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RESEARCH ARTICLE

STUDY OF THE ANOMALIES ASSOCIATED WITH THE HUMAN STERNA IN SOUTH INDIAN POPULATION

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ABSTRACT

Objectives: To study the variations in adult human sterna. Knowledge of sternal anomalies helps in understanding its importance in cardiac surgery, Radiology, genetics, Acupuncture and Medico legal fields. It helps in understanding and analyzing the level of involvement of enthesial regions in autoimmune or degenerative disorders.

Materials and Methods: The study was conducted on 75 dry sterna, collected from the Medical students, in the departments of anatomy, M.S. Ramaiah Medical College, Bengaluru, IMS, MSU, Bengaluru campus, during the last seven years. The sterna were examined for the presence of anomalies like sternal foramina and synostosis.

Results: Of the 75 sterna studied, 5 bones presented with sternal foramina, which were more near the lower half of the body of the sternum, 7 Manubriosternal fusions, 6 xiphisternal fusions, six bones with chondrosternal synostosis, two with sternocostal synostosis. The xiphoid process presented variations like bifid, single and pointed, quadrilateral. More than one anomaly were seen in one sternum.

Conclusion: The causes of sternal foramina have been mentioned as nonfusion or incomplete fusion of the developing sternum from two cartilaginous bars. If there is complete nonfusion, there will be a midline fissure with two separate halves of sternal bone. The fusion of sternum with bones and cartilages articulating with it are probably due to degenerative disorders like DISH (Degenerative Idiopathetic Skeletal Hyperostosis), The chondrocalcinosis also has been attributed to some genetic factors like 'ank' gene, variant of 'ank' gene called 'ANKH' gene present in 5p and 8q chromosomes. Another gene called ENPP1 responsible for soft tissue calcification has been identified.

INTRODUCTION

Sternum is a midline bone present in the anterior wall of the thorax. It is made up of spongy bone which is filled with hemopoietic tissue throughout life. The compact part of the bone surrounding the spongy bone is thin and is traversed by many foramina. It is a flat bone, consisting of cranial manubrium or prosternum, middle, the body or gladiolus or mesosternum and the caudal xiphoid process or metasternum. The manubrium is the broadest part among the three parts and articulates with clavicles (sternoclavicular joints which are synovial joints), first costal cartilages (first chondrosternal joints – primary cartilaginous joints, upper halves of second costal cartilages (synovial joints) and the body of the sternum (secondary cartilaginous joints). The body of the sternum is broad above and narrows below with maximum width at the level of 5th costal facets. From above downwards it articulates with the lower end of manubrium at secondary cartilaginous joint, with lower half of second costal cartilages and third to sixth or seventh costal cartilages (synovial joints) and with xiphisternum (at secondary cartilaginous joint). Developmentally sternum consists of horizontal bars dividing the sternum into four sternbrae visible in anterior view. The facets for the sixth and seventh costal cartilages are merged especially in female. The xiphoid process is the narrowest part of the sternum and represents the unossified mesosternum which projects from the posterior border. It is a single midline process with tapering lower end, can be deviated to any one side, it can be either incurved or curved outside, it can be bifid or with an opening. It articulates with the lower end of the mesosternum. First chondrosternal joint is an unusual variety of synarthroses. The xiphisternal joint is secondary cartilaginous joint, undergoes synostosis at a later age i.e., above 40 years or remains separate throughout life (Standring *et al.,* 2005; McMinn 1990).

The development of the sternum is from two cartilaginous plates which are on either side of the median plane, in the anterior chest wall of the developing fetus, formed between 5th and 9th weeks of gestation. The manubrium is the first to ossify from one to three centers appearing at fifth month of IUL. The first and the second sternebrae ossify from one centre each,

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appearing at about fifth month of IUL. Centers for third and fourth sternebrae appear in fifth and sixth month of IUL and they are paired for each sternebra. The xiphoid process begins to ossify in the third year after birth. The centers for the upper part of sternum are single and placed in the midline whereas the lower centers are paired but may be symmetric or asymmetric. The union begins from the lower sternebrae to upper ones and by 25 years of life all the sternebrae are fused. The number of ossification centers and their arrangement vary depending upon the width of the sternal plates, time of fusion and level of completeness of the bone. Incomplete fusion of these centers leads to formation of sternal foramina, either single or multiple (Standring *et al*., 2005). The centers of ossification appear from above downwards whereas the fusion of the sternebrae is from below upwards during adolescence. The body of the sternum does not fuse with the manubrium even in advanced old age as this joint provides movement of the thoracic cage during respiration (McMinn 1990). When sternal foramina are present the heart and the great vessels are not provided with bony protection in these gaps (Standring *et al.,* 2005). The knowledge of existence of the sternal foramina is very important in acupuncture treatment or sternal puncture to collect the bone marrow for investigation in blood dyscrasias (Ensar *et al.,* 2006**).**

Most of the costal cartilages ossify or calcify after middle age. The articulation between first costal cartilage and the manubrium of sternum are most frequently ossified joints among all the joints. This fixation is to provide stability to the clavicle and the pectoral girdle. It is also believed that the manubrium develops from the mesoderm of the pectoral girdle. (McMinn 1990). The sternoclavicular joint is a saddle variety of synovial joint. Manubriosternal joint is a symphyseal joint and the xiphisternal joint is the synchondrosis or a primary cartilaginous joint. With the exception of articulation with fisrt rib and the manubriosternal joint, the remaining joints which are synovial joints, allow movement of the chest wall during respiration. (Standring *et al*., 2005). Some of the degenerative disorders like ankylosing spondylitis, Forestier's disease (also called – Degenerative Idiopathic Skeletal Hyperostosis / DISH) cause ossification of the ligaments leading to fusion of sternum with adjacent articulating bones (Resnik *et al*., 1978; Resnik *et al*., 1978). In the present study the various anomalies like the sternal foramina at various levels in the lower half, fusion of manubrium with body, xiphisternum with body, fusion of costal cartilages with manubrium and with first rib were observed.

MATERIALS AND METHODS

Seventy five dry and processed sterna obtained from the departments of anatomy, M.S.Ramaiah Medical College Bengaluru, IMS MSU, Bangalore campus, Bengaluru, Karnataka, India. Bones belonging to the students of first MBBS from the college mentioned above, during the last seven years.

Inclusion criteria: All the processed and dried sterna, both normal and abnormal were included in the study.

Exclusion criteria: Damaged bones were excluded.

Observation and Result: Out of the seventy five Sterna, ten presented with variations. Since more than one anomaly was present in each bone, the anomalies in each bone have been tabulated.

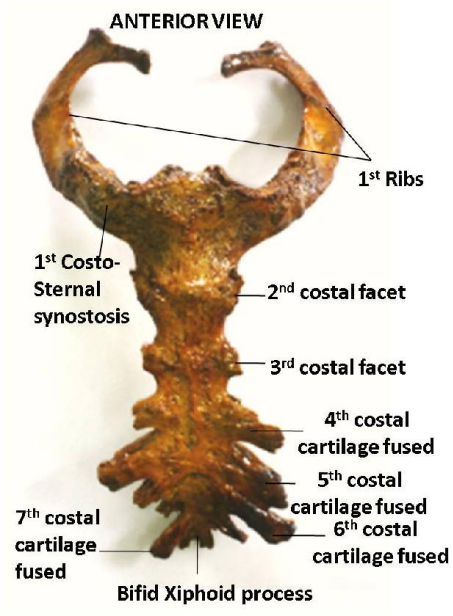

Fig. 1. Anterior view of sternum: Bilateral 1st sternocostal synostosis, Bilateral 4th to 7th chondrosternal fusion, Manubriosternal fusion, xiphisternal fusion and bifid xiphisternum

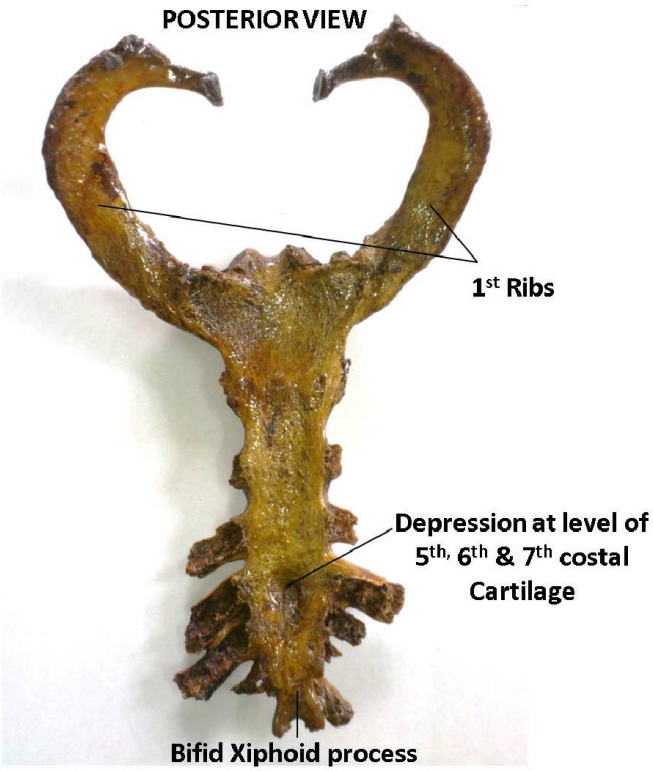

Fig 2. Posterior view of sternum: Bilateral 1st sternocostal synostosis, Bilateral 4th to 7th chondrosternal fusion, Manubriosternal fusion, xiphisternal fusion and bifid xiphisternum and depression at the level of 5th to 7th costal cartilage

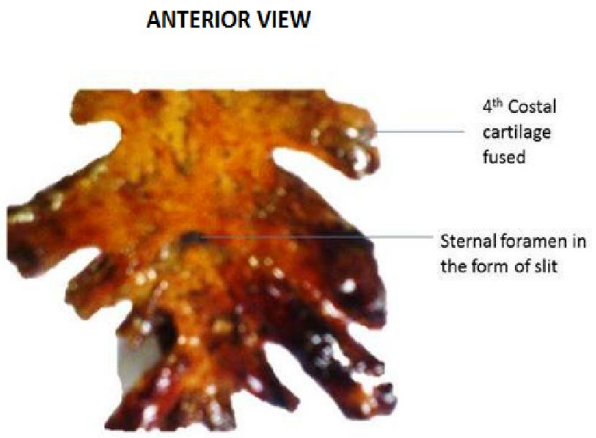

Fig. 3. Anterior view of lower part of sternum: sternal foramen in the form of a slit, at the level of 4th chondrosternal fusion and bifid xiphisternum

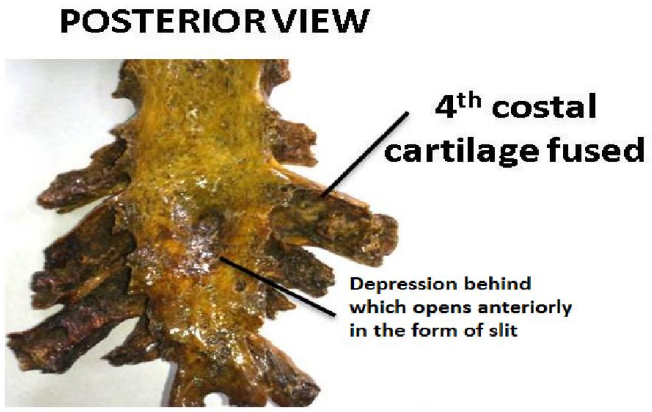

Fig 4. Posterior view showing the sternal foramen which is in the form of depression in the lower part of the body at the level of 4th,to 6th costal cartilages that opens anteriorly in the form of a slit

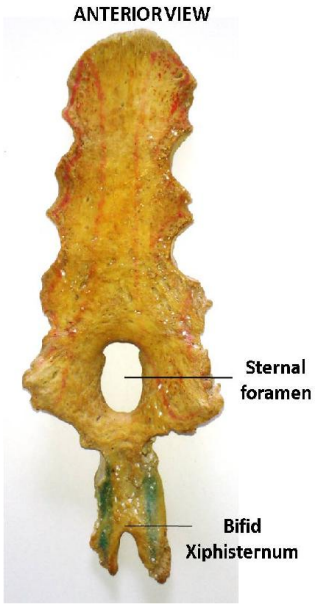

Fig. 5. Anterior view of sternum: A large sternal foramen at the level of 5th to 7th costal facets, Xiphisternal fusion and bifid xiphisternum

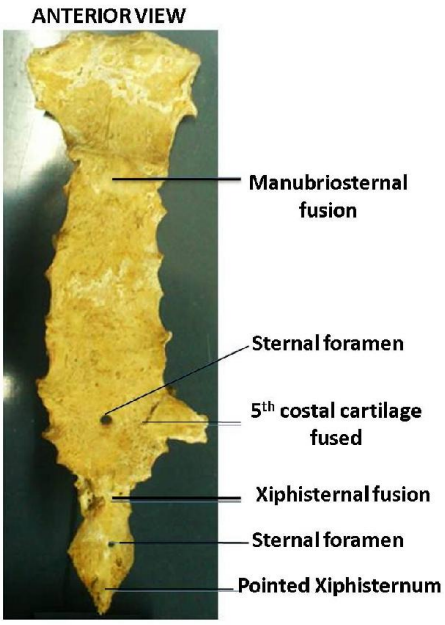

Fig 6. Anterior view of sternum: Manubriosternal fusion, xiphisternal fusion and Dagger like xiphisternum. Sternal foramina are present, 2 in number one at the level of 5th costal cartilage and another in xiphisternum

1. Sternal foramina in 5 sterna (6.66%)
2. Fusion of manubrium with body in 7 sterna (9.33%)
3. Xiphisternal fusion in 06 sterna (8%)
4. Sterno chondral fusion in 06 sterna (8%)
5. Sternocostal synostosis was seen in 02 sterna (2.6%) out of which one was bilateral (1.3%) and another was unilateral, on left side in (1.3%).

Various shapes of the xiphisternum noted were, 'bifid' in two specimens, pointed (typical dagger like) in one and quadrilateral in one specimen.

DISCUSSION

The sternum belongs to axial skeleton and situated on the anterior thoracic wall. Situated in the midline and articulates with clavicles, upper six or seven costal cartilages and corresponding ribs through costal cartilages. It is made up of a thin layer of compact bone which lines the trabeculated tissue containing the red bone marrow. Sternum is longer than broader in male and it is mainly due to the body of the sternum. The length of the body is less than twice the length of the manubrium in female and it is more than twice the length of the manubrium in male. This is probably attributed to the size of the manubrium which is proportionately smaller in male than in female (Frazer 1946).

The sternal anomalies were classified into

1. Sternal foramina
2. Fusion of manubrium with body of sternum
3. Xiphisternal fusion
4. Sterno chondral fusion
5. Sternocostal synostosis

Table 1. List of anomalies in ten sterna showing sternal foramina and sternal fusion with adjacent bones

S.No	Photograph No.	Sternal foramen	Manubrio-sternal fusion	Xiphisternal fusion	Sterno chondral fusion	Sterno costal fusion
1	0005	b/w 4th & 5th costal facets.	+	_	6th Rt. Costal cartilage	_
2	0008 (Fig 6)	2 in no. 5th costal cartilage. In xiphisternum.	+	+ Dagger like xiphisternum	5th Lt Costal cartilage	_
3	0009 (Fig 5)	Large, oval b/w 5th & 7th costal facets.	_	+ Bifid xiphisternum	_	_
4	0010	Round foramen, at the level of 6th & 7th costal facets.	+	_	7th left chondrosternal fusion	_
5	0012	_	+	_ Oval body max width at the level of 3rd costal facet. Prominent, broad 1st , 2nd sternebral junction and.	_	_
6	0014	_	+	+	_	_
7	0016	_	+	+	Left side- 1st ,5th and 8th to 10th together	_
8	0018	_	_	+ Quadrilateral xiphisternum	_	_
9.	0019 unilateral sternocostal synostosis	_	_	_	Right 1st chondrosternal fusion	Left sternocostal synostosis
10	0020 (Fig 2,3,4)	Depression on the back (5th,6th,7th costal cartilages) Slit anteriorly at 5th costal cartilage	+	+ bifid xiphisternum	1st, 4th, 5th, 6th and 7th bilaterally. Cover bifid xiphisternum.	Bilateral sternocostal synostosis.
	TOTAL	05 (6.66%)	07 (9.33%)	06 (8%)	06 (8%)	02 (2.6%)

1. Sternal foramina

The ribs appear as mesodermal condensations in the somatopleure. Chondrification ensues and almost immediately ossification begins towards the back and spreads forwards. A segment remains unossified in the anterior part, which persists as the costal cartilage. The cartilaginous ribs grow ventrally from the vertebral column and their anterior ends are united on each side by a bar of cartilage. The protruding pericardium at first prevents these bars from fusing; later they meet in front of the pericardium and form the cartilaginous body of the sternum. Non fusion of these bars will lead to bifid sternum. The manubrium is probably developed in situ from the mesoderm of the pectoral girdle or the medial ends of the clavicles (Keith 1948; McMinn 1990). There may be a continuous cartilaginous plate. Five bony centres (often double) appear in this plate of cartilage from above downwards. The upper centres form the manubrium. The others form separate bones of the body called sternebrae. The sternebrae fuse with each other from below upwards during adolescence. The body of sternum, thus fused into one plate of bone, normally never fuses with the manubrium, even in advanced old age. The two are united by secondary cartilaginous joint. In childhood each costal cartilage articulates with two adjacent sternebrae, just as the posterior end of the rib articulates with two vertebrae. There is a separate synovial joint between costal cartilage and each sternebra. When the sternebrae fuse with each other the two synovial cavities between costal cartilage and sternebrae coalesce. Since fusion does not occur at sternal angle (between manubrium and body) the two separate cavities persist at second chondrosternal joint (McMinn 1990). Failure of formation of joint cavity between the ribs and the lateral borders of developing sternal body give rise to fusion of ribs to sternum. The reason for non-fusion of the manubrium with the body of the sternum is probably the development of manubrium which is believed to be from the mesoderm of both halves of pectoral girdles and the body develops from the fusion of ribs to form a vertical mesodermal bars (Keith 1948).

The sternal foramina are oval defects in the sternum due to incomplete fusion of mesenchymal sternal bars formed in the 5th and 9th weeks of gestation. Incomplete fusion occurs due to bilateral ossification especially in the third and fourth sternebrae. Complete nonfusion leads to complete sternal fissure and incomplete fusion leads to sternal foramen (O'Rahilly 1986). Most of these foramina are asymptomatic but may cause hazard which may be fatal when the sternal biopsies are done inadvertently leading to puncture of pericardium or the great vessels. In radiographs of sternum, the gaps in the region of sternal foramen appear as osteolytic lesions or gunshot wounds in anterior thoracic wall. One of the reasons for the presence of sternal foramina is believed to be genetic. The foramina were observed in the lower segments than the upper segments. Therefore sternal puncture has to be confined to the upper half than the lower half. The xiphisternum is the most variable part of sternum morphologically and sometimes may simulate fracture of the xiphoid process. The population incidence of sternal foramina have been carried out by H.E. Busaid and in most of the countries the incidence varied between 4.3% to 6.7% except

in Kenyan population where in the incidence was 13.8% (El-Busaid *et al*., 2012). In the present study sternal foramina are in 5 sterna (6.66%) and all of them are located in the lower sternebrae and xiphisternum. (Fig. 5 & 6)

The shape and the contour of the sternum is altered by dislocation, fracture, tubercular osteitis or syphilitic osteitis (Anson *et al*., 1977). The factors which control the process of ossification are poor nutrition, poor vascularization and degenerative changes in the bone at the time of endochondral ossification. If there are excessive mechanical stimuli where there is tensile force and friction there will be ossification. Thus the process of ossification is affected by tension and pressure (Le Gros Clark 1980). It is believed that the congenital defects are very rare in humans and are less in animals. When present they are caused by genetic defects leading to midline fusion defects or ingestion of infective plants during early part of gestation in case of grazing animals. In human, the defects are either detected accidentally when radiographs or CT or MRI are carried out for other thoracic anomalies or during autopsy. The anomalies included are branched or bifid xiphoid process, asymmetrical bone and sternal foramen. Therefore the knowledge of sternal foramen, their numbers and their placement (situation) is very important while performing the sternal puncture for bone marrow aspiration or else it may lead to cardiac tamponade or heart damage which may be fatal (Azizi *et al*., 2012).

2. Fusion of manubrium with body of sternum, 3.Xiphisternal fusion, 4. Sterno chondral fusion, 5. Sternocostal synostosis: (Fig. 1,2,5,6.)

In the present study fusion of manubrium in 7 specimens (9.33%), Xiphisternal fusion in 06 (8%), Sterno chondral fusion in 06 (8%) and Sternocostal synostosis in 2 cases, (2.6%) – which had unilateral on left side in one and bilateral in another accounting to 1.3% each. The xiphisternum is the most variable part of sternum morphologically and sometimes may simulate fracture of the xiphoid process. It appears as an extension from the posterior surface of the lower part of the body. It also presents variation s in shape. It is fused with the body at a very late age, may be after 70 – 75 years of life (El-Busaid *et al*., 2012). In the present study bifid, pointed and quadrilateral xiphoid processes observed which had fused with the body. Some of the degenerative disorders like Diffuse Idiopathetic Skeletal Hyperostosis (DISH), Ankylosing Spondylitis (AS), Calcium PyroPhosphate Dihydrate Crystal Deposition Disease (CPPD CDD) and Spondylo Arthritis (SpA) lead to shoulder girdle and/or pelvic girdle ankylosis and ossification of cartilages and ligaments. It commences as early as 24 years of life. Usually the joints of axial skeleton are involved. In the shoulder girdle the joints affected are glenohumeral, acromio clavicular and sternoclavicular joints. AS, CPPD CDD, SpA and (DISH) are not identifiable by the clinicians as the clinical manifestations are not associated with important consequences. It is either identified accidentally by radiography for some other disorders or it is an autopsy finding or when the bones are obtained by exhumation either for medico legal purpose or for the study of osteology by medical students. In about 28% of population such a disorder is seen in the average age group of 65 years. The prevalence is higher in males than in females. It is also believed that there is a positive relation between DISH and Diabetes Mellitus.

The genetic causes have been identified which are involved in the metabolism of PPi (inorganic pyrophosphate) which leads to ectopic calcifications in CPPD CDD. There are many genes involved in the rate of production, transportation, and degradation of PPi. It leads to deposition of crystals throughout skeleton when there is an unbalanced level of serum PPi. The disorder identified is autosomal dominant and runs in families. The chromosomes linked to these kinds of disorders are 8q (CCAL1) and 5p (CCAL2) which are primarily related to osteoarthritis, CPPD CDD deposition is secondary which is enhanced by the degenerative changes in cartilage. A study conducted suggested that a gene called 'ank' gene in mouse is responsible for the cause of CPPD CDD and was confirmed to be an autosomal dominant. In mouse it is the 'loss-of-function' mutation in gene that causes deposition of hydroxyapatite whereas in humans it is homologue, 'gain-of-function' mutations which is responsible. It was confirmed in families as an autosomal dominant. In 2005 Zhang *et al*. demonstrated a common promoter region polymorphism of a 4-basepair G to A transition that was found in about 4% of cases wherein there was widespread premature chondrocalcinosis which may or may not be associated with gout. This suggests that the variant ANKH gene plays an important role in familial and severe forms of sporadic chondrocalcinosis. Though the exact mechanism of ANKH gene mutation is not known, the ANKH gene is believed to encode about 492 amino acid multiple pass transmembrane protein, which is involved in the transportation of inorganic pyrophosphate (PPi) across plasma membrane to the extracellular compartment that leads to accumulation of PPi in the extracellular compartment and excessive calcification of the extracellular tissue. In case of DISH, there was abnormally increased activity of osteoblasts in the bones and ligaments. Insulin Growth Factor (IGF) – I stimulates the alkaline phosphatase and type II collagen in the osteoblasts; and growth hormone induce the production of IGF – I and IGF binding proteins in chondrocytes and osteoblasts. It was also observed that there were higher serum levels of MGP (Matrix Gla Protein) and higher serum levels of BMP (Bone Morphogenic Protein) observed in DISH patients, which led to hyperostosis. Another gene called ENPP1 responsible for soft tissue calcification has been identified (Armas *et al*., 2009).

In earlier studies there were cases of Sterno clavicular synostosis (Mysorekar VR, 1990), fusion of first sternebra with the manubrium sterni wherein the sternal angle was at the level of third costal cartilage instead of second costal cartilage. The manubrio sternal junction was at the level of third costal facet and the same specimen presented with multiple sternal foramina limited to the lower half of the body and xiphisternum (Kulkarni R, 2010). In old age certain poorly nourished tissues usually undergo calcification. It can occur in the middle of the tumor due to poor vascularity or avascularity. Therefore the deposition of calcerous material in the first stages of endochondral ossification is a degenerative change (Le Gros Clark WE, 1980).

Conclusion

The sternum is anterior midline bone belonging to axial skeleton. Developmentally the sternum is from the migrated

mesoderm of the ribs which grow above and down to fuse with each other on that side. A cartilaginous model of sternum is formed which is the site of sternal development. Initially the two halves remain separate due to the developing pericardium but later both halves join to form the sternum. It is believed that the manubrium which articulates with body of sternum develops from the mesoderm of the pectoral girdle and therefore remains separate for a long time from the body of sternum and only in later age, fuses it. If there is nonfusion of the two halves at various levels, it leads to formation of sternal foramen/foramina. Similarly there may be early fusion of the manubrium, xiphisternum, costal cartilages and ribs with the sternum. In the present study out of seventy five sterna, five bones presented with sternal foramina, seven Manubriosternal fusions, six xiphisternal fusions, six sterna with chondrosternal synostosis and two with sternocostal synostosis. The xhiphoid process presented variations like bifid, single and pointed and quadrilateral. More than one anomaly were seen in one sternum. It is thought that this early fusion is associated with various degenerative disorders like DISH and CPPD CDD etc. where there will be abnormal ossifications of the interarticular cartilages leading to synostosis. CPPD CDD deposition is secondary which is enhanced by the degenerative changes in cartilage. It was also reported by geneticists that the cause may be genetic and the chromosomes identified for these disorders are 8q (CCAL1) and 5p (CCAL2) which are primarily related to osteoarthritis. The genes identified for such an anomalous fusion between the parts of sternum and adjacent costal cartilages and ribs, are 'ank' genes and their variants. The sternal foramina are to be kept in mind while performing sternal puncture to aspirate the red marrow for laboratory investigations. Fusions between various parts of sternum, i.e., sternum with costal cartilages and ribs may restrict the expansions of lungs during respiration.

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