Bratislava Medical Journal (2025) 126:872–880
https://doi.org/10.1007/s44411-025-00114-8

RESEARCH

In Vivo Morphology of the Sternum with Emphasis on the Frequency of Sternal Foramen

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Received: 23 February 2025 / Revised: 12 March 2025 / Accepted: 14 March 2025 / Published online: 31 March 2025

Abstract

Objective To determine the incidence and morphology of the foramen in the sternum and to investigate the connection between the foramen and the types of xiphoid process terminations.

Materials and Methods A total of 1600 subjects over the age of 18 were evaluated retrospectively with three-dimensional bone configuration from computed tomography. The localization, morphology of the sternal foramen, and types of xiphoid process terminations were investigated.

Results A sternal foramen was found in 127 subjects, with 74 (58.3%) located in the corpus and 53 (41.7%) in the xiphoid process. The xiphoid process termination types were as follows: single in 87 subjects (68.5%), double-ended in 34 subjects (26.8%), and triple-ended in 6 subjects (4.7%). No statistically significant correlation was found between xiphoid process termination type and foramen localization ($p = 0.92$, $p > 0.05$).

Conclusion The sternal foramen is of clinical important due to the important vital structures such as pericardium and pleura located posteriorly. Due to the high incidence of the sternal foramen and its morphologically large area, preliminary screening must be performed before clinical applications to the region. In addition, the sternal foramen is an important embryological variation that should be taken into consideration in terms of forensic medicine research and medical education.

Keywords Sternal foramen · Sternum morphology · Xiphoid process ending type · Sternum anatomy · Radiological evaluation of the sternum

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1 Introduction

The sternal foramen is a congenital anomaly resulting in complete perforation of different areas of the sternum [1]. The sternum begans developing during the sixth week of embryonic life, forming two sternal bars from mesenchymal tissue. Starting in the tenth week of gestation, the sternal bars begin to fuse craniocaudally along the midline [2]. Ossification progress segmentally, with each segment referred to as a sternebra. Sternal foramen occurs when the ossification of the sternebra is not properly completed [3–5].

The sternum is positioned anterior to the vital organs, namely the lungs and the heart. Sternal foramen is typically asymptomatic. Understanding these variations during surgical procedures is crucial to avert potential consequences [5]. The foramen located in the corpus sterni and the xiphoid process hold significant clinical relevance. The application of bone marrow biopsy and acupuncture may result in harm to the pericardium or pleura if the existence of these foramen is overlooked. It is also important to know the incidence of sternal foramen in forensic medicine [6, 7].

The xiphoid process, the terminal segment of the sternum, is the last to undergo ossification. While the xiphoid process is characterized as single-ended in most references, it may terminate with various alternative forms [8, 9].

The Louis angle (sternal angle); is an important angle formed between the manubrium and the body of the sternum. The normal value of this angle is between 145 and 175 degrees. If the Louis angle is above or below this reference range, it can cause chest deformities and also affect the rib count in the clinic. It is important for the surgical procedures to be performed correctly in the clinic [10, 11].

The frequency of sternal foramen and xiphoid process morphology has been examined radiographically and in cadaveric studies across several research investigations [4, 12–14]. The objective of this study was to ascertain the incidence of sternal foramen and the classification of xiphoid process in a broader population. In addition, to contribute to the literature for thoracic surgery and forensic medicine research by determining the location of the sternal foramen and by morphological measurements.

2 Material and Methods

Ethical approval for this retrospective investigation was acquired from the Alanya Alaaddin Keykubat University Clinical Research Ethics Committee, with approval number 13–12 given on 27 September 2023.

Patients aged 18 and older who received thoracic computed tomography (CT) for diverse indications between June 15, 2022, and June 15, 2024, were retrospectively evaluated. Patients who received thoracic surgery for whatever indication, those who had a bone marrow biopsy, and individuals with thoracic trauma resulting from vehicular accidents were excluded from the study.

CT scans were conducted using a 16-detector CT apparatus (Toshiba Alexion™/Advance, Toshiba Medical Systems Corporation, Nashua, Japan). The parameters for the chest CT were established as follows: 1 mm slice thickness; 120 kVp; 50–65 mAs; 0.938 pitch; 0.75 s rotation time; 16×1 collimation; 512×512 matrix; and 250×300 mm field of view. Assessments were conducted via three-dimensional (3D) multiplanar image reformation on a radiology workstation (Sectra Workstation IDS 7, Linköping, Sweden).

CT images of 1600 patients included in the study was evaluated by an experienced radiologist using 3D bone configuration. The presence and location of the sternal foramen was determined. Sternal foramen were classified according to their localization in the corpus and xiphoid process. Furthermore, costal foramina identified during the assessment were recorded (Fig. 1). The xiphoid termination types of the patients with foramen were determined (Fig. 2). Additionally, the Louis angles of patients with foramen were measured and recorded between the manubrium sterni and the sternal body.

The transverse and vertical diameters of the identified foramen were measured (Fig. 3). The closeness of the foramen to the pericardium and pleura was observed. In patients with foramen: the distance between the sternal foramen and the skin (subcutaneous tissue distance), bone width and the distance from the skin to the intrathoracic area were measured on the radiologist workstation (Fig. 4).

The area measurement of the foramen was made by transferring the CT images obtained in DICOM format to the MicroDicom software. 'Closed curve' was selected from the 'Measure and annotate' section, and then the foramen area was automatically calculated by the software (Fig. 5).

In the data analysis, descriptive statistics are provided, including mean, standard deviation, frequency, and percentage values. The Kolmogorov–Smirnov test was utilized to assess the assumption of normality in the data. Non-parametric tests were utilized due to the non-normal distribution of the measurements in the study and the small sample sizes. The Mann–Whitney U and Kruskal–Wallis tests were employed to analyze the differences among the study groups. Chi-square analysis was employed to assess categorical variables. P values below 0.05 were regarded as statistically significant in the study. Analyses were conducted using the SPSS 25.0 software package.

3 Results

In the study, it was determined that sternal foramen was observed in 8% ($n = 127$) of the 1600 samples. It was observed that sternal foramen was detected with 44.1% male and 55.9% female. It was observed that foramen localization was in the corpus region with 58.3% and in the xiphoideus process region with 41.7%. It was observed that the xiphoid termination type was single with 68.5%, double-ended with 26.8% and triple-ended with 8% (Table 1).

Mean transverse diameter measurements were found to be 5.21 ± 1.08 mm, mean vertical diameter measurements were found to be 7.77 ± 1.63 mm. Mean foramen area was found to be 63.59 ± 19.78 mm^2, mean bone width measurements were found to be 9.33 ± 1.91 mm. Mean subcutaneous distance measurement was found to be 13.43 ± 4.06 and mean the distance from the skin to the intrathoracic area was found to be 22.75 ± 3.15 mm. The mean age of the general group was found to be 52.79 ± 13.73 (Table 2).

Transverse diameter measurement was found to be significantly higher in subjects with a sternal foramen in the corpus than in subjects with a sternal foramen in the xiphoid process. ($p = 0.04$, $p < 0.05$). It was determined that the

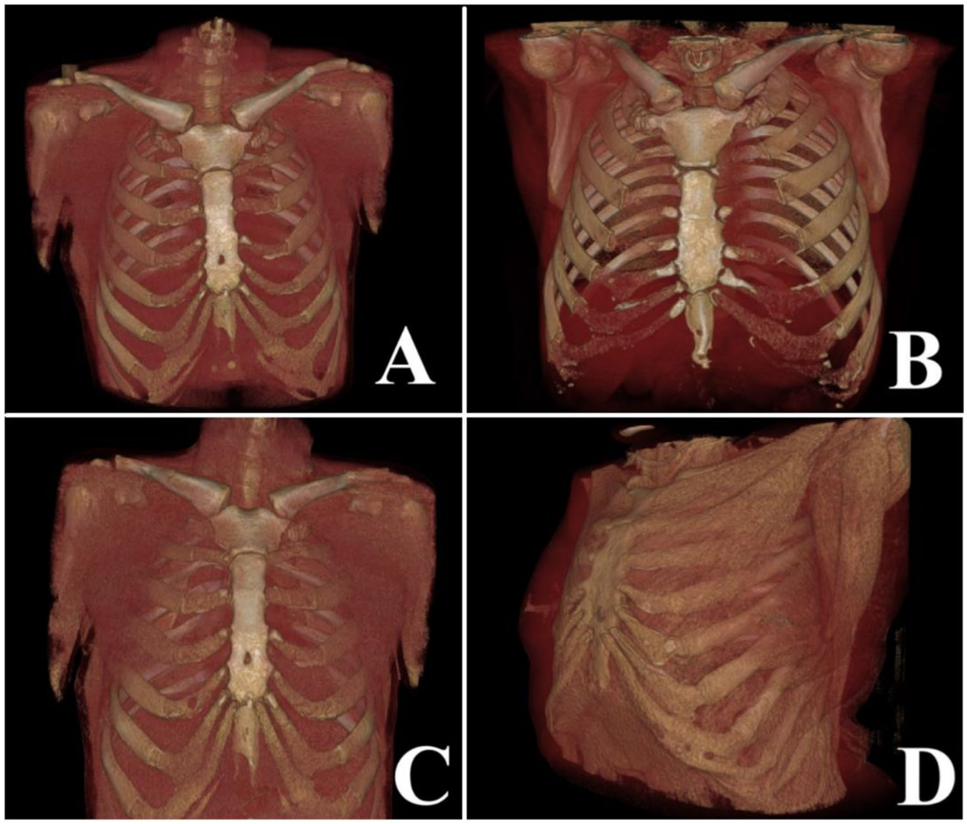

Fig. 1 Foramen localizations (**A** Foramen localized in the corpus, **B** Foramen localized in the xiphoid process, **C** Sternal foramen and costal foramen, **D** Sternal foramen and triple costal foramen)

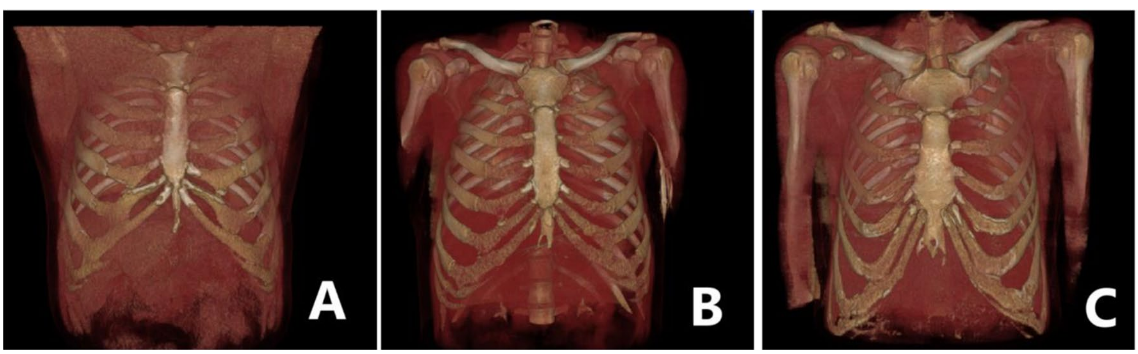

Fig. 2 Xiphoid process ending type. (**A** Single-ended, **B** Double-ended, **C** Triple-ended)

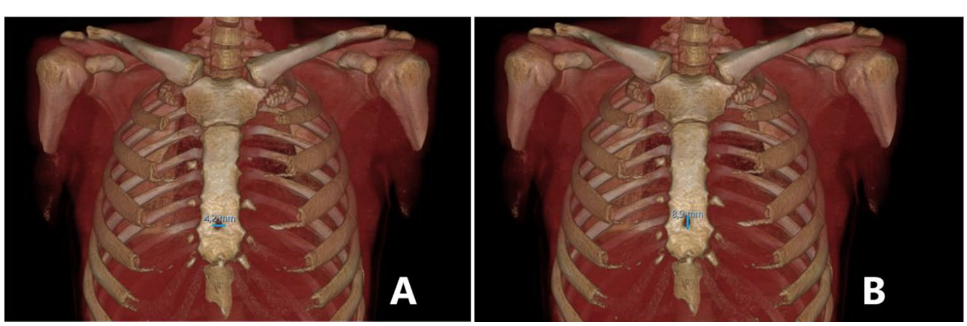

Fig. 3 Transverse diameter (**A**) and vertical diameter (**B**) measurements of the foramen

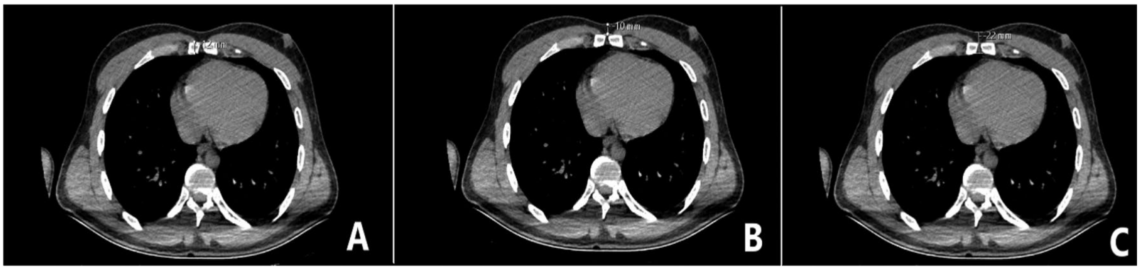

Fig. 4 Bone width (**A**), subcutaneous distance measurement (**B**), distance from skin to intrathoracic area (**C**) measurements

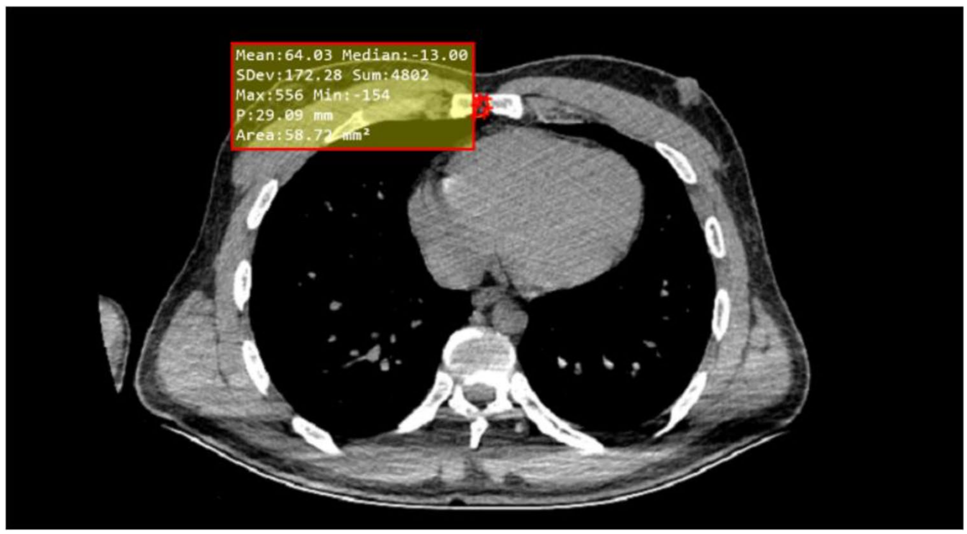

Fig. 5 Foramen area measurement

Table 1 Sternal foramen location and xiphoid process ending type

	n	%
Sexes		
Male	56	44.1
Female	71	55.9
Sternal foramen localization		
Corpus	74	58.3
Xiphoid process	53	41.7
Xiphoid process ending type		
Double-ended	34	26.8
Single-ended	87	68.5
Triple-ended	6	4.7
Sternal foramen incidence %	127	8

Table 2 Morphological measurements

Measurement	Mean ± SD
Transverse diameter (mm)	5.21 ± 1.08
Vertical diameter (mm)	7.77 ± 1.63
Foramen area (mm^2)	63.59 ± 19.78
Bone width (mm)	9.33 ± 1.91
Subcutaneous distance measurement (mm)	13.43 ± 4.06
Distance from skin to intrathoracic area (mm)	22.75 ± 3.15
Age	52.79 ± 13.73

SD Standard Deviation, *mm* millimeter

vertical diameter, foramen area, bone width, subcutaneous distance measurement, and distance measurements from the skin to the intrathoracic area of the individuals did not differ significantly according to foramen localization ($p > 0.05$) (Table 3).

Transverse diameter was found to be significantly lower in the triple-ended xiphoid termination type ($p = 0.03$). Foramen area measurements were found to be significantly lower in the triple-ended xiphoid termination type ($p = 0.04$). It was found that vertical diameter, bone width, subcutaneous distance measurement, distance from skin to intrathoracic area and age measurements did not differ significantly according to termination type ($p > 0.05$) (Table 4).

It was observed that there was no significant relationship between foramen localization and sexes. It was observed that foramen localization occurred at similar rates in female and male individuals ($p = 0.59$, $p > 0.05$).

Table 3 Evaluation of morphological measurements according to foramen localization

	Foramen localization		p
	Corpus	Xiphoid process	
	Mean ± SD	Mean ± SD	
Transverse diameter (mm)	5.37 ± 0.74	5.13 ± 1.08	0.04*
Vertical diameter (mm)	7.84 ± 1.69	7.67 ± 1.55	0.52
Foramen area (mm^2)	64.44 ± 20.14	62.4 ± 19.39	0.63
Bone width (mm)	9.38 ± 1.87	9.26 ± 1.97	0.35
Subcutaneous distance measurement (mm)	13.42 ± 4.41	13.43 ± 3.57	0.61
Distance from skin to intrathoracic area (mm)	22.8 ± 3.4	22.68 ± 2.81	0.84
Age	52.46 ± 14.51	53.25 ± 12.68	0.55

SD Standard Deviation, *mm* millimeter

$^{*}p < 0.05$

Table 4 Evaluation of morphological measurements according to xiphoid process ending type

	Xiphoid process ending type			p
	Double-ended	Single-ended	Triple-ended	
	Mean ± SD	Mean ± SD	Mean ± SD	
Transverse diameter (mm)	5.53 ± 1.07	5.36 ± 1.07	4.2 ± 1.12	0.03*
Vertical diameter (mm)	8.06 ± 1.54	7.68 ± 1.68	7.37 ± 1.45	0.34
Foramen area (mm^2)	67.09 ± 19.96	64.85 ± 19.72	52.52 ± 18.74	0.04*
Bone width (mm)	9.59 ± 1.83	9.28 ± 1.91	8.67 ± 2.34	0.29
Subcutaneous distance measurement (mm)	13.74 ± 4.39	13.39 ± 3.89	12.17 ± 5.19	0.57
Distance from skin to intrathoracic area (mm)	23.32 ± 3.35	22.66 ± 3	20.83 ± 3.87	0.21
Age	49.82 ± 14.78	53.57 ± 13.19	58.17 ± 14.47	0.16

SD Standard Deviation, *mm* millimeter

$^{*}p < 0.05$

Table 5 Evaluation by sexes

	Sexes				p
	Erkek		Kadın		
	n	%	n	%	
Foramen localization					
Corpus	31	55.4	43	60.6	0.59
Xiphoid process	25	44.6	28	39.4	
Xiphoid process ending type					
Double-ended	14	25.0	20	28.2	0.74
Single-ended	39	69.6	48	67.6	
Triple-ended	3	5.4	3	4.2	

It was observed that there was no significant relationship between xiphoid termination type and sexes. It was observed that xiphoid termination type distributions occurred at similar rates in female and male individuals (p = 0.74, p > 0.05) (Table 5).

It was observed that there was no significant relationship between the xiphoid ending type and foramen localization (p = 0.92, p > 0.05) (Table 6).

A single costal foramen accompanying the sternal foramen was observed in 6 individuals (4 males, 2 females), and a double costal foramen accompanying the sternal foramen was observed in 1 male individual (Fig. 6).

According to the structures located behind the sternal foramen, its neighborhood is as follows: In males, it is neighboring the pericardium in 29 individuals and the pleura in 42 individuals. In females, it is neighboring the pericardium in 23 individuals and the pleura in 33 individuals.

In individuals with foramen detected, mean value of the Louis angle was found to be 159.04 ± 2.41 degrees in women and 157.43 ± 1.68 degrees in men. It was observed that the Louis angle measurements differed according to sexes. It was found that the Louis angle measurements of female individuals were significantly higher than those of male individuals (p = 0.01).

Table 6 Correlation evaluation of foramen localization and xiphoid process ending type

	Xiphoid process ending type						p
	Single-ended		Double -ended		Triple-ended		
	n	%	n	%	n	%	
Foramen localization							
Corpus	51	58.6	20	58.8	3	50.0	0.92
Xiphoid process	36	41.4	14	41.2	3	50.0	

4 Discussion

Although direct radiographs provide clinically important technically information about the sternal foramen and xiphoid process, they may have limitations in detecting various variations [15]. In our study, high-resolution and thin-slice CT images were used. Three-dimensional (3D) multiplanar image reformation was applied in the analysis of the images. In addition, MicroDicom software, which provides area measurement, was used with the the DICOM format images obtained from CT. This facilitated the detection of variations in patients and morphological measurements.

The ilium is the most commonly preferred bone for bone marrow aspiration in clinical settings [16, 17]. In cases where a sample cannot be obtained from the ilium, the preferred alternative is the sternum [16, 18]. The vital organs, including the lungs and heart, situated posterior to the sternum, posing a risk during bone marrow aspiration from that area. Therefore, it is great importance to know the sternal foramen from a clinical perspective. Research indicates that life-threatening complications, such as cardiac tamponade, may arise after bone marrow biopsies performed on the sternum [3].

Knowing the existence and incidence of sternal foramen is also important for acupuncture applications. Shangzong acupuncture point (CV 17) and Zhongting acupuncture point (CV 16) are important acupuncture points located on the sternum. Considering the size of acupuncture needles, any application that falls on the foramen may damage the pericardium and pleura [1, 19].

When an unknown sternal foramen is present, nearby structures are at risk during procedures such as sternal bone marrow aspiration, sternal body biopsy, or thoracic acupuncture. The presence of a sternal foramen, located close to mediastinal structures, leaves the lungs, heart, and major vessels unprotected during invasive procedures [20]. Additionally, it can lead to life-threatening complications such as pneumothorax due to lung perforation [21]. Therefore, it is an anatomically significant variation with clinical importance.

The first case of a sternal foramen being diagnosed intraoperatively during open-heart surgery for coronary artery disease was reported by Sungur et al. [22] The patient underwent median sternotomy for coronary artery bypass grafting. During this procedure, the presence of the foramen was detected. Since it had not been previously identified, it was reported that its presence could pose specific challenges for surgeons, as it could potentially cause pericardial tamponade during sternotomy.

Detailed studies on the localization and incidence of the sternal foramen should be increased. In addition, the importance of its existence and localization should be emphasized in clinical anatomy and radiology textbooks. In this way, preliminary screenings can be performed before performing procedures on patients in order to prevent potential complications. Various studies have been conducted in the past regarding the existence and localization of the sternal foramen [2, 8, 23]. One of the most important advantages of our study compared to other regional studies is the evaluation of a patient population of 1600. We obtained detailed information about the sternal foramen through the CT scans performed on this large population.

According to studies conducted on various populations in different time periods, the incidence of sternal foramen was found to be between 0.2 and 43.2% [3, 8, 20, 24, 25]. The reasons for the significant differences observed between the rates may be geographical changes, sample size and evaluation method. However, when the studies are examined in general, the incidence of sternal foramen is reported to be between 4 and 10% [2, 26–29]. Pasieka et al. [1] reported the incidence of sternal foramen as 8.9% (corpus = 6.5%, xiphoid process = 2.9%) in their meta-analysis on the incidence of sternal foramen. According to the meta-analysis, the incidence of sternal foramen is more common in African and South American populations than in European and North American populations. The incidence of sternal foramen according to years in some studies reported in this meta-analysis was reported as; 7.7% in the American population in 1981 by McCormick et al. [28], 43.2% in the Turkish population in 2011 by Akin et al. [8], 3.3% in the Spanish population in 2014 by Macaluso et al. [27], 20% in the Chilean population in 2014 by Del Sol et al. [24], 0.2% in the French population in 2015 by Verna et al. [25], 10.5% in the Brazilian population in 2015 by Babinski et al. [3], 4.2% in the Indian population in 2016 by Chaudhari et al. [26], 2.8% in the Chinese population in 2017 by Yang et al. [29], 14.3% in the Greek population in 2017 by Gkantsinikoudis et al. [20], and 7.5% in the Turkish population in 2020 by Kuzucuoglu et al. [2]. In our study, the incidence of sternal foramen was found to be 8%.

Research on the transverse and vertical diameters of the sternal foramen indicates that its size varies based on geographical and genetic factors [2, 30]. Kuzucuoglu et al. [2] reported the mean transverse diameter of the sternal foramen as 5.13 mm and the mean vertical diameter as 7.75 mm. In a study conducted in another region, the mean transverse diameter of the sternal foramen was reported as 5.58 mm and the mean vertical diameter as 6.68 mm [30]. In our study, in accordance with other studies, we found the mean transverse diameter of the sternal foramen to be 5.21 mm and the mean vertical diameter as 7.77 mm. We also found that the transverse diameter was significantly wider in the sternal foramen located in the corpus than in the foramen located in the xiphoid process ($p < 0.05$).

The mean area of the sternal foramen was determined to be 63.59 mm^2. In previous studies examining the morphology of the sternal foramen [2, 21, 30], no information regarding the area of the foramen was provided. We aimed to contribute to the literature by measuring the area, thinking that the area information could help clinicians imagine a qualitative dimension regarding the foramen size.

The distance between the skin and the intrathoracic area is important for bone marrow biopsy and acupuncture applications. Damage to the pericarium or pleura may occur as a result of an invasive application directed into the sternal foramen. Therefore, the presence of the foramen should be well determined before the applications and the distance between the skin and the intrathoracic area should be determined. Research reported that the mean distance from the skin to the intrathoracic region ranges from 20.95 to 49.6 mm [2, 21, 30]. Our study determined that the mean distance from the skin to the intrathoracic region is 22.75 mm, which is consistent with these studies.

According to a study conducted by Akin et al. [15], the xiphoid termination types were reported as single with 62.6%, double-ended with 32.8% and triple-ended with 4.6%. In our study, we found the xiphoid termination type to be single with 68.5%, double-ended with 26.8% and triple-ended with 4.7%. Although the results are similar, we think that the reason for the small differences may be the number of patients participating in the study and regional differences.

The angle of Louis has been reported to be within normal limits in the literature between 145 and 175 degrees [10, 11, 31]. In the study by Kirum et al. [31], the mean angle of Louis was reported as 165.0 ± 6.4 degrees in women and 163.4 ± 6.7 degrees in men. In our study, it was found to be 159.04 ± 2.41 degrees in women and 157.43 ± 1.68 degrees in men, consistent with the literature.

Excessive increase or decrease in the angle of Louis causes chest deformities. An increase in the angle of Louis causes pectus carinatum, and a decrease causes pectus excavatum [32]. The presence of these deformities poses a risk for median sternotomy. Median sternotomy is important for surgical procedures involving the mediastinum and pulmonary region, and interventions to be applied to the great vessels. In the presence of these deformities, incorrect rib counting poses a risk for the surgical procedure to be applied [10, 11]. Although our study results show that the angle of Louis is normal in individuals with sternal foramen, it should not be forgotten that there may be regional variations.

No significant correlation was found between xiphoid termination type and foramen localization. Accordingly, we think that xiphoid termination type does not effect on the foramen formation mechanism. Contrary to the findings Kuzucuoglu et al. [2] who found a significant correlation between sexes and foramen localization, no significant correlation was found between sexes and foramen localization in our study. We also found that there was no significant correlation between sexes and xiphoid termination type. According to our study, we think that sexes has no effect on foramen localization and xiphoid termination type.

There are some limitations in our study. This study was conducted retrospectively. Therefore, morphological measurements were made only on CT images of the participants in the supine position. Considering that surgical procedures are not always performed in the supine position, prospective studies are needed for detailed analysis of the distance of the sternal foramen to the intrathoracic area. In addition, this study is a regional study. Studies on larger populations are needed.

5 Conclusion

The sternal region is highly risky due to vital structures such as pericardium and pleura located posteriorly. Although all sternal foramen cases observed are asymptomatic, it is advisable to perform a CT scan before any invasive procedures are carried out in this region. When the sternal foramen is observed and surgery is required in this region, the distance from the skin to the intrathoracic area should be measured. We believe that patient safety can be ensured and complications can be minimized in this way. In addition, due to the high incidence of sternal foramen; we believe that awareness of the region should be increased in anatomy and radiology education.

Acknowledgements None to declare.

Author Contributions Conceptualization: [Mehmet Karagulle], [Nigar Keles-Celik]; Methodology: [Mehmet Karagulle], [Busra Candan], [Ebru Torun], [Arzu Hizay]; Formal analysis: [Mehmet Karagulle];

Investigation: [Mehmet Karagulle], [Ebru Torun]; Writing—original draft preparation: [Mehmet Karagulle], [Busra Candan]; Writing—review and editing: [Mehmet Karagulle], [Arzu Hizay]; Supervision: [Nigar Keles-Celik]. All authors read and approved the final manuscript.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK). None to declare.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of Interest The authors declare no competing interests.

Ethical Approval The Declaration of Helsinki on Biomedical Studies Involving Human Subjects (WMA, 1997) was followed when conducting the investigations. The regional ethics review board approved this retrospective study (Ethics committee approval: 13–12).

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