Libyan Med J. 2026;18(6):301-307
https://doi.org/10.69667/lmj.26601

Libyan Medical Journal

https://lmj.ly/index.php/ojs/index *eISSN: 2079-1224*

Original article

Frequency of Sternal Variations and Anomalies in a Libyan population Using Computed Tomography

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Keywords:
Sternum, Sternal Foramen, Xiphoid Morphology, Anatomical Variation, Computerized Tomography.

ABSTRACT

The sternum is one of the skeletal elements that most frequently exhibits morphological variability in cross-sectional imaging and autopsy series. Congenital anatomical variations of the anterior chest wall can closely mimic, or be obscured by, acquired pathologies such as malignancies, fractures, or severe chest trauma. Therefore, a precise understanding of these benign variants is critical to prevent diagnostic errors. This study aimed to identify the prevalence and morphological diversity of anatomical variations of the sternum within a Libyan population in Benghazi using multi-detector computed tomography (MDCT) scans. This retrospective cross-sectional study was carried out from September 2024 to March 2026. The information was collected from 320 randomly chosen chest CT scans of patients who came to the Benghazi Medical Center (BMC). Patients are male and female Libyan patients (159 women and 161 men) aged 10 and above. Two examiners examined each scan. The data collected was analyzed, and results were obtained. This retrospective cross-sectional study evaluated the prevalence and morphological diversity of sternal variations using MDCT scans of 320 Libyan patients (161 males, 159 females) at the Benghazi Medical Center. The findings revealed that anatomical variants are relatively common, occurring in 26.25% (n = 84) of the total population, with a higher overall prevalence observed in males (32.3%) than in females (20.1%). Variations of the xiphoid process heavily dominated the cohort, with a double-ended (bifid) xiphoid process emerging as the single most common anomaly (33.3%, n = 28), followed by the sternal foramen (17.9%, n = 15), which uniquely demonstrated a female predominance. Furthermore, complex or rare anomalies such as triple-ended and four-ended xiphoid processes, bilateral suprasternal bones, and manubrial foramina were observed exclusively in male subjects, while 10.7% of all variant cases presented with multiple co-occurring anomalies. These regional baseline data underscore the clinical importance of pre-procedural thoracic imaging to prevent diagnostic errors or inadvertent iatrogenic punctures during invasive chest wall interventions.

Introduction

The sternum is a flat axial bone and a part of the anterior thoracic wall has three parts: manubrium, body, and xiphoid process. The sternal bone ossifies from a cartilaginous precursor, starting from the 5th month of prenatal life to just before birth. The development processes of the sternum continue even after birth, till calcification and fusion of sternal body segments is usually complete by 25 years of age. Any failure in this developmental process results in sternal variations and anomalies. (1) In the first embryologic development of the sternum, there are two cartilaginous bars, one on each side of the median plane, which are attached to the cartilages of the upper nine ribs on their own side. The cartilaginous sternum is formed by the fusion of these two bars along the midline and ossified from six centers. They divide the sternum into six transverse pieces and emerge between the articular facets for the costal cartilages. One for manubrium: First appears in the sixth month and rarely joins with other centers except at an old age. Four for the body: The first of these four occurs in the sixth month, followed by the second and third in the seventh, and the fourth one year after birth. After puberty, they come together. Rare sternal foramina or sternal fissures are caused by incomplete or uneven fusion of sternal bars in this area, along with eccentric sites of ossification. One for the xiphoid process: It first presents between the ages of five and eighteen, but it is still partially cartilaginous and may last throughout adulthood.

Compared to manubrial and gladiolal malformations, xiphoid abnormalities are uncommon. (2,3) Multiple sternal variations have been identified, like: Suprasternal or episternal ossicle or suprasternal bone, suprasternal tubercle, manubriosternal and sternoxiphoidal fusion, sternal and xiphoid foramen, sternal cleft and band, sternal defect or notch, xiphoid ending, ossification, and xiphoid ligament calcification. All

Received*: 27-03-2026 -* ***Accepted****: 25-05-2026 -* ***Published****: 01-06-2026*

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of these variations and anomalies have been frequently identified by multidetector computed tomography (MDCT).(1)
Serious complications after sternal puncture for bone marrow biopsy or acupuncture have been reported. Fatal cardiac tamponade resulting from a congenital sternal foramen located in the inferior part of the sternum and a thin sternal body was seen during the sternal puncture. Therefore, the awareness of the presence of sternal variations and anomalies and understanding their clinical interference is important to prevent these fatal complications.[4,5] Furthermore, sternal variation and anomalies are underreported in routine radiological practice and usually remain poorly understood outside specialized literature; therefore, a cross-sectional study of sternal variations and anomalies by CT scan in a specific population is highly important to improve diagnostic accuracy and enhance procedural safety. This study aims to assess the frequency of sternal variation and anomalies detected by CT scan in our population (Libyan people who live in Benghazi).

Methods

Participants and CT imaging

This retrospective, cross-sectional study included 320 individuals who underwent thoracic computed tomography (CT) scans between September 2024 and March 2026 at the Benghazi Medical Center (BMC). In all included cases, the entire sternum was fully intact. The images were evaluated in the axial, sagittal, and coronal planes using multiplanar reconstruction (MPR) with a bone algorithm. Sternal variations were subsequently identified utilizing maximum intensity projection (MIP) and volume rendering (VR) techniques. The study population consisted of Libyan males (n = 161) and females (n = 159) of known sex, ranging in age from 10 to 80 years.

Eligibility criteria

Patients were included in the study if they underwent thoracic CT examinations that demonstrated optimal image quality and clarity, and possessed complete demographic documentation, including verified age and sex. Patients were excluded from the study based on the following criteria: 1) the presence of any gross pathological conditions or structural distortions affecting the sternum, such as primary bone malignancies, metastatic lesions, osteomyelitis, or severe traumatic fractures. 2) Motion artifacts or poor-resolution CT scans that compromised the precise evaluation of sternal morphology.

Image Analysis

All thoracic CT examinations were performed using a standard multi-detector CT scanner. Initial data acquisition was obtained in the axial plane, followed by multiplanar reformation (MPR) to generate sagittal and coronal views. Subsequently, high-resolution three-dimensional (3D) reconstructions of the sternum were generated to facilitate detailed morphological evaluation.

The sternal variations and anomalies have been observed through these chest CT films

Sternal foramen, Sternal cleft, Suprasternal bone (accessory bone at the upper margin of manubrium), Sternal tubercle (suprasternal bone fused with the manubrium), Elongated xiphoid process (>4 cm), Manubriosternal fusion, Xiphisternal fusion, Xiphoid process morphology (absence, single, double, or Triple ending), and Xiphoid foramina.

Ethical considerations

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

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Figure 1: Chest CT coronal image of sternum showing A) 36-year-old woman with sternal foramen and two xiphoidal foramina (CT image illustrates the xiphoid process with two foramina), B) 57-year-old man with sternal foramen in the body, and C) 72-year old man with xiphoidal foramen.

Figure 2: Chest CT coronal image of sternum, showing A) 44-year-old man with Double-ended xiphoid processes, B) 39-year-old man with Triple-ended xiphoid processes, and C) 61-year-old man with Single elongated xiphoid processes.

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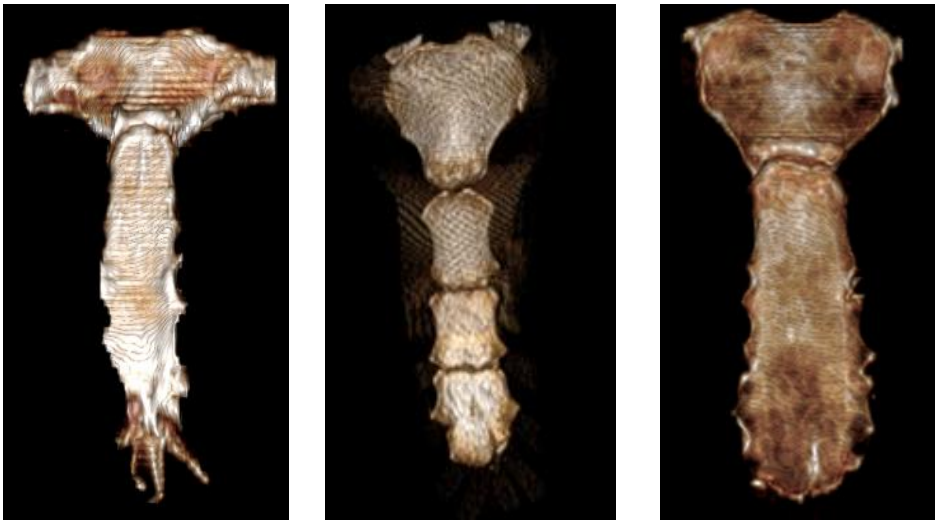

Figure 3: Chest CT coronal image of sternum, showing A) 64-year-old man with Four-ended xiphoid process, B) Coronal image of sternum shows non-fused sternal body segments in a 12-year-old child, C) 65-year-old woman with absence of xiphoid process.

Results

A total of 320 patients were scanned and evaluated in this study, comprising 161 males (50.31%) and 159 females (49.69 %). The overall prevalence of sternal variations within the entire study population was found to be 26.25% (n = 84). When analyzed by gender, a notable discrepancy was observed: sternal variants were considerably more prevalent in male subjects, appearing in 32.30 % (52/161) of all males, compared to only 20.13 % (32/159) of female subjects. Conversely, the absence of any sternal variations was documented in 73.75% (n = 236) of the overall cohort, representing 67.70 % of the male group and 79.87% of the female group, respectively (**Table 3**).

Table 1. Frequencies of sex

Sex	**Counts** (NO)	**% of Total**
Male	161	50.30%
Female	159	49.70%
Total	320	100%

Table 2. Patients with and without sternal variants

Total Patients	**Without Sternal Variants**	**With Sternal Variants**
320 (100.0 %)	236 (73.75 %)	84 (26.25 %)

Table 3. The distribution of patients with and without sternal variants by gender

Gender	**With Sternal Variants**	**Without Sternal Variants**	**Total n (%)**
Male	52 (32.3%)	109 (67.7%)	161 (100%)
Female	32 (20.1%)	127 (79.9%)	159 (100%)
Total	84 (26.2 %)	236 (73.8 %)	320 (100 %)

Table 4. Distribution of Specific Sternal Variations by Gender (N = 84)

Sternal Variation	**Male (n)**	**Female (n)**	**Total (n)**
Suprasternal Bone -Bilateral	1	0	1
Manubrial foramen	1	0	1
Sternal foramen	6	9	15
Xiphoid foramen	7	3	10
Elongated xiphoid processes	8	1	9
Double-ended xiphoid processes	14	14	28
Triple-ended xiphoid process	4	0	4
Four ended xiphoid processes	1	0	1
Absent xiphoid process	2	1	3
Xiphisternal Fusion	2	1	3

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As detailed in Table 4, a diverse spectrum of anatomical anomalies was observed among the 84 patients presenting with sternal variations. The most frequently encountered variation was the double-ended xiphoid process, accounting for 33.3% (n = 28) of all variations, distributed perfectly equally between male (n = 14) and female (n = 14) cohorts. This was followed by the sternal foramen at 17.9% (n = 15), which notably showed a higher frequency in females (n = 9) compared to males (n = 6). Interestingly, certain rare variations showed strict gender-specificity within our sample size. For instance, the triple-ended xiphoid process (n = 4), bilateral suprasternal bone (n = 1), four-ended xiphoid process (n = 1), and manubrial foramen (n = 1) were observed exclusively in male patients. Furthermore, a complex clinical finding was the presence of co-occurring variants; 10.7% (n = 9) of the variant population presented with more than one variation simultaneously, comprising 5 male and 4 female subjects (Table 5)."

Table 5. Prevalence of Co-occurring Multiple Sternal Variations

Category	Male (n)	Female (n)	Total (n)	% of Total Sternal Variants
More than one variation	5	4	9	10.70%

Table 6. Percentages Relative to the Sternal Variant Group (N = 84)

Sternal Variation	Male (n)	% within Male Variants (n=52)	Female (n)	% within Female Variants (n=32)	Total (n)	% of Total Variants (N=84)
Double-ended xiphoid processes	14	26.9%	14	43.8%	28	33.3%
Sternal foramen	6	11.5%	9	28.1%	15	17.9%
Xiphoid foramen	7	13.5%	3	9.4%	10	11.9%
Elongated xiphoid processes	8	15.4%	1	3.1%	9	10.7%
Triple-ended xiphoid process	4	7.7%	0	0.0%	4	4.8%
Absent xiphoid process	2	3.8%	1	3.1%	3	3.6%
Xiphisternal Fusion	2	3.8%	1	3.1%	3	3.6%
Suprasternal Bone - Bilateral	1	1.9%	0	0.0%	1	1.2%
Manubrial foramen	1	1.9%	0	0.0%	1	1.2%
Four ended xiphoid processes	1	1.9%	0	0.0%	1	1.2%
More than one variation	5	9.6%	4	12.5%	9	10.7%

Table 7. Prevalence Relative to the Total Scanned Population (N = 320)

Sternal Variation	Male (n)	% of Total Males (N=161)	Female (n)	% of Total Females (N=159)	Total (n)	% of Total Population (N=320)
Double-ended xiphoid processes	14	8.70%	14	8.81%	28	8.75%
Sternal foramen	6	3.73%	9	5.66%	15	4.69%
Xiphoid foramen	7	4.35%	3	1.89%	10	3.13%
Elongated xiphoid processes	8	4.97%	1	0.63%	9	2.81%
Triple-ended xiphoid process	4	2.48%	0	0.00%	4	1.25%
Absent xiphoid process	2	1.24%	1	0.63%	3	0.94%
Xiphisternal Fusion	2	1.24%	1	0.63%	3	0.94%
Suprasternal Bone - Bilateral	1	0.62%	0	0.00%	1	0.31%
Manubrial foramen	1	0.62%	0	0.00%	1	0.31%
Four ended xiphoid processes	1	0.62%	0	0.00%	1	0.31%
More than one variation	5	3.11%	4	2.52%	9	2.81%

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Among the subgroup of patients with detected sternal anomalies (N = 84), a double-ended xiphoid process was the absolute most prominent feature, representing 33.3% of the total variants by 28 patients and demonstrating a high relative frequency in both variant males (26.9%), 14 patients out of 52 patients, and variant females (43.8%), 14 patients out of 32 patients. In terms of the entire study population (N = 320), double-ended xiphoid processes occurred at a steady baseline rate of 8.75% overall. Conversely, the second most frequent variant, the sternal foramen, exhibited a clear sex preference, making up 28.1% of all female variations compared to only 11.5% of male variations, corresponding to an overall population prevalence of 5.66% among all females and 3.73% among all males.

Discussion

The sternum is derived from a pair of longitudinal mesenchymal condensations, the sternal bars, which develop in the ventrolateral body wall. The sternal bars meet at the midline and start to fuse. Fusion begins at the cranial end of the sternal bars and proceeds caudally until the xiphoid process is formed in the ninth week. The sternal bones, like the ribs, ossify from cartilaginous precursors. The sternal bars ossify in the craniocaudal order from the fifth month to shortly after birth to form the three definitive bones of the sternum: the manubrium, body, and xiphoid process.(6) Any failure in this developing process results in sternal malformations of varying degrees, such as fissures and foramina.(7-9) Inadequate fusion of the inferior end of the sternum may result in a bifid or perforated xiphoid process.(10)

This study included 320 patients (161 men, 50.31%, and 159 females, 49.69%) who were scanned and assessed. Sternal variations were observed in 26.25% (n = 84) of the study population. The gender analysis revealed that sternal variations were more common in males (32.30 % or 52/161 male subjects) than in females (20.13% or 32/159 female subjects). However, 73.75% (n = 236) of the whole cohort, 67.70% of the male and 79.87% of the female groups, respectively, did not exhibit sternal changes (see Table 3). The overall prevalence of sternal variations in our Libyan population (26.3%) is in good agreement with the international radiological literature on Multi-Detector Computed Tomography (MDCT) . Our results are well within the commonly reported global range of 20%-30% for congenital sternal defects. While ethnic variations are seen, this rate is close to the observations of Asghar et al.(11) in a South Asian community, where the frequency was 28.1%.

The sternal foramen was detected in 17.9% (n=15/84) of the variant population in our study and was a significant finding. Interestingly, our data showed that females were more frequent (n = 9) than males (n = 6). But in classic literature like Yekeler et al. (2006) (12) and Bayarogullari et al. (2014) (13), sternal foramina generally showed equal gender distribution or slight male predominance. The overrepresentation of females in our Libyan sample may indicate possible regional genetic differences in the fusion of the primitive cartilaginous sternal bars during embryonic development. The sternal foramen is a round defect in the lower part of the sternum due to the incomplete fusion of several ossification centers. It is usually asymptomatic and may be accidentally discovered by CT. (14) Sternal foramina were found in 6.7% of a large autopsy population. (8) These sternal foramina were located in the body of the sternum, and were often single.. They also observed a foramen in the manubrium. Similar results were found by Moore et al. (9) In an autopsy population on plastron radiographs, 135 (6.6%) sternal foramina were found in 2,016 radiographs. Stark found six cases (4.3%) of a midline sternal foramen from 140 chest CTs. The percentage of sternal foramina in our subjects was slightly higher than that of Yekeler et al. (12) (4.69% vs. 4.5%) and Stark's study (15) (4.69% vs. 4.3%).

On the other hand, the xiphoid process can be wide, bifid, trifurcated, duplicated, deflected or absent. Different xiphoid morphologies, such as bifid or trifurcated xiphoid processes, are due to incomplete fusion of ossification centers. (16) Morphological variations of the xiphoid process dominated our results, with the double-ended (bifid) xiphoid process being the most common variation (33.3%). The xiphoid process is the most changeable part of the human sternum, according to recent imaging studies, which are strongly consistent with this high rate of xiphoid bifurcation. Additionally, only male patients in our study had the triple-ended (n=4) and four-ended (n=1) xiphoid processes. This validates the developmental theory that the ultimate ossification patterns of the lower sternal segments may be influenced by testosterone or sex-linked variable chest wall kinematics during late skeletal maturation. In the present study. A xiphoidal foramen is a highly frequent variation and a single foramen is the most common type of variation (3.13%).

According to Yekeler et al. (12) 's study in Istanbul, Turkey, which evaluated MDCT images of 1000 consecutive patients, the incidence of xiphoid foramen was 27.4%, and the incidence of double-ended xiphoid process was 27.2% [Yekeler]. 86 dry sterni were used in the study by Shivakumar G et al. (17) 3.5% of cases had xiphoid foramen, and 4.6% had bifid xiphoid process. 5.8% had broad, thin xiphoid processes, whereas 7% had elongated ones. (17) Xiphoid foramen was observed in 2.5% of the 80 cadavers examined by El-Busaid et al. (16), bifurcated in 10 cases (5M, 5F) (12.5%), and duplicated in 6 cases (4 M, 2 F) (7.5%). (16). The sternum's xiphoid process frequently has variations and foramina. Because of their close proximity

Received*: 27-03-2026 -* ***Accepted****: 25-05-2026 -* ***Published****: 01-06-2026*

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to the heart, lungs, diaphragm, liver, and stomach, they are clinically significant. These differences could be mistaken for a traumatic fissure, fracture, or epigastric tumor. (16)
Sternal anatomy can be revealed, and variations and anomalies can be described using MDCT scans. Understanding how sternal changes and anomalies appear on MDCT allows for a more accurate differential diagnosis with pathologic diseases. Lastly, an important clinical finding is that 10.7% (n=9) of our variant cases had multiple co-occurring variants. Procedural medicine procedures such as bone marrow aspiration, acupuncture, or anterior chest trauma assessment have a significantly increased risk of an accidental cardiac or internal thoracic artery puncture when an undiagnosed sternal foramen and modified xiphoid landmark are present. Our regional data suggest the need to confirm preprocedural CT images and not rely on the typical textbook anatomy.

Conclusion

This study provides the first comprehensive, multi-detector computed tomography (MDCT) based evaluation of sternal variations within a Libyan population. The findings reveal that structural variations of the sternum are a frequent phenomenon rather than an exception, occurring in 26.25% of the studied cohort. The structural morphology of the sternum is highly diverse, with variations in the xiphoid process being the most dominant. A double-ended (bifid) xiphoid process represents the single most common variation (33.3% of all variants), showing a uniform distribution across both genders. However, more complex anomalies, such as triple-ended and four-ended xiphoid processes, alongside bilateral suprasternal bones and manubrial foramina, appear to be exclusively male-specific traits in this population. Conversely, the sternal foramen, the second most common variant overall, demonstrates a notable female predominance. Furthermore, the co-occurrence of multiple variations in 10.7% of variant cases underscores the intricate nature of sternal development. Clinicians, radiologists, and anthropologists need to be aware of these variations, and their presence should be taken into consideration in everyday practice in Libya. A clear understanding of these regional prevalence rates is vital for minimizing risks during blind clinical procedures, such as bone marrow aspirations, sternal punctures, acupuncture, and blind chest tube insertions. Awareness of these developmental variants prevents critical diagnostic errors, ensuring that benign congenital anomalies (like a sternal foramen or a missing xiphoid process) are not mistaken for osteolytic lesions, fractures, or traumatic sternal dehiscence on imaging.

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Received*: 27-03-2026 -* ***Accepted****: 25-05-2026 -* ***Published****: 01-06-2026*