Clinical Relevance of Sternal Foramina: A Morphometric Study

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Introduction

The adult sternum or the dagger bone consists of the three distinct parts viz. manubrium, body of the sternum and the xiphoid process with two intervening secondary cartilaginous joints the manubriosternal and the xiphiosternal joints. Manubrium is the broad polygonal part articulating cranially with the sternal end of the clavicles and first costal cartilages and caudally with the body of the sternum. Manubriosternal joint is the site of articulation of the second costal cartilage which serves as the bony landmark for rib counting. The demifacets on the lateral aspect of the body of the sternum articulate with the true bone via their respective costal cartilages(1).

Two embryonic mesenchymal bands called sternal bars aggregate ventro-laterally in the future thoracic region. Initial chondrification in those bars form the primordial cartilaginous model that later undergoes cartilaginous ossification to give rise to sternum. The number and distribution of ossification centre are variable at different stages of sternum development. Segments of the bony bars called ‘sternebrae’ developing on either side of the median plane may sometimes fail to fuse with each other. Incomplete fusion leads to occurrences of sternal foramina (2). The developmental abnormality of sternum can occur in isolation or in combination with other associated anomalies of the thoracic cavity or the heart(3). The most frequently involved region is the lower part of the body of the sternum(4), with occasional involvement of manubrium (1).

Sternal foramina are usually identified incidentally while performing radiological examination for some other indication. Though asymptomatic, they can be the reason of potential unfavourable outcome during certain procedures or interventions. Presence of sternal foramina exposes the intrathoracic viscera and places them vulnerable for injury as in during procedures such as bone marrow aspiration and therapeutic interventions like acupuncture (Fig 1). Furthermore, sternal foramina particularly the midline ones are of rare occurrence. Such a defect can be easily mistaken for midline sternum mass lesion such as a lytic lesion or may be confused with gunshot injuries in radiological evaluation. Therefore it is imperative that clinicians and especially acupuncturist should be aware of this anatomical variation of sternum development. There is paucity of data from cadaveric studies on incidence of sternal foramina in adult. This study aims to determine the frequency of sternal foramina in the adult dry bones of North Indian descent along with a mini literature review.

Abstract

Objectives. The present study aimed at determining the incidence of sternal foramina in adult dry bones of North Indian descent. We also aimed to determine the number, precise location of the sternal foramina with a standard reference point which might have considerable importance with regard to procedures involving sternal puncture.

Methods. This cross sectional descriptive study was conducted on 72 dry adult human sternums. Various measurements in relation to the sternal foramina were taken with a non-stretchable measuring tape and digital vernier calliper and expressed as: [A]-total sternal length, [B]-distance between the jugular notches to the foramen, [C]-distance between the angle of Louis to the foramen and [D]-distance of the foramen from the mid sternal plane. Statistical analysis was performed with Microsoft Excel version 2019. A p-value of <0.05 was considered significant.

Results. We found 6.94% (5 out of 72 sternums) incidence of sternal foramina which corroborates well with the existing literature. Mean sternal length was 127.7 ± 09 mm. The mean distance of the foramina from suprasternal notch, sternal angle and from the median plane were 118.12 ± 0.3 mm, 116.7 mm and 2.4 mm respectively. Incidence of sternal foramina was almost similar to previously reported studies.

Conclusions. The precise knowledge about the expected location of sternal foramina is imperative to avoid intra-thoracic visceral injury during commonly performed acupuncture needle insertion and while doing bone marrow aspiration for diagnostic evaluation. Clin Ter 2023; 174 (6):503-508 doi: 10.7417/CT.2023.5017

Key words: Sternal foramen, sternal puncture, chest acupuncture, sternum development

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Methods

This study was conducted on 72 dry adult human sternums. The study protocol was designed adhering strictly to the institutional guideline on the use of human cadaver and skeletal remains for teaching and research and relevant informed consent was obtained from body donor’s kin at the time of whole body donation. The objective was to study the site, number, appearance and any other special characteristics of sternal foramina in a random sample of 72 dry sternums of unknown origin. The detail demographic parameters pertaining to the individual dry bones could not be traced. We excluded grossly damaged bones from the study. Total sternal length, along with the site, number and morphology of the sternal foramina were recorded using a non-stretchable measuring tape and digital vernier caliper. We also analysed the distance of the sternal foramina from the suprasternal notch, sternal angle and from the median plane of the sternum. The sternal foramina location was determined by dividing total sternal length into three equal segments. The measurement A in the study denotes total sternal length (irrespective of the lost portion of the sternum), B denotes the distance of the sternal foramen from the suprasternal notch, C denotes distance of the foramen from sternal angle and D denotes the distance of the foramen from the mid sternal plane. Microsoft Excel version 2019 was used for statistical analysis.

Results

We found sternal foramina in 6.94% of specimens (5 sternums out of the 72 sternums). Four out of five (80%) foramina were located at the lower third of the body of sternum. Three of the remaining four foramina were rounded and one was elliptical in shape. The fifth one was located in the xiphoid process. The foramen at the xiphoid was keyhole shaped having a non-fused portion directed caudally. The shape of the foramina were round (60%) to oval (40%) ranging from 5 mm to 9 mm (Fig 1). The mean sternal length (A) was 127.07 ± 0.9 mm. The values of various descriptive measurements B, C and D were 118.12 ± 0.3 mm, 116.7 mm and 2.4 mm respectively (Fig 1). Distance from suprasternal notch were not taken in four of the specimens with sternal foramen as manubrium was absent in those specimens. No multiple foramina were encountered in any of the studied bone. The various measurements recorded in the study are summarized in table 1.

Discussion

Developmentally the sternum arises from two independent mesenchymal condensation derived from somatopleuric mesoderm(5). Development of sternum begin at 6th week of intrauterine life when somatopleuric part of the lateral plate mesoderm shift ventrally forming two longitudinal parallel mesenchymal plates or strips in the anterior body wall of the future thoracic region(6). These plates start coalescing in a craniocaudal sequence at around 7th week of gestation and later differentiating as the initial cartilaginous model of the sternum at around 10th week of gestation. In the cartilaginous model multiple centre of ossification appears in a craniocaudal sequence. However the fusion of the sternal bars occur in a caudal to cranial direction(5)(7)(8). The process of fusion of bony bars ends with the formation of the xiphoid process. The cartilaginous model derived
Table 1. Characteristics of morphology and dimensions of sternal foramina in the five specimens

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Shape</th>
<th>Location</th>
<th>Size</th>
<th>Distance from suprasternal notch (B)</th>
<th>Distance from sternal angle (C)</th>
<th>Distance from mid sternal plane (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen 1</td>
<td>Round</td>
<td>Lower third of the body of the sternum</td>
<td>1.8 mm x 2.2 mm</td>
<td>117.7 mm</td>
<td>119.4 mm</td>
<td>116.7 ± 0.3 mm</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>Round</td>
<td>-do-</td>
<td>1.3 mm x 1.4 mm</td>
<td>116.3 mm</td>
<td>115.9 mm</td>
<td>2.4 mm</td>
</tr>
<tr>
<td>Specimen 3</td>
<td>Round</td>
<td>-do-</td>
<td>4.3 mm x 4.2 mm</td>
<td>119.4 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specimen 4</td>
<td>Elliptical</td>
<td>-do-</td>
<td>1.2 mm x 3.2 mm</td>
<td>118.12 ± 0.3 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specimen 5</td>
<td>Key hole shaped</td>
<td>Xiphoid process</td>
<td>2.9 mm x 2.4 mm</td>
<td>118.12 ± 0.3 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Clinical Relevance of Sternal Foramina

A sound knowledge about the sternal foramen is essential for clinicians and also for alternative medicine practitioners like acupuncturist. This is because it has been observed that lack of awareness about sternal foramen might lead to life threatening complications including even sudden death during procedures. One very commonly performed diagnostic procedures leading to such complications is sternal puncture for bone marrow sampling. Sternum is a preferred site of bone marrow sampling as it houses red bone marrow. Similar risk is also associated with acupuncture, an ancient alternative medicine speciality which has gained wide popularity these days and utilizes therapeutic interventions comprising of puncturing specific points in the body with needles. Acupuncture though considered to be minimally invasive and not associated with any major adverse effects, both fatal and non fatal traumatic complications are well documented in literature. Sudden cardiac pain and death due to cardiac tamponade while performing acupuncture was also reported in a case with a patent sternal foramen. The autopsy of those cases confirmed accidental injury to the right ventricular wall by the acupuncture needle through the non-anticipated patent sternal foramen. Cardiac tamponade as a complication of sternal bone marrow biopsy has also been reported. A recent paper describes a fatal case of cardiac tamponade following sternal bone marrow sampling to diagnose multiple myeloma and it reiterates the precautionary measures to be observed. The risk is attributed to the very close location of many important viscera in the mediastinum especially the pericardium and
Table 2. Comprehensive mini literature review of sternal foramina incidence and their characteristics

<table>
<thead>
<tr>
<th>Authors</th>
<th>Population &amp; sample size</th>
<th>Incidence of sternal foramina</th>
<th>Other findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aktan Z A et al, 1998(3)</td>
<td>Turkish, 350 for HRCT; 62 for anatomic study</td>
<td>5.43% in HRCT study</td>
<td>3.22 % in anatomic study</td>
</tr>
<tr>
<td>Saccheri P et al, 2012(12)</td>
<td>Italian</td>
<td>Case report</td>
<td></td>
</tr>
<tr>
<td>Gossner J. 2013(26)</td>
<td>German</td>
<td>15%</td>
<td>20% of patients had heart directly related to the sternal foramen</td>
</tr>
<tr>
<td>Bermio V S et al, 2014(4)</td>
<td>Indian</td>
<td>Case report</td>
<td>One midline foramen in the lower third</td>
</tr>
<tr>
<td>Babinski M A et al, 2015(16)</td>
<td>Brazilian, 114</td>
<td>10.5%</td>
<td></td>
</tr>
<tr>
<td>Michał Spałek et al, 2016(27)</td>
<td>Polish</td>
<td>6.72%</td>
<td></td>
</tr>
<tr>
<td>Chaudhari S H et al, 2016(28)</td>
<td>Indian, 96</td>
<td>4.1%</td>
<td></td>
</tr>
<tr>
<td>Sukre S B et al, 2016(29)</td>
<td>Indian, 71</td>
<td>4.22%</td>
<td>All sternal foramina were found in male sternum</td>
</tr>
<tr>
<td>Turkay R et al, 2017(30)</td>
<td>Turkish, 500</td>
<td>5.2%</td>
<td></td>
</tr>
<tr>
<td>Gkantsinikoudis N et al 2017(31)</td>
<td>Greek, 35</td>
<td>14.2%</td>
<td>A special case observed as sternal pseudo-fornamen at the region of stern-xiphooidal junction</td>
</tr>
<tr>
<td>Nayak G et al, 2018(32)</td>
<td>Indian, 30</td>
<td>6.66%</td>
<td></td>
</tr>
<tr>
<td>Cenk Baita C.2018(33)</td>
<td>Turkish</td>
<td>Case report</td>
<td>Double sternal foramina</td>
</tr>
<tr>
<td>Tripathi A et al. 2019(34)</td>
<td>Indian, 100</td>
<td>10%</td>
<td>8% had single foramen and 2% had double foramen</td>
</tr>
<tr>
<td>Kuzucuoğlu M et al, 2020(35)</td>
<td>Turkish, 68</td>
<td>8.44%</td>
<td></td>
</tr>
<tr>
<td>B Hari Har Guptha et al, 2020(36)</td>
<td>Indian, 150</td>
<td>16% showed xiphoid foramen</td>
<td>MDCT detection of sternal foramina</td>
</tr>
<tr>
<td>Duchania S et al 2021(37)</td>
<td>Indian, 350</td>
<td>6.57%</td>
<td></td>
</tr>
<tr>
<td>Sagnik Roy et al, 2022(9)</td>
<td>Indian</td>
<td>Case report</td>
<td>Single large sternal foramen</td>
</tr>
<tr>
<td>Tandon A et al, 2022(38)</td>
<td>Indian</td>
<td>Case report</td>
<td></td>
</tr>
<tr>
<td>Neves E H et al, 2022(39)</td>
<td>Brazilian, 63</td>
<td>4.76%</td>
<td>Figure of 8 shaped foramen between 4th and 6th sternebrae</td>
</tr>
</tbody>
</table>

Fig. 2. Schematic diagram to show the posterior relations of the sternum; I-Manubrium, II-Body of the sternum, III-Xiphoiod process, a-Trachea, b-Oesophagus, c-Body of T4 vertebra, d-Transverse thoracic plane, e-Arch of aorta, f-Right main bronchus, g-Carina, h-Descending thoracic aorta, i-Diaphragm, j-Body of T12 vertebra (Adapted from Cunningham's manual 16th Edition, volume 2)
the heart (Fig 2). The risk increases manifold if the individual is a young child, having thin built body. Therefore, it is always advisable to have a pre-procedural radiological or ultrasonographical assessment before the desired intervention. Mere physical examination is unyielding and the investigation of choice is always a computed tomography scan. Newer multidetector computed tomography (MDCT) can even pick up smaller sternal foramina not detectable by routine radiological techniques. Additionally it is also recommended to undertake such procedure only under computed tomography or ultrasound guidance. The problem of harbouring sternal foramina might also lead to faulty diagnosis or mis-interpretation. It can be easily mistaken for any lytic bone lesion if the clinician is unaware about this anatomical variation (11).

Conclusions

It is important to realize that though a common feature, the chance of encountering sternal foramina might not strike the minds of clinicians especially before performing diagnostic sternal bone marrow puncture. This hold truer for acupuncturists planning needle insertion in the region. There can be devastating life-threatening catastrophes following such procedures if that is not taken into consideration. Therefore clinicians and other alternative medicine practitioners should be well aware of the possible chance of encountering the same and also remain aware of the probable location. In addition to that, it is recommended to have a radiological or sonographic evaluation prior to such procedures.

Limitations

This study involved only a limited number of dry preserved sternum stored in our bone bank since many years. Therefore many demographic details and history of the individuals while alive could not be retrieved. This is why the data and the conclusions derived from the study might not be contemplated towards living individuals.

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Conflict of Interest

Authors hereby declare that there is no competing interest.

Author’s Contributions

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Rajesh Kumar-MBBS, MD; Contribution- Researched literature and conceived the study, involved in protocol development, wrote the first draft of the manuscript; final approval of manuscript.

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All authors have read and reviewed the final manuscript.

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