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Anatomical and Morphological Study of the Sternal Foramen Using Computed Tomography Imaging

Saman Ali, Zumirah Atiq, Zunaira, Aniba Zahid, Maria Binte Tariq, Athar Maqbool

ABSTRACT

Objective: This study aims to determine the prevalence and anatomical variations of the sternal foramen (SF) in Pakistani population, and to emphasize its critical clinical significance in preventing complications-such as cardiac tamponade and pneumothorax-during anterior chest wall interventions.

Study Design and Setting: This retrospective, observational CT based morphometric study on human sternum was carried out in Pakistani population at M. Islam Teaching Hospital, Gujranwala from December 2023 to October 2024.

Methodology: The evaluation of images was done using coronal multiplanar reconstruction (MPR) over axial images. The diameters of the detected sternal foramina along with its distance from suprasternal notch and xiphisternum were measured. Male and female groups were compared for differences in various dimensions of the sternal foramina. For statistical analysis, SPSS version 27.0 was used.

Results: In the present study, 580 CT scans were observed. The incidence of sternal foramina in our study is 9.31% (54 out of 580) with 19 men and 35 women. The results showed that both transverse and vertical diameters are generally larger in males than females, with p-value statistically significant. A larger proportion of females (68.6%) have the sternal foramen in the body of the sternum compared to males (52.6%). Maximum number of sternal foramina were observed at the level of the 5th intercostal space 16.67% (n=9).

Conclusion: Awareness of sternal foramina, a congenital defect, is essential for medical professionals to diagnose and prevent complications during surgery, particularly when considering varying prevalence and characteristics across populations.

Keywords: Congenital defect, CT, Human sternum, Morphology, Sternal foramen, Suprasternal notch, Xiphisternum.

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Saman Ali
Senior Lecturer, Department of Anatomy
M. Islam Medical College (Previous)
Fazaia Ruth Pfau Medical College (Current
Email: dr.samanali87@gmail.com

Zumirah Atiq
Senior Lecturer, Department of Anatomy
M. Islam Medical College
Email: zumirahatiq@gmail.com

Zunaira
Lecturer, Department of Anatomy
M. Islam Medical College
Email: zunaira.ikram0066@gmail.com

Aniba Zahid
Lecturer, Department of Anatomy
M. Islam Medical College
Email: zahidaniba@gmail.com

Maria Binte Tariq
Lecturer, Department of Anatomy
M. Islam Medical College
Email: mariabintetariq@gmail.com

Athar Maqbool
Professor, HOD Department of Anatomy
M. Islam Medical College
Email: maqboolathar@yahoo.com

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INTRODUCTION

The sternum is a flat bone which is present along the anterior midline of the chest. Anatomically it consists of three parts; the manubrium superiorly, the body in the middle, and the xiphoid process inferiorly. [1,2] The manubrium articulates laterally with the clavicles on both sides at the sternoclavicular joints. It also articulates with the first costal cartilage and the upper half of the second costal cartilage. Inferiorly, the manubrium connects with the body of the sternum at the manubriosternal joint. The body of the sternum establishes lateral articulations with the lower half of the second costal cartilage, the third to sixth costal cartilages, and the upper half of the seventh costal cartilage. Inferiorly, it articulates with the xiphoid process at the xiphisternal joint. The xiphoid process itself contributes to the thoracic wall by forming a junction with the lower part of the seventh costal cartilage laterally. Embryologically, the sternum is derived from a pair of mesenchymal sternal bars that develop on either side of the midline in the ventral thoracic wall. These bars begin to fuse in a craniocaudal sequence, a process that commences around the 10th week of intrauterine life. The fusion and subsequent ossification of the sternum occur through endochondral ossification, where cartilaginous templates

are gradually replaced by bone. This developmental sequence ensures the formation of a single, continuous sternum, with multiple ossification centers appearing in a segmental fashion from the manubrium to the xiphoid process.[1]

Sternal foramina (SF) are congenital defects arising from incomplete fusion of these ossification centers. These can be observed in any of the three parts of the sternum, most commonly observed in the lower part of the sternal body.[2] Skeletal variations, particularly those involving the sternum, are relatively common anatomical occurrences that may often be misidentified or misunderstood as pathological abnormalities.[3] Often asymptomatic, SF are usually discovered incidentally on imaging or autopsy. However, they carry immense clinical significance, as SF may lead to iatrogenic injury. The knowledge of their presence is crucial during acupuncture, bone marrow biopsy, and sternal aspiration, as they lie near vital structures like the heart and pericardium.[2,4] These anomalies may appear singly or as multiple defects along the sternum, with prevalence rates ranging from as low as 0.2% to as high as 57.8%.[5]

The sternum, known for its durability and resistance to deformation over time, plays a crucial role in determining both age and gender in forensic medicine. SF if misidentified as bullet wounds, may complicate cause-of-death determinations in cases of suspected homicide or suicide.[6,7] High-resolution CT scans have also linked them to accessory lung fissures and sternal clefts, as well as sclerotic bands near the foramen.[7,8] The sternal foramen is a developmental anomaly that is considerably more prevalent than commonly assumed, yet it often goes unrecognized in clinical and radiological settings.[9] This underscores the importance of its detailed evaluation and documentation, particularly in anatomical and imaging studies. A comprehensive understanding of the topographical relationship between the sternal foramen and the underlying vital structures—such as the heart, pericardium, and great vessels—is critically important.[10]

This study aims to evaluate the prevalence and anatomical dimensions of the SF to enhance clinical safety and diagnostic accuracy. Understanding its occurrence will help to mitigate risks during invasive blind sternal procedures, prevent misdiagnosis in radiological assessments, and aid forensic differentiation from trauma. An important aspect of this evaluation is the measurement of the distance of the SF from the suprasternal notch, which is crucial for identifying a safe zone for blind sternal procedures. Although several global studies have quantified the prevalence of SF, there is limited morphometric data from South Asia, particularly Pakistan, where genetic and environmental factors may influence ossification patterns.

To the best of our knowledge, no previous study on this topic has been conducted in Pakistan, highlighting the gap between existing information and its practical implications.

METHODOLOGY

This retrospective, observational CT based morphometric study on human sternum was carried out on Pakistani population at M. Islam Teaching Hospital, Gujranwala from December 2023 to October 2024. The Institute's Research Committee approved this study (Approval no: CM/MIMDC/00019/2023) and waived the requirement for informed consent, as it was conducted retrospectively. The exclusion criteria included: (1) patients younger than 18 years, (2) patients older than 65 years, (3) history of trauma, (4) prior sternal surgery, (5) presence of sternal fractures, (6) metastatic tumors or bony lesions, and (7) presence of a bifid xiphoid process.[2,4] The patients had undergone CT thorax for various reasons. Initially, the data collected from 800 patients was assessed out of which 580 met the inclusion criteria of which 408 were females and 172 were males. Thoracic CT scans of all patients with sternal foramen were evaluated by applying 3D bone configuration to evaluate foramina in the sternum.

The CT examinations were performed using a multidetector 128 slices Philips incisive CT (version 5.0.1.771, China). The parameters used were 120 kV, 100 mA, 1-mm slice thickness, and automatic exposure control in all patients. Chest CTs were taken during a breath-hold in deep inspiration. CT scans were obtained as images containing the entire sternum including xiphoid process. In the software of CT scan machine the evaluation of images was done using coronal multiplanar reconstruction (MPR) over axial images. 3D reforming volume rendering technique (VRT) and maximum intensity projection (MIP) were used to display the morphology of entire sternum. Final readings were taken after applying these techniques in bone window.

The diameters of the detected SF were measured transversely and vertically in the coronal section of the thoracic CT bone window. The planes and points of reference used for measuring various readings are shown in figures 1 and 2. The morphometric measurements were taken in millimeters (mm), and following linear readings were obtained;

1. From the deepest part of suprasternal notch to the superior part of SF (A)

2. From the tip of the xiphoid process to the inferior part of SF (B)

3. Transverse diameter (width) of the SF (C)

4. Vertical diameter (length) of the SF (D)

We also noted the level of costal cartilage or intercostal space at which SF was present. Two researchers along with one radiologist and one radiographer took the readings and evaluated the images with a consensus on the presence and morphometry of SF

For statistical analysis, IBM SPSS version 27.0 was used. Independent-samples t-test was used to compare male and female measurements; $p < 0.05$ was considered significant.

RESULTS

The incidence of SF in our study is 9.31% (54 out of 580) with 11.04% in males (19 out of 172) and 8.57% in females (35 out of 408). The mean age of those with SF was 49.88 ± 12.54 years, with 51 ± 14.69 years in males and 49.68 ± 12.15 years in females. The group statistics and independent samples t-test compare the transverse and vertical diameters between males and females. Results showed that both the transverse and vertical diameters are generally larger in males than females, with significant statistical evidence to support these differences as shown in Table no. 1. The percentage and frequency of SF at each level is given in Table no. 2.

Figure no. 1: Distance of Sternal Foramen (SF) from suprasternal notch (A) and tip of xiphoid process (B

DISCUSSION

Sternal foramina (SF) an overlooked anomaly offers an insight into human skeletal variation, with potential implications that extend beyond the bones themselves. SF are usually asymptomatic defects and are not visible on X-rays due to less tissue resolution. Multiplanar reconstruction images of CT scans have shown great efficiency in studying the normal bone anatomy and associated malformations.

The percentage of SF in our study is 9.31% which is somewhat similar to another CT based study by Kuzucuoglu[9] where it was 8.44%. The reported incidence of SF in CT scan based studies of Ma,[4] Gossner,[10] Turkay[11] and Boruah[2]

Figure no. 2: Sternal foramen (SF) Transverse Diameter (C) and Vertical Diameter (D)

Table No. 1: Statistical Overview and Gender Comparison of Sternal Foramina (SF)

	Mean±SD	Male	Female	p-value
Transverse diameter	3.6±1.73mm	5.10±1.73mm	3.43±1.74mm	0.001*
Vertical diameter	5.0±2.8 mm	4.80±1.44mm	3.60±1.61mm	0.009*
Distance from the deepest point of suprasternal notch	99.92±37.10mm	100.57±48.39mm	99.58±30.09mm	0.926
Distance from the tip of the xiphoid	46.36±43.09mm	54.02±49.01mm	42.20±39.65mm	0.341

Table No. 2: Percentage and Frequency of Sternal foramina (SF) at each level

Location	Frequency (n)	Percentage
Manubrium	10	18.51%
Third costal cartilage level	1	1.85%
Third intercostal space	3	5.55%
Fourth costal cartilage level	3	5.55%
Fourth intercostal space	4	7.40%
Fifth costal cartilage level	7	12.96%
Fifth intercostal space	9	16.67%
Sixth costal cartilage level	7	12.96%
Xiphoid	10	18.51%

The Bar Chart shows the gender-based distribution of sternal foramen location

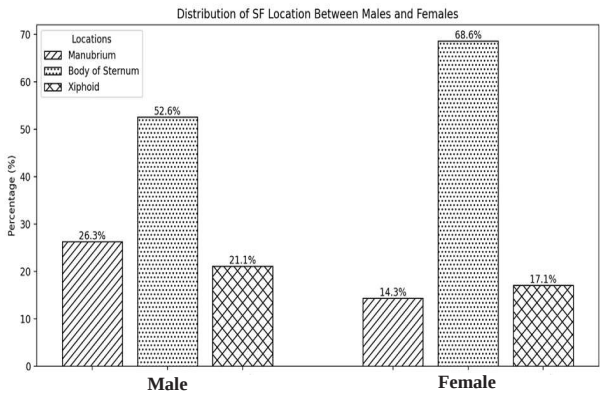

Table no. 3: Sternal foramina (SF) percentage and diameters in various populations

Authors (year)	Place / Country	Type of Study (specimen)	Sample size (sternum)	Percentage of Sterna presenting Sternal Foramen	Transverse Diameter ± SD (mm)	Vertical Diameter ± SD (mm)
Gossner 2013 [10]	Germany	Radiologic (CT)	352	4.5%	3.3	-
Babinski et al. 2015 [20]	Brazil	Radiologic (CT)	114	10.5%	-	-
Sandesh H Chaudhari 2016 [15]	India	Anatomic (dry specimens)	96	4.1%	7.0	5.5
Sukre Shivaji 2016 [7]	India	Anatomic (Dry Specimens)	71	4.22 %	-	-
Boruah et al. 2016 [2]	India	Radiologic (CT)	1180	11.6%	5.57 ± 2.27	6.65 ± 3.35
N. Gkantsinikoudis 2016 [1]	Greece	Anatomic (dry specimens)	35	14.2%	4.8	5.1
Turkay 2017 [11]	Turkey	Radiologic (MDCT)	500	5.2%	-	-
Vulovic 2019 [17]	Serbia	Radiologic (MDCT)	422	5.9%	3.9 ± 1.9	4.2 ± 1.7
Alok tripathi 2019 [19]	India	Anatomic (dry specimen)	100	10%	-	-
Kuzucuoglu 2020 [9]	Turkey	Radiologic (CT)	912	8.44%	5.13 ± 2.63	7.75 ± 4.72
Sunil duchania 2021 [18]	India	Anatomic (dry specimens)	350	6.57%	7.70	9.96
Vatzia 2021 [16]	Greece	Radiologic (MDCT)	950	4.9%	-	-
De-TingMa 2023[4]	China	Radiologic (CT)	2500	4.44%	6.0 ± 2.9	6.8 ± 3.9
Gautam 2023 [13]	India	Anatomic (Dry Specimens)	112	9.82%	5.75	7.16
Lema 2023 [3]	Ethopia	Anatomic (dry Specimens)	94	19.1%	7.08 ± 3.32	7.88 ± 4.28
Present study 2024	Pakistan	Radiologic (CT)	580	9.31%	3.6 ± 1.73	5.0 ± 2.8

was 4.4%, 4.5%, 5.2% and 11.6% respectively, which shows contrast to our study. The global comparison of SF incidence recorded by different researchers along with their transverse and vertical diameters from cadaveric dry specimens to CT scan-based studies is shown in Table no. 3.

Previous studies showed significant correlation between incidence of SF and gender, showing it to be more frequent in males,[2,4,12] and our study (11.4% in males, 8.7% in females) further augments this point.

The size of SF in our study was very different from other studies with mean transverse diameter being 3.6±1.73 mm which is quite less as compared to other studies. Boruah et al[2] measured the mean transverse diameter as 5.58±2.28 mm, Ma[4] reported it to be 6.0±2.29 mm, Gautam[13] reported it to be 5.75 mm and 5.13 ± 2.63 mm by Kuzucuoglu.[9]

Similar trend was observed with the mean vertical diameter in our study which was found to be 5.0±2.8 mm which is lesser than Gautum[13] (7.16 mm), Boruah[2] (6.65±3.35 mm), Ma[4] (6.8±3.9 mm) and Kuzucuoglu[9] (7.75±4.72 mm). These differences suggest that the ossification process in the sternum varies across populations. Our findings indicate less pronounced gaps when the ossification centers fail to fuse completely. This may be influenced by genetic and environmental factors specific to the Pakistani population, highlighting the importance of regional variations.

An interesting finding of our study was that both transverse and vertical diameters of the SF were greater in males as compared to female with p-values of 0.001 and 0.009 respectively (p-value<0.05). This statistically significant gender difference similar to Ma[4] study suggests that male patients may have different anatomical considerations during procedures involving the sternum, necessitating tailored approaches to ensure safety and effectiveness in surgical interventions.

The analysis of the distances between the SF and both the sternal notch and xiphoid tip demonstrates no notable differences between male and female measurements.

The distance of the SF from the suprasternal notch provides another method for sternal puncture site selection. This distance in our study ranged between 25 mm to 191 mm suggesting that the safe area for sternal biopsy will be anywhere within 25 mm from the suprasternal notch for the Pakistani population.

In our study, 62.96% (n=34) SF in the sternal body were reported. This result was quite similar to Gautam[13] where the percentage of SF in body was 72.73% and Kuzucuoglu[9] with 66.2% (n=45). Quite contrasting from Ma[4] where all the SF were observed in the body of the sternum from 4th to 6th costal cartilage only, with maximum SF present at 5th costochondral junction 45.95% (n=51). Boruah[2] also reported the maximum prevalence of SF at 5th costochondral junction being 78.8% (n=108) which was also seconded by Lema[3]and Sukre Shivaji B[7]. However, no foramen was reported in manubrium and xiphoid in all three of these studies which is contrasting to ours as we observed 18.51% SF both in manubrium and xiphoid separately. Also, in our

study maximum number of SF were observed at the level of the 5th intercostal space 16.67% (n=9). Another study by Bolatli[6] also reported 11.7% SF in the xiphoid as compared to only 5.1% in the sternal body. Boruah[2] suggested that sternal procedures should be avoided from 4th to 6th costal cartilages considering it to be a danger zone. This suggestion is valid but taking into consideration the greater percentage of foramina in manubrium and xiphoid in Pakistani population, preliminary CT should be advised before performing any sternal procedures. SF can easily be mistaken as an osteolytic lesion but smooth edges and contour of the foramen in CT differentiates it from osteolytic lesions which has irregular edges.[14]

LIMITATIONS:

The limitations of the study include its single-center design, which may limit the broader applicability of the findings to other populations. The use of advanced imaging techniques is also recommended for future studies to enable more detailed and spatially accurate evaluation of the sternal foramen. Furthermore, the study focused exclusively on adults aged 18 to 65 years, thereby excluding potential anatomical variations present in pediatric and elderly populations. Incorporating data from a wider age range in future research could offer a more comprehensive understanding of sternal anatomical variations.

CONCLUSION:

Sternal foramen (SF) emerges as a surprisingly frequent anatomical variant within the Pakistani population. Its often-overlooked presence carries serious clinical implications, particularly during invasive procedures where unrecognized SF can lead to devastating outcomes such as cardiac tamponade or pneumothorax. By shedding light on its prevalence and morphology, this study reinforces the need for heightened anatomical vigilance in surgical, radiological, and emergency settings. Future large-scale, multicenter investigations are warranted to map regional differences.

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Authors Contribution:
Saman Ali: Concept and design of study, data analysis, revising critically
Zumirah Atiq: Drafting, data collection, data analysis
Zunaira: Drafting, data collection
Aniba Zahid: Drafting, revising critically
Maria Binte Tariq: Drafting
Athar Maqbool: final approval of version

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