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Magnetic Resonance Imaging Findings of Anatomy, Variation and Pathologies of Sternum, Sternoclavicular and Sternocostal Joints

Sternum, Sternoklavikular ve Sternokostal Eklemlerin Anatomi, Varyasyon ve Patolojilerinin Manyetik Rezonans Görüntüleme Bulguları

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ABSTRACT

Objective: The study aimed to assess the sternum's morphology and morphometry, and to find anomalies and diseases using breast magnetic resonance imaging (MRI).

Materials and Methods: Retrospective evaluations of 320 breast MRIs were conducted. Congenital abnormalities accompanying pathological conditions were investigated. The sternum overall's length, the manubrium-corpus' width and length, and the manubrium-corpus-xiphoid's shape were all measured. The relationship between the manubriosternal fusion and age was analyzed.

Results: Pectus excavatum, sternal band, sternal foramen, angled sternum and the sternal band, rachitic rosary, intraosseous ganglion, sternoclavicular joint degeneration, sternoclavicular joint ganglion cyst and costal cartilage calcifications, breast carcinoma metastasis, enchondroma and invasion of costal cartilages by malignant mesenchymal tumour were determined. The average length of the sternum was 144±14 mm, the manubrium length is 46±6 mm and the corpus length is 89±10 mm for adults. Manubrium was most commonly trapezoid in shape, the corpus was longitudinal oval and xiphoid was flat. 67% had no manubriosternal fusion. The degree of manubriosternal fusion did not show statistically significant correlation with increasing age.

Conclusion: The sternum, sternoclavicular, and sternocostal joints are susceptible to a wide range of congenital abnormalities and clinical conditions. Age increase has no relation to manubriosternal fusion.

Keywords: Magnetic resonance imaging, pathology, sternocostal joints, sternum

ÖZ

Amaç: Sternum, sternoklavikular ve sternokostal eklemlerin morfoloji ve morfometrisini değerlendirmek ve meme manyetik rezonans görüntülemede (MRG) anomali ve patolojileri saptamak amaçlandı.

Materyal ve Metot: 3 Tesla ana mayetik alan gücündeki bir sistemle elde edilen, 320 kadına ait meme MRG tetkikleri retrospektif olarak değerlendirildi. Konjenital anormallikler ve eşlik eden patolojik durumlar araştırıldı. Toplam sternumun uzunluğu, manubrium-korpus genişliği ve uzunluğu ve manubrium-korpus-ksifoid şekli değerlendirildi. Manubriosternal füzyon ile yaş arasındaki ilişki istatistiksel olarak analiz edildi.

Bulgular: Pektus ekskavatum, sternal bant, sternal foramen, açılı sternum (ve Poland sendromu), raşitik rozari, intraosseöz ganglion, sternoklavikular eklem dejenerasyonu, sternoklavikular eklem ganglion kisti ve kostal kıkırdak kalsifikasyonları, meme karsinomu metastazı, enkondrom ve malign mezenkimal tümör tarafından kostal kıkırdak invazyonu belirlendi. Morfometrik analiz, kadın erişkinlerde ortalama sternum uzunluğunun 144±14 mm, manubrium uzunluğunun 46±6 mm ve korpus uzunluğunun 89±10 mm olduğunu göstermiştir. Manubrium en yaygın olarak yamuk şeklinde, korpus uzunlamasına oval ve ksifoid düzdü. Olguların çoğunda (%67) manubriosternal füzyon yoktu. Manubriosternal füzyon derecesi, artan yaş ile istatistiksel olarak anlamlı bir korelasyon göstermedi.

Sonuç: Birçok doğumsal anomali ve patolojik süreç sternum, sternoklavikular ve sternokostal eklemleri etkileyebilir. Manubriosternal füzyon artan yaşla ilişkili değildir ve yaş tespiti için kullanılması uygun olmayabilir.

Anahtar Kelimeler: Manyetik rezonans görüntüleme, patoloji, sternokostal eklem, sternum

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INTRODUCTION

For practices in radiology, pediatrics, thoracic surgery, cardiovascular surgery, and forensic medicine, knowledge of the radiographic appearance of the anatomy, variation, and pathologies of the sternum, sternoclavicular, and sternocostal joints is crucial. It is known that these structures' variations, abnormalities, and diseases might cause various cardiopulmonary complications.[1-6] Additionally, it is essential to avoid potential and undesirable consequences before various interventional procedures.[7] In forensic circumstances, knowledge of the anatomy of the sternum may be useful in determining age and gender.[8-10]

Some anatomical features and numerical data of the sternum have great significance in anthropological researches. Sternal anomalies and morphometric analyses in living individuals have been evaluated especially by spiral computed tomography, multislice computed tomography, or magnetic resonance imaging (MRI).[11-15] These studies, however, are limited in number and no previous study has been performed by a 3 Tesla system.

When evaluating the sternum, sternoclavicular, and sternocostal joints, MRI is a crucial imaging technique. It has a high spatial and contrast resolution, is ionizing radiation-free, and supports multiplanar imaging. It can assess soft tissues, cartilage, and bone's cortex and medulla. Compared to computed tomography, bone marrow oedema and replacement are defined more precisely.[13] The likelihood of finding certain small lesions may increase in images taken with high main magnetic strength devices.

The aim of this study is to determine the anomalies and pathologies of the sternum, sternoclavicular and sternocostal joints, to perform the morphological and morphometric analysis of the sternum and evaluate the age-manubriostenal fusion relationship by evaluating breast MRIs.

MATERIALS AND METHODS

Ethical Status: Our study was approved by the Ethics Committee of the Institute of Health Sciences of Ataturk University (Date: 19.03.2013, decision no: 2.2/6). Informed consent was not obtained because of the retrospective observational design. The study design was evaluated for compliance with the guidelines for strengthening the reporting of epidemiological observational studies (STROBE).

Patients*:* We reviewed breast MRI data sets of patients who were evaluated at our institution between October 2010 and September 2014. A total of 320 females (mean age±standard deviation 39±12 years, range 3-67 years) were enrolled. The main indications for breast MRI were to detect multifocal, multicentric or contralateral breast carcinomas; to reveal invasive components in ductal carcinomas in situ; to identify occult cancer in patients with metastatic axillary nodes; to detect unequivocal findings on conventional imaging, to follow-up of neoadjuvant chemotherapy, to evaluate breast implants, and post-surgical findings.[16-20]

Breast MRIs: Breast MRIs were performed by a 3T system (Skyra; Siemens, Germany) with a dedicated breast coil in the prone position. The obtained sequences were sagittal fat-saturated turbo spin echo (TSE) T2-weighted imaging (WI), transverse short tau inversion recovery (STIR), transverse TSE T1-WI, transverse diffusion-WI using single-shot echo-planar imaging, transverse pre- and post-contrast fat-saturated fast low-angle shot (FLASH) 3D T1-WI. All the patients' gadolinium chelate was injected intravenously at 0.1 mmol/kg, followed by a 20 mL saline flush. The injection rate was 2 mL/s and a power injector was used. Dynamic imaging with FLASH 3D T1-WI was started after a fixed delay of 30 sec following contrast material injection.

Image Analysis: Images were retrieved from PACS (Picture archiving and communication system), and sternum, sternoclavicular and sternoclavicular joints were evaluated at the workstation (Syngo Via, Siemens, Enlarge, Germany). Variations and pathologies (such as pectus excavatum, pectus carinatum, angulated sternum, sternal band-cleft, sternal foramen, episternal ossicle, degenerative and inflammatory pathologies, infections, fractures, sternoclavicular dislocation, manubriosternal dislocation, et.c.) were noted, frequency of pathologies was investigated. Morphometric and morphologic analysis was performed in cases when the entire sternum or related part was displayed.

Morphometric analysis was performed from coronal STIR and coronal and sagittal reformations of FLASH 3D images. Total sternum length, length and width of manubrium and corpus, the shape of manubrium, corpus and xiphoid and manubriosternal fusion were all evaluated. Total sternum length was measured from the jugular notch to the end of the xiphoid. The manubrium's length was calculated from the jugular notch to the manubriosternal junction along the cortex's edge. The manubriosternal junction to the xiphoid was the point used to measure the corpus length.

Manubrium shape was visually assessed as quadrangle, trapezoid or triangle. Corpus length and width were evaluated on the longest coronal section. The shape of the corpus was visually evaluated as "O" shaped, longitudinal oval and flat.

The shape of the xiphoid was evaluated as flat, triangular, quadrangular and bifurcated.

Manubriosternal fusion was evaluated as "no fusion" and "fusion.

Statistical Analysis: Statistical analysis was performed using SPSS (Statistical Package for the Social Sciences) 24.0 software. The cases were divided into three groups according to their age (Group 1: 20 -35 years, Group 2: 36-50 years and Group 3: 51-70 years). In addition, the manubriosternal fusion of the patients was evaluated as "no fusion" and "fusion (complete or partial)". The Chi-square test was used to determine whether there was any difference between the age groups in terms of manubriosternal fusion. Spearman correlation test and Chi-square trend tests were used to determine whether manubriosternal fusion increased with increasing age. When the p-value was less than 0.05, it was considered statistically significant.

RESULTS

Among congenital anomalies, sternal band (n=1), sternal foramen (n=3) (Figure 1A), *pectus excavatum* (n=1) (Figure 1B), angled sternum and the sternal band (Figure 1D) with Poland syndrome (n=1) were detected. Among the degenerative and developmental pathologies, rachitic rosary due to rickets (n=1), sternal intraosseous ganglion adjacent to the sternoclavicular joint (n=1) (Figure 1C), sternoclavicular joint degeneration (n=3) (Figure 1E), and costal cartilage calcification (n=12) were detected (Figure 1). 11 cases of breast carcinoma metastasis, 7 cases of the benign bony lesion (Figure 1F) and 1 case of costal cartilage invasion by malign mesenchymal tumour (Figure 2) were detected.

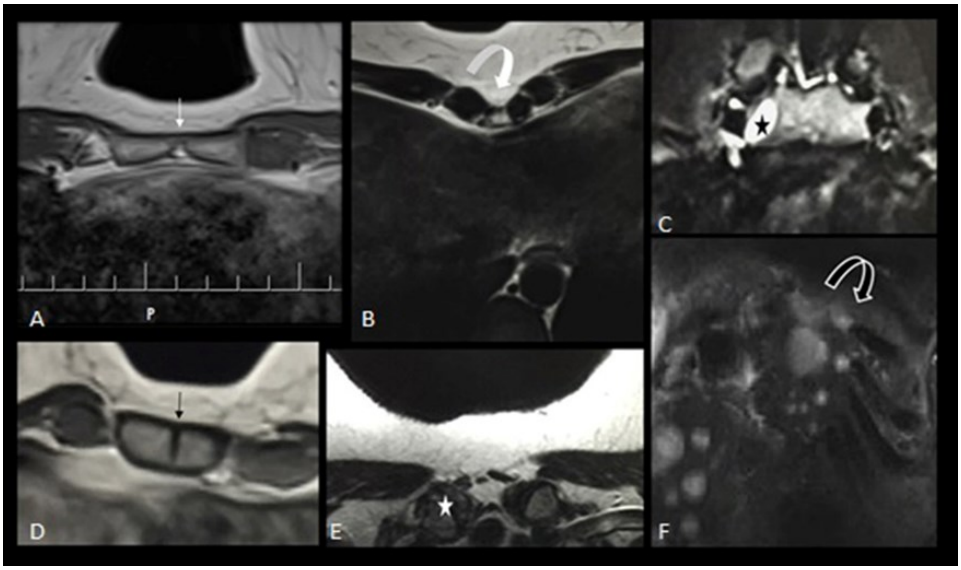

Figure 1. Sternal pathology and anomalies.
Sternal foramen (white arrow, A), pectus excavatum (solid curved arrow, B), manubrial intraosseous ganglion (black star, C), sternal band (black arrow, D), sternoclavicular joint degeneration (white star, E), sternal metastases (curved arrow, F).

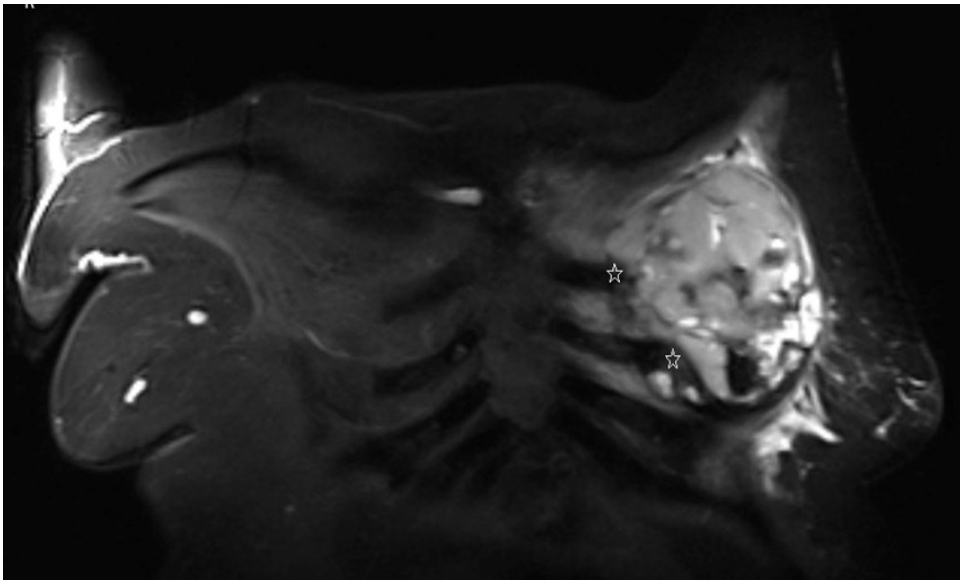

Figure 2. 67-year-old female patient. In the coronal STIR image, local invasion of the left costal cartilages (arrows) by malign mesenchymal tumor is observed.

In adult cases, morphometric and morphologic analysis was performed in cases when the entire sternum or related part was displayed. For this analysis, we included 113 cases older than 19 years old. 7 children were excluded. The mean sternal length was 144±14 millimetres (mm) ranging from 109 to 179 mm (Table 1).

The mean manubrium length (±stardard deviation) was 46±6 mm (27-70 mm). The mean manubrium width (±stardard deviation) was 54±6 mm (30-65 mm) (Table 1). Manubrium shape was evaluated as a trapezoid in 73 cases (65%), quadrangle in 28 cases (25%) and triangle in 12 cases (10%) (Table 2). The mean sternal body length (±stardard deviation) was 89±10 mm (56-113 mm). The mean sternal body width (±stardard deviation) was 36±6 mm (25-52 mm) (Table 1).

The sternal body shape was evaluated as longitudinal oval in 68 cases (60%), O-shaped in 25 cases (22%), and flat (18%) in 20 cases (Table 2). The xiphoid shape could be evaluated for 81 cases. Thirty-two (40%) of them were flat, 27 (33%) triangle, 18 (22%) quadrangle and 4 (5%) bifurcated (Table 2).

Manubriosternal fusion was seen in 37 (33%) cases and was not seen in 76 cases (67%). Manubriosternal fusion was complete in 15 cases (13%) and partial in 22 cases (20%). There was no statistically significant difference (p=0.43) by Chi-square test between groups (Group 1: 20-35 years, Group 2: 36-50 years and Group 3: 51-70 years) in terms of manubriosternal fusion (Table 3). In the Spearman correlation test, there was a pretty weak correlation between increased age and manubriosternal fusion (R = 0.06), and the correlation was not statistically significant (p=0.48). According to the Chi-square trend test, manubriosternal fusion did not progress with increasing age (p=0.38).

Table 1. Findings of morphometric analysis of sternum.

	n	Minimum- Maximum (mm)	Mean± Standard deviation (mm)
Total sternum length	113	109-179	144±14
Manubrium length	113	27-70	46±6
Manubrium width	113	30-65	54±0
Sternal body length	113	56-113	89±10
Sternal body width	113	25-52	36±6

mm: millimetre.

Table 2. Findings of morphological analysis of sternum.

		Case, n (%)
Manubrium shape	**Trapezoid**	73 (65)
	Quadrangle	28 (25)
	Triangle	12 (10)
Sternal body shape	**Longitudinal oval**	68 (60)
	"O" shaped	25 (22)
	Flat	20 (18)
Xiphoid shape	**Flat**	32 (40)
	Triangle	27 (33)
	Quadrangle	18 (22)
	Bifurcated	4 (5)

Table 3. Statistical analysis of age groups and manubriosternal fusion.

		Manubriosternal fusion (number, %)		Total	Statistical analysis
		No fusion	**Fusion (partial or complete)**		
Age groups	Group 1 (20-35 years)	15 (68)	7 (32)	22 (100)	p=0.43* R=0.06**
	Group 2 (36-50 years)	41 (72)	16 (28)	57 (100)	p=0.48*** P=0.38****
	Group 3 (51-70 years)	20 (59)	14 (41)	34 (100)	
Total		76 (67)	37 (33)	113 (100)	

*: Chi-square test between the age groups; **: Spearman correlation test between increased age and manubriosternal fusion; ***: Correlation test between increased age and manubriosternal fusion ; ****: Chi-square trend test, manubriosternal fusion between increased age.

DISCUSSION AND CONCLUSION

In this study, many different conditions affected this part of the thoracic wall. The most common manubrium-shape was a trapezoid, the corpus shape was longitudinal oval, and the xiphoid was flat. In the majority of cases, there was no manubriosternal fusion. There was no statistically significant correlation between increasing age and manubriostenal fusion.

In a study with multislice computerized tomography, one thousand consecutive patients were evaluated and sternal variations and anomalies were investigated. 4.1% suprasternal ossicles, 4% suprasternal tubercles, 19.6% complete manubriosternal fusion, 30.3% sternoxifoidal fusion, 4.5% sternal foramen and 37.1% sternal sclerotic band were detected.[11] The xiphoid process was 71% single piece. In another study, the morphologic features of the sternum and sex-related changes in adults were evaluated for 200 cases between 18-87 years of age and morphometric analysis was performed by multislice computerized tomography.[7] This study consisted of healthy men and women. For the determination of gender, the total length of the sternum was found to be more useful than corpus or manubrium lengths. 3.5% of the sternal foramen and 0.5% of sternal cleft changes were frequently seen in that investigation.[7] In our study, only females were evaluated with breast MRI, but the results were not analyzed regarding gender differences. In this group, congenital abnormalities were found 1.9% of the population. The fact that we only included females in our study could be one factor in the low prevalence. Breast MRI is not a main technique for breast, and it is only used on a limited number of patients. As a result, our study population did not accurately reflect the overall population.

In order to assess the degree of fusion between the sternum bones and identify its significance for determining age and gender, Pekcan et al. examined multislice computed tomography data from 620 patients (310 females and 310 men).[21] According to their research, the manubrium and corpus fully fuse at 31 years of age for men and 26 years of age for women. They stressed that the degree of fusion increases with age but that modelling of age prediction is impossible due to the large diversity in the degree of fusion.[21] The study of Garg et al. aimed to determine the radiological age by examining the manubriosternal joint between the people living in Punjab.[22] They evaluated lateral radiographs of the sternum, and it was concluded that the earliest age for manubriosternal fusion was 35 for males and 37 for females. The latest age was 65 for both sexes. According to their study, 60% of 60-65 year-old patients of cases did not show complete manubriosternal fusion.[22] Therefore, the authors did not find appropriate the manubriosternal fusion-based age determination during forensic medicine applications.[22] In our study, the degree of manubriosternal fusion did not show a statistically significant difference among age groups, and there was no significant correlation between the increasing age and fusion as well. The basic distinction between these last two studies is their different imaging methods. High-contrast resolution of MRI provides a better understanding of the boundaries of cartilaginous areas than radiography and computed tomography. It is possible to evaluate the fusion with a more realistic result by MRI.

Aslam et al., in their study on evaluating sternum and sternoclavicular joints by MRI emphasized that these anatomic structures can be examined ideally by MRI.[13] They especially mentioned that the sagittal plan is important in evaluating the sternum and retrosternal region. They also pointed out that MRI is an appropriate method for associated abnormalities of the other intrathoracic structures. It is also important and useful in assessing some features accompanying malignant lesions, such as bone destruction, bone marrow infiltration, periosteal reaction, and soft tissue components.[13]

Aslam et al. have also noted that primary and secondary tumors and infections may be better assessed by MRI.[13] They emphasized the advantage of evaluating pathologic specimens of the sternoclavicular joints, especially in the coronal plane.[13] In our study, transverse, coronal and sagittal images obtained with a 3T scanner were evaluated. It was also possible to evaluate subcentimetric lesions due to high magnetic field strength and high spatial resolution. The sternal band, sternal foramen, rachitic rosary, enchondromas, ganglion cysts and the joint degeneration findings were tiny lesions, and they were easily detected by MRI in our study.

Morphometric differences in various organs and systems among individuals have been defined and are relatively standardized. However, there is limited information about morphometry and morphology of the sternum. These findings are of great importance in terms of anthropological investigations.[6] Selthofer and colleagues performed morphometric analyses of 55 male and 35 female cadaveric sternums from their osteological collections.[6] They evaluated the sternal segments in terms of width, length and thickness, and found that the overall sternum structure was similar in both males and females, but they found that the female sternum was relatively short, narrow and thin.[6] According to their results, the mean manubrium length was 52 mm and width 45 mm, sternal body length 94 mm and width 27 mm and total sternum length 182 mm in females.[6] According to the study of Atesoglu et al., the manubrium length was found to be 46.7±5.1 mm, the sternal body length 86.6±9.7 mm and the total sternum

length 133.1±1.1 mm.[7] In our study, as mentioned earlier, in adult women, the total length of the sternum was 144±14 mm, the length of the manubrium was 46±6 mm, and the length of the sternal body was 89±10 mm.

One of the strengths of this study, which assesses the anatomy, variation and pathology of the sternum, sternoclavicular and sternocostal joints, and perhaps most importantly, is the use of an ideal imaging modality. Another strength of this study is the fact that the quality of examinations could provide enough spatial and contrast resolution to discover minor lesions. The study could be applied to a relatively large group of patients, and a wide spectrum of variations, anomalies and pathologies were identified.

Because breast MRI is primarily a female imaging technique and the male population has not been studied, this is one of the study's limitations (population bias). A limitation of the study is that it does not reflect the general population, as was already highlighted. Others included a retrospective design, no control group, and fewer patients.

In conclusion, congenital anomalies, developmental and degenerative processes, and a wide variety of abnormalities and pathologies, such as neoplasms can affect the sternum, sternoclavicular and sternocostal joints. An accurate diagnosis means that the patients are directed correctly to the appropriate interventions and treatments. MRI has the impression of being one of the most suitable methods for assessing the morphology and pathological processes in a wide variety of anatomical regions that can be observed in such a narrow but complex anatomical region with the ability to evaluate the anatomic compartments in more detail than other imaging modalities and to enable characterization of tissues.

Ethics Committee Approval: Our study was approved by the Ethics Committee of the Institute of Health Sciences of Ataturk University (Date 19.03.2013, decision no:2.2/6). Informed consent was not obtained because of the retrospective observational design. The study design was evaluated for compliance with the guidelines of strengthening the reporting of observational studies in epidemiology (STROBE).

Conflict of Interest: No conflict of interest was declared by the authors.

Author Contributions: Concept–IDS, MS, SD; Supervision–IDS, MS, SD; Materials–IDS; Data collection and/or Processing–IDS; Analysis and/or interpretation–IDS, MS, SD; Writing–IDS, MS, SD.

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