubrium, sternal body, xiphoid process, and the total sternal length in a cohort of individuals, correlating these measurements with their age and sex. A secondary aim was to determine the prevalence of sternal foramina within the study population.

Materials and methods:

This study followed a retrospective study design and was carried out on 245 chest CT films for Libyan individuals of both sexes. Subjects were randomly chosen from Dar Alshifa Hospital (DSH), of known birthdate and sex and included those aged between 20 and 60. In this study a number of 148 cases (95 males & 53 females) were included. Patients younger than 20 and older than 60, any data that misses the gender and/or the age, as well as any inappropriate CT image or image with inadequate quality, were excluded from the study. According to the exclusion criteria 97 cases were excluded.

The individuals were divided into 4 groups according to age as follows:

1. Group A: Their ages ranged from 20 years up to 29 years.
2. Group B: Their ages ranged from 30 years up to 39 years.
3. Group C: Their ages ranged from 40 years up to 49 years.
4. Group D: Their ages ranged from 50 years up to 60 years.

Each group has been subjected to the following:

1. Personal information: name, age, and gender.

2. The cases have been examined by chest CT scan as follows: The CT scanner was used for all the thoracic CT procedures. Axial plane images were obtained, then multiplanar reformatting (MPR) of the sagittal images was performed, and three-dimensional images of the sternum were obtained (3).

The following parameters have been measured through these chest CT films:
1. Manubrium length: the distance from the centre of the jugular notch to the centre of the manubrio-sternal junction.
2. Sternal body length: the distance from the manubrio-sternal junction to the xiphi-sternal junction of the sternum.
3. Xiphoid length: the distance from the xiphi-sternal junction to the tip of the xiphoid process.
4. The total length of the sternum from the jugular notch to the tip of the xiphoid process. From 3D CT films: to detect the presence of a sternal foramen.

The morphometric parameters were measured using the RadiAnt DICOM Viewer 2025 (64-bit) (Digital Imaging and Communications in Medicine) program, and then the measurements were analysed in relation to age and sex.
The tests this research used to analyse the data were:
1. Descriptive statistics were performed to calculate the mean and standard deviation (± SD) for the quantitative data.
2. Two-way-MANOVA: Used to compare the mean of more than two groups of quantitative data.
3. Chi-Square test: For comparison between two groups as regards qualitative data.

Statistical analysis: The collected data was processed, computed, and analyzed using SPSS software version 26 (IBM, Armonk, NY, USA). Statistical analysis was conducted using the mean, standard deviation (SD), standard error, and Student's t-test. A P-value below 0.05 indicated statistical significance. Comparisons among genders was evaluated, and results were considered significant when P-value was less than 0.05.

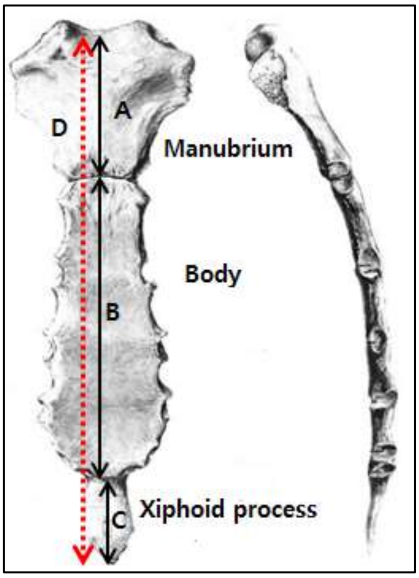

Figure 1: Illustrations showing the methods of measuring the sternal parameters which include the lengths of manubrium (A), sternal body (B), xiphoid process (C), the whole sternal length (D).

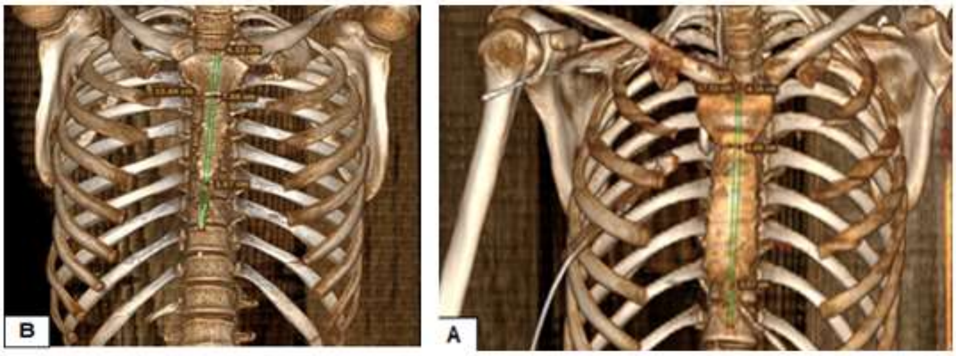

Figure 2: CT image of chest (A &B) showing the methods of measuring the sternal parameters which include the lengths of manubrium, sternal body, xiphoid process, the whole sternal length in males "A" & females "B"

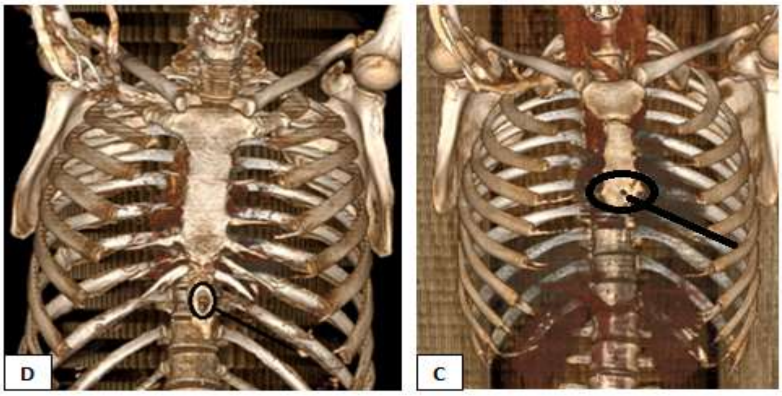

Figure 3: CT image of chest showing the presence of sternal foramen (C) foramen on the body of sternum (D) foramen on the xiphoid process.

Ethical considerations: Ethical considerations will be adhered to throughout the study. This research was done after obtaining the ethical approval from the committee of the Libyan International Medical University.

Study period: The study will be conducted in a 9-month period, from October 2024 to July 2025.

Results

Morphometric parameters of the sternum were measured as shown in Table (1):

Table 1: Shows sternal diameters (manubrium length, body length, xiphoid length, total length of the sternum) in different age groups.

Measurement	Group A (n=32)	Group B (n=28)	Group C (n=46)	Group D (n=42)	*P* value
Manubrium length (cm)	4.22 ± 0.64	4.11 ± 0.55	4.20 ± 0.85	4.07 ± 0.55	0.964
Body length (cm)	9.26 ± 1.39	9.63 ± 1.36	9.73 ± 1.19	9.40 ± 1.35	0.090
Xiphoid length (cm)	2.85 ± 1.11	3.57 ± 1.09	3.60 ± 1.22	3.21 ± 1.18	0.022
Total length (cm)	16.34 ± 2.56	17.31 ± 2.03	17.53 ± 2.25	16.68 ± 2.34	0.013

Manubrium length in different age groups:

Manubrium length was measured as 4.22 ± 0.64 cm in Group A, 4.11 ± 0.55 cm in Group B, 4.20 ± 0.85 cm in Group C, and 4.07 ± 0.55 cm in Group D. These results were not statistically significant across the age groups ($p = 0.964$), indicating minimal change in manubrium length with age.

Body length in different age groups:

The sternal body measured 9.26 ± 1.39 cm in Group A, 9.63 ± 1.36 cm in Group B, 9.73 ± 1.19 cm in Group C, and 9.40 ± 1.35 cm in Group D. Although a general increasing trend was observed, the difference was not statistically significant ($p = 0.090$).

Xiphoid length in different age groups:

Xiphoid length was measured 2.85 ± 1.11 cm in Group A, 3.57 ± 1.09 cm in Group B, 3.60 ± 1.22 cm in Group C, and 3.21 ± 1.18 cm in Group D. These results were statistically significant ($p = 0.022$), showing a notable increase in xiphoid length with age.

Total length of sternum in different age groups (sum of manubrium, body, and xiphoid):

The total length of the sternum was 16.34 ± 2.56 cm in Group A, 17.31 ± 2.03 cm in Group B, 17.53 ± 2.25 cm in Group C, and 16.68 ± 2.34 cm in Group D. These results were statistically significant ($p = 0.013$), indicating that total sternal length increases significantly with age.
Overall, only the xiphoid and total sternal length showed a statistically significant increase with age. The manubrium and body lengths did not show a significant age-related change in the studied population.

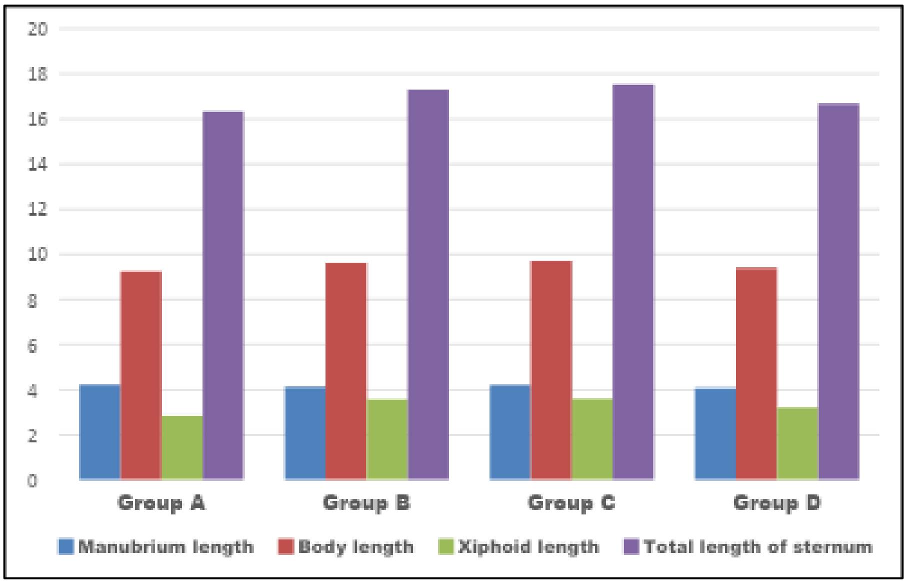

Figure 4: Shows sternal diameters (manubrium length, body length, xiphoid length, total length of the sternum) in different age groups.

Table 2: Showing Sex distribution of length of manubrium.

Manubrium length	**Male**	**Female**	**P value**
Group A	4.43 ± 0.62	3.73 ± 0.34	0.02
Group B	4.30 ± 0.48	3.82 ± 0.55	0.021

Group C	4.48 ± 0.80	3.71 ± 0.72	0.002
Group D	4.16 ± 0.45	3.89 ± 0.67	0.135

The mean length of manubrium in males and females:

The mean length of manubrium in group A was 4.43±0.62 cm in males, while in females was 3.73±0.34 cm. This difference was statistically significant. The mean length of manubrium in group B was 4.30±0.48 cm in males, while in females was 3.82±0.55 cm. This difference was statistically significant. The mean length of manubrium in group C was 4.48±0.80 cm in males, while in females was 3.71±0.72 cm. This difference was statistically significant. The mean length of manubrium in group D was 4.16±0.45cm in males, while in females was 3.89±0.67 cm. This difference was not statistically significant.

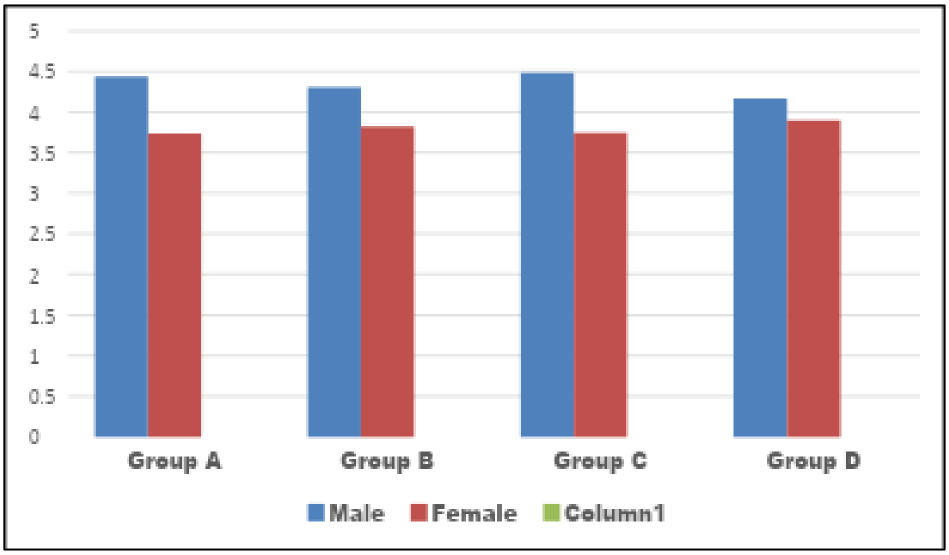

Figure 5: Showing Sex distribution of length of manubrium.

Table 3: Showing Sex distribution of length of the sternal body.

Body length	**Male**	**female**	**p-value**
Group A	9.72 ± 1.30	8.23 ± 1.01	0.003
Group B	10.24 ± 1.35	8.68 ± 0.69	0.002
Group C	10.25 ± 1.00	8.83 ± 0.93	0.000
Group D	10.11 ± 0.96	8.11 ± 0.92	0.000

The mean length of body in males and females:

The mean length of body in group A in males was 9.72 ± 1.30 cm, while in females was 8.23 ± 1.01 cm. The mean length of body in group B in males was 10.24 ± 1.35 cm, while in females was 8.68 ± 0.69 cm. The mean length of body in males in group C was 10.25 ± 1.00 cm, while in females was 8.83 ± 0.93 cm, the mean length of body in group D in males was 10.11 ± 0.96 cm, while in females was 8.11 ± 0.92. for the all groups, the p-value was highly statistically significant.

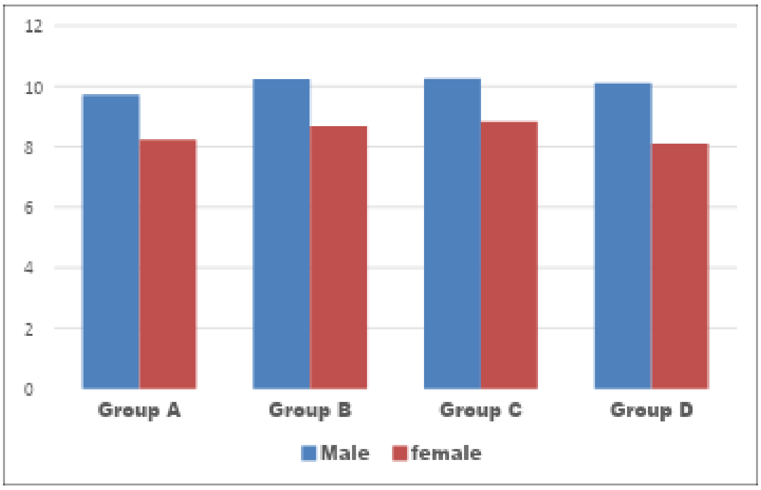

Figure 6: Showing Sex distribution of length of the sternal body.

Table 4: Showing Sex distribution of length of the xiphoid.

Xiphoid length	Male	Female	P- value
Group A	3.03±1.20	2.43±0.73	0.161
Group B	3.72±0.99	3.34±1.23	0.384
Group C	3.90±1.29	3.09±0.87	0.027
Group D	3.45±1.13	2.78±1.19	0.079

The mean length of xiphoid in males and females:

The mean length of xiphoid in group A in males was 3.03±1.20 cm, while in females was 2.43±0.73 cm. This difference was not statistically significant. In group B was 3.72±0.99 cm in males, while in females was 3.34±1.23cm. There is no statistic significant ion both groups. In group C was 3.90±1.29 cm in males, while in females was 3.09±0.87 cm. A p-value of 0.027 is considered statistically significant. In group D was 3.45±1.13 cm in males, while in females was 2.78±1.19 cm. This difference was statistically not significant.

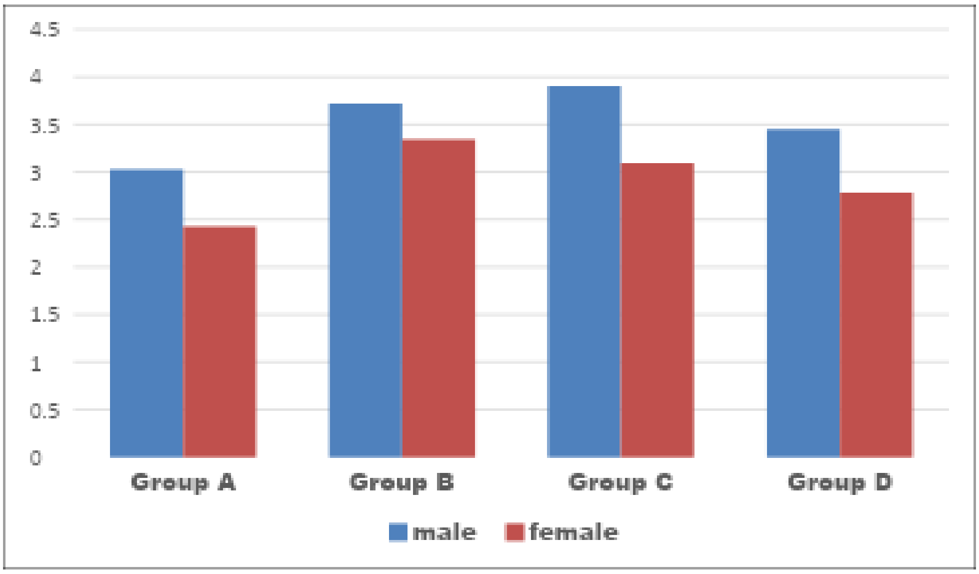

Figure 7: Showing Sex distribution of length of the xiphoid.

Table 5: Showing Sex distribution of total sternal length.

Total sternal length	Male	Female	P value
Group A	17.22±2.40	14.40±1.71	0.002
Group B	18.25±1.68	15.86±1.64	0.001
Group C	18.64±1.82	15.64±1.82	0.000
Group D	17.73±1.85	14.79±1.94	0.000

Total length of the sternum in males and females:

The mean total length of the sternum in group A in males was 17.22±2.40 cm, while in females was 14.40±1.71 cm. In group B was 18.25±1.68 cm in males, while in females was 15.86±1.64 cm. In group C was 18.64±1.82 cm in males, while in females was 15.64±1.82 cm. In group D was 17.73±1.85 cm in males, while in females was 14.79±1.94cm. This difference was highly statistically significant.

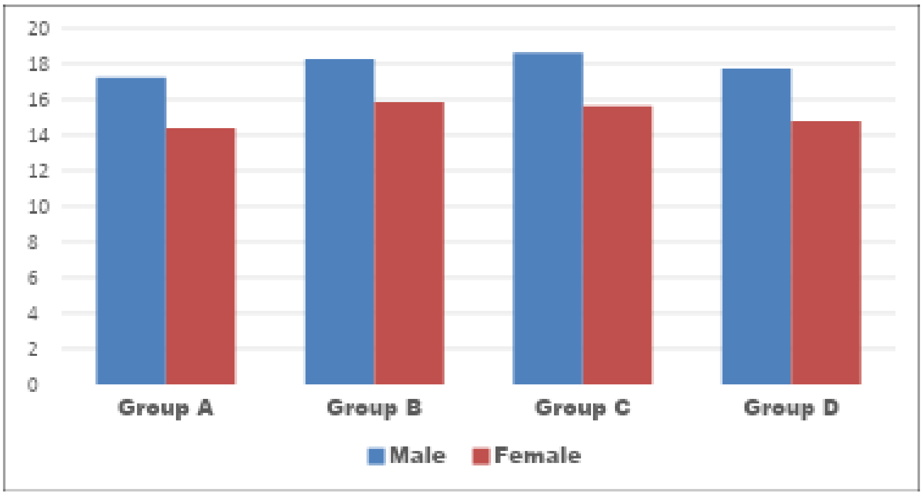

Figure 8: Showing Sex distribution of total sternal length.

Table 6: Showing the presence of sternal foramen.

Presence of Foramen	Group A (10–19)	Group B (20–29)	Group C (30–39)	Group D (40–49)	Total	P value
Foramen in Body	4 (12.5%)	2 (7.1%)	1 (2.2%)	6 (14.3%)	13 (8.8%)	0.343
Foramen in Xiphoid	1 (3.1%)	2 (7.1%)	4 (8.7%)	5 (11.9%)	12 (8.1%)	0.343

Sternal foramina

The foramina were found present in the sternal body and the xiphoid process. overall, they occurred in 25 cases (16.9%). The foramina were present in the body in 13 cases (8.8%), while the xiphoid foramina were present in 12 cases (8. 1%).The presence of the foramina was not found to be correlated with age and sex.

Discussion:

According to this study, the average manubrium length for males and females aged 20 to 60 years was 4.

.4 cm and 3.8 cm, respectively. The findings mirrored those of Eid EM, Abd-Elsalam et al. (2019) [5], who examined 240 normal chests of Egyptians of both sexes, ranging in age from 10 to over 60. The mean manubrium was 3.6 cm for females and 3.8 cm for males. But differing from Selthofer et al. (2006) [11] who studied 90 human sterna with an average age of 65, their results were 5.52 cm in males and 5.34 cm in females. We also found , the mean body length in males was 10.1 cm, while in the females it was 8.4 cm in patients who were in the 20 to 60 years' age group. This body length result was almost identical to that of Ateşoğlu et al. (2018) [12], who conducted MDCT scans on 200 patients ranging in age from 18 to 87 years and found that the males' and females' lengths were 10.2 cm and 8.6 cm, respectively. Contrary to Eid EM, Abd-Elsalam et al. (2019) [5]., who examined 240 Egyptians ranging in age from 10 to over 60, it was 8.6 cm for males and 7.9 cm for females. When compared to earlier research, our measurements reveal a wide range of variation. According to the current study, males' mean xiphoid length was 3.5 cm, while females' was 2.9 cm. These measurements are almost identical with those reported by Selhofer et al., (2006) [11] , who conducted MDCT scans on a cohort of 200 individuals aged 18-87 years, reporting mean lengths of 3.9 cm in males and 2.9 cm in females. The results, however, are not in line with those of Eid EM, Abd-Elsalam et al. [5], whose research on Egyptian participants produced male and female values of 2.5 cm and 1.9 cm, respectively. This indicates that the male measures tend to be larger than the female measures for every age group. The mean total sternal length in the current study was 15.2 cm for females and 17.9 cm for males. The findings of the study by Eid EM and Abd-Elsalam et al. [5] were somewhat in line with our findings; in males, it measured 15.0 cm, while in females, it measured 13.6 cm. However, it differed significantly from Selthofer et al. [11]; it was 18.2 cm for females and 20.6 cm for males. For this, the measurements presented highly differed when compared to the previous studies. By considering our primary findings and earlier research on sternum morphometry, we can answer the study's primary research question. The sternum was found to be significantly longer in males than females, suggesting a significant relationship between sternal bone length and gender. In terms of age, the xiphoid and total sternal lengths gradually increased in length with age, suggesting a strong correlation between age and these parts' growth. Compared to Eid et al. (2019) [5], who used CT to examine 240 individuals and found an incidence of 6.7%, and Boruah et al. (2016) [13], who reported 11.6% in their CT-based studies of 1190 individuals, the incidence of the sternal foramina in this study was 16.9%. In this study, the xiphoid (8.1%) and sternal body (8.8%) both had comparable frequencies of sternal foramina. This finding contrasts with that of Paraskevas et al. (2015) [14], who used CT to locate the majority of foramina in the xiphoid in Greek people. In order to avoid complications during acupuncture and sternal bone biopsy and to prevent the heart from suffering fatal damage, it is essential to recognize and evaluate these variations (Duraikannu et al.) [15]. The purpose of this study was to raise awareness of sternum anatomical variations and congenital foramina. It also aimed to provide useful information that would help radiologists, bone marrow samplers, postmortem forensic reporters, and acupuncturists gain a more complete and accurate understanding of these conditions. Additionally, it emphasizes how clinically significant these morphological observations are for improving diagnostic accuracy and lowering the risk of iatrogenic complications associated with sternal procedures. It also serves to highlight how important sternum radiological evaluations are for estimating human age.

Recommendations:

Considering these findings, it is necessary to take into account significant confounding variables when examining the sternum. It is highly recommended that before surgeons or other specialists attempt any procedures on the sternum, tests such as CT scans be performed to closely examine it. These tests can assist in predicting potential issues and selecting the best surgical techniques. Furthermore, additional research involving a larger sample size from various Libyan cities is required to collect more data on the country's population. Further study is also required to determine the ways in which environmental factors influence the variations in sternum shape among Libyans.

Limitations:

This project encountered several limitations, primarily due to insufficient datasets. The absence of comprehensive data, 3D imaging, or fully ossified sternums resulted in exclusions, which influenced the study's findings. Moreover, essential elements like personal background, including name, age, place of living, current health problems, chest injuries, or previous operations, were excluded because of data restrictions. Ultimately, the sample, restricted to the Benghazi area, might not adequately reflect the larger Libyan populace. Despite these constraints in available resources and information, the study's results align with earlier international research.

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