



Evaluation of the postnatal development of the sternum and sternal variations using multidetector CT

Hanifi Bayaroğulları, Erhan Yengil, Ramazan Davran, Ela Ağlagül, Sinem Karazincir, Ali Balcı

PURPOSE

We aimed to evaluate the postnatal development and the maturation of the sternum and sternal variations using multidetector computed tomography (MDCT). Additionally, we aimed to examine the roles of gender and age in sternal development.

MATERIALS AND METHODS

Two hundred and fifty patients who underwent thorax MDCT examinations were evaluated for sternal development and variations. Coronal curved planar reconstruction and maximum intensity projection images were used to better assess the ossification centers in the manubrium and the body of the sternum. Multiplanar images were used to accurately measure the thickness and the sagittal dimension of the manubrium, the sagittal dimension of the body, and the total sagittal dimension of the sternum in the sagittal plane.

RESULTS

No significant differences in the manubrium measurements were observed between the genders. The thickness and sagittal dimension of the manubrium, sagittal dimension of the body, and total sagittal dimension of the sternum in the sagittal plane were significantly different between the age groups. We evaluated the ossification centers; shape and developmental variations in the manubrium and body; direction, calcification, and termination of the xiphoid process; developmental variations in the xiphoid process; and manubriosternal and sternoxiphoid fusion. Significant variations were observed from person to person.

CONCLUSION

The anatomy and the developmental properties of the sternum should be well understood in cases of potential chest and sternum injuries and in several surgical procedures. Therefore, knowledge of the development and the maturation of the sternum, and sternal variations and anomalies is important. We suggest that the postnatal development and the morphogenesis of the sternum can be adequately assessed using MDCT.

The sternum is a flat bone that extends vertically through the middle of the anterior thoracic cage. The sternum consists of the following three parts: the manubrium, the body, and the xiphoid process (XP) (1, 2). The sternum develops over a long period of time, which begins during the prenatal period and continues through the third and fourth decades of the postnatal period (3–6). Ossification centers in the manubrium and the body form on cartilage plates that are located on both sides of the middle line during the prenatal period. The ossification centers in the manubrium generally merge before birth. Two or more ossification centers that develop on each segment of the mesosternum (body) are referred to as sternabrae, which are located on cartilage plates on both sides of the middle line. From 6–12 years of age, the ossification centers usually merge completely into a single ossification center. The calcification and the fusion of the sternabrae are usually complete by 25 years of age (6–8). Postnatal development, maturation, and ossification center development of the sternum differ significantly from person to person.

Several radiographic studies in the literature have evaluated sternal development and its variations; however, few studies have used computed tomography (CT) to assess sternal development and sternal variations in pediatric and early adult groups. Multidetector CT (MDCT) has become the primary imaging method for assessing the sternum due to its higher image quality and its ability to perform a three-dimensional evaluation. In this study, we aimed to evaluate postnatal development, maturation, ossification centers and variations in the sternum using MDCT, and we aimed to examine the roles of gender and age in sternal development.

Materials and methods

Patient selection

The study included patients who were 0–25 years of age and who underwent a chest CT with MDCT at our department from 2011–2012. The upper age limit for the study was 25 years of age because many studies have found that sternum ossification and fusion of the sternabrae are complete by 25 years of age. Patients who underwent thorax examinations with MDCT for various reasons, such as pulmonary infection, malignant tumor development, foreign body aspiration, and thoracic and pulmonary abnormalities, were included in the study. Patients were not exposed to unnecessary radiation and were not administered drugs because all the selected patients had undergone mandatory thoracic CT examination for other reasons. Patients with sternal deformities, a history of severe chest trauma, a history of thoracic or sternal surgery, a sternal mass or infection, chronic disease, or malnourishment were excluded.

From the Departments of Radiology (H.B. ✉ hanbayar67@gmail.com, R.D., E.A.,S.K.) and Family Medicine (E.Y.), Mustafa Kemal University School of Medicine, Antakya, Turkey; the Department of Radiology (A.B.), Dokuz Eylül University School of Medicine, Izmir, Turkey.

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ed from the study. Our study included patients whose sternums were unaffected by disease. The study excluded pediatric patients who were examined with MDCT because of developmental problems or growth retardation.

A total of 250 patients were evaluated, and 10 people were randomly chosen from every age group without gender distinction. We excluded 50 patients who were 21–25 years of age from the statistical analysis, and we used 200 patients who were 0–20 years of age because the calcification and the fusion of the sternebrae are usually complete by 21–25 years of age. All the cases were divided into four age groups (0–5, 6–10, 11–15, and 16–20 years).

MDCT protocol

A 64-row MDCT scanner (Toshiba Aquilon, Toshiba Medical Systems, Otawara, Japan) was used for all the thoracic CT procedures. A routine thoracic CT protocol was followed. Axial plane images were obtained and were transferred to a workstation for post-processing. At the workstation (Basic Vitrea®2, version 4.0), maximum intensity projection (MIP), curved planar reconstruction (CPR), and multiplanar reformatting (MPR) of the sagittal and coronal plane images were performed, and three-dimensional images of the sternum were obtained.

Assessment of the images

After downloading all the images to the workstation, MIP, CPR, and MPR of the sagittal and coronal plane images were performed, and three-dimensional images of the sternum were obtained for better identification of the anatomical details, the ossification centers, and the developmental variations in the sternum. CPR and MIP images were used to better assess the centers of ossification in the manubrium and the body. MPR images were used to accurately measure the thickness and the sagittal dimensions in the sagittal plane.

We used the sagittal dimensions of the manubrium (SDM) the thickness of the manubrium (TM) (both measured at the thickest and the thinnest part), the sagittal dimensions of the body (SDB), and the total sagittal dimensions of the sternum (TSDS) to evaluate

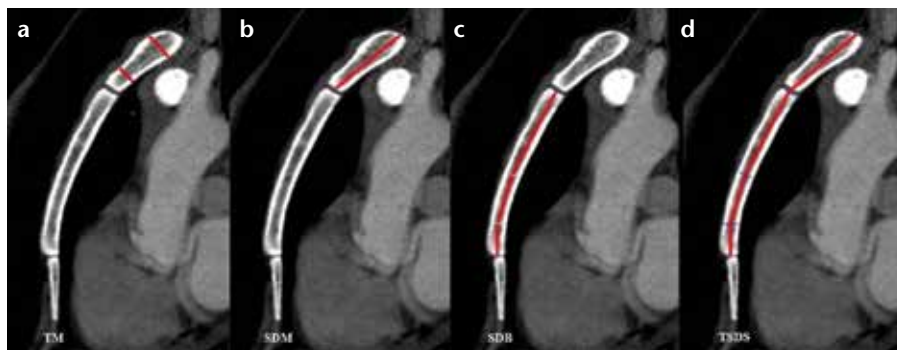


Figure 1. a–d. Multiplanar reformatted MDCT images show the thickness of the manubrium (TM) (a), the sagittal dimension of the manubrium (SDM) (b), the sagittal dimension of the body (SDB) (c), and the total sagittal dimension of the sternum (TSDS) (d), which were obtained to minimize errors caused by angulation.

the postnatal development of the sternum based on age and gender. Parallel measurements of the sagittal plane of the sternum on multiplanar MDCT images were used to minimize errors that arose from the angulations of the sternum (Fig. 1). The TM, SDM, SDB, and TSDS measurements were obtained by the same researcher a total of three times in intervals. The relationship between the three readings was assessed using the intraclass correlation test. The TM, SDM, SDB, and TSDS measurements were all statistically similar ($r=0.98$, $P < 0.001$; $r=0.96$, $P < 0.001$; $r=0.94$, $P < 0.001$; $r=0.98$, $P < 0.001$, respectively).

In addition, the following variables were considered: the ossification centers and the ossification pattern types, the shape of the manubrium, the number of sternebrae on the mesosternum, age-specific sternebrae fusion, the morphological shapes of the sternum, the shape and the direction of the XP, calcification, manubriosternal and sternoxiphoidal fusion, developmental variations in the sternum, and anomalies of the sternum.

Statistical analysis

The sternal development was statistically evaluated according to age and gender. A commercially available software (Statistical Package for Social Sciences, version 15.0, SPSS Inc., Chicago, Illinois, USA) was used for the statistical analysis. Both descriptive and analytical statistics were used. The continuous variables were presented as the mean \pm standard deviation, whereas the categorical variables were displayed as the

number or the frequency. The distributions of the continuous variables were tested using the Kolmogorov-Smirnov test. The chi-square test was used to compare the categorical variables. For the continuous variables, Student's *t* test was performed. Comparisons of the normally distributed continuous variables between more than three groups were performed using one-way analysis of variance (ANOVA-Bonferroni test). A *P* value less than 0.05 was considered statistically significant for all the statistical data.

Results

Two hundred patients who were 0–20 years of age, 44.5% female ($n=89$) and 55.5% male ($n=111$), were included in the study. No significant differences in the manubrium measurements were observed between the genders ($P = 0.120$). The mean age was 10.57 ± 5.86 years for the male patients and 10.40 ± 5.70 years for the female patients ($P = 0.835$).

The female and male patients had similar TM (9.74 ± 2.65 and 10.26 ± 3.03 mm, respectively; $P = 0.200$) and SDM (34.43 ± 11.67 and 34.62 ± 12.01 mm, respectively; $P = 0.913$) measurements. The mean SDB measurements were 70.11 ± 23.31 mm for the male patients and 60.99 ± 17.76 mm for the female patients. The SDB was significantly larger in the male patients ($P = 0.002$). The mean TSDS measurements were 109.07 ± 33.57 mm for the male patients and 98.28 ± 28.76 mm for the female patients. The TSDS was significantly larger in the male patients ($P = 0.015$).

The TM, SDM, SDB, and TSDS values were significantly different between the age groups (Table 1). Compared to their age groups in each age group separately, The averages of measured TM, SDM, SDB, and TSDS were statistically different from each other ($P = 0.0001$). The manubrium develops similarly according to age in both genders in the postnatal period.

Ossification patterns

A total of 139 cases in the age group of 0–15 years were evaluated to determine the ossification pattern types because the ossification centers in the sternebrae generally fuse at 12 years of age. In the 139 cases, the type 2 ossification pattern was the most common pattern, which occurred in 97 cases (67%). The type 1 ossification pattern occurred in 39 cases (28%), and the type 3 ossification pattern was detected in seven cases (5%).

Ossification centers, shape, and developmental variations in the manubrium and manubriosternal fusion

The manubrium was spherically shaped in 36 cases aged 0–15 years. The spherical shape of the manubrium was identified in 19/50 cases (11 males and eight females) in the age group of 0–5 years, 11/50 cases (four males and seven females) in the age group of 6–10 years, and 6/50 cases (six males) in the age group of 11–15 years (Fig. 2a, 2b). Two to four ossification centers in the manubrium were identified in 28 cases 0–10 years of age. Additionally, partial fusion was observed in several of these cases (Fig. 2c–l). Five cases had suprasternal bone, of which three were bilateral and two were unilateral (Fig. 3a, 3b). A bilateral tubercle was located on the upper part of the manubrium in nine cases, and a unilateral tubercle was identified in one case (Fig. 3c, 3d). Full fusion was observed in six cases, and partial manubriosternal fusion was identified in six cases. The earliest fusion occurred in the age group of 6–10 years. Table 2 shows the distribution of the manubrium shapes, the number of ossification points, and manubriosternal fusion according to age and gender.

Table 1. Sagittal dimensions (mm) of sternum in different age groups

	Age groups				P^a
	0–5 years (n=50)	6–10 years (n=50)	11–15 years (n=50)	16–20 years (n=50)	
SDM	20.45±4.61	29.53±4.98	39.43±5.54	48.73±5.85	0.0001
TM	6.95±1.14	8.68±1.13	11.03±1.68	13.46±1.91	0.0001
SDB	42.71±10.51	57.28±7.55	75.14±14.25	89.08±15.50	0.0001
TSDS	68.53±10.51	91.07±9.69	116.53±22.65	140.96±18.52	0.0001

^aOne-way analysis of variance.

SDB, sagittal dimension of the body; SDM, sagittal dimension of manubrium; TM, thickness of manubrium; TSDS, total sagittal dimension of the sternum. Data are given as mean±standard deviation.

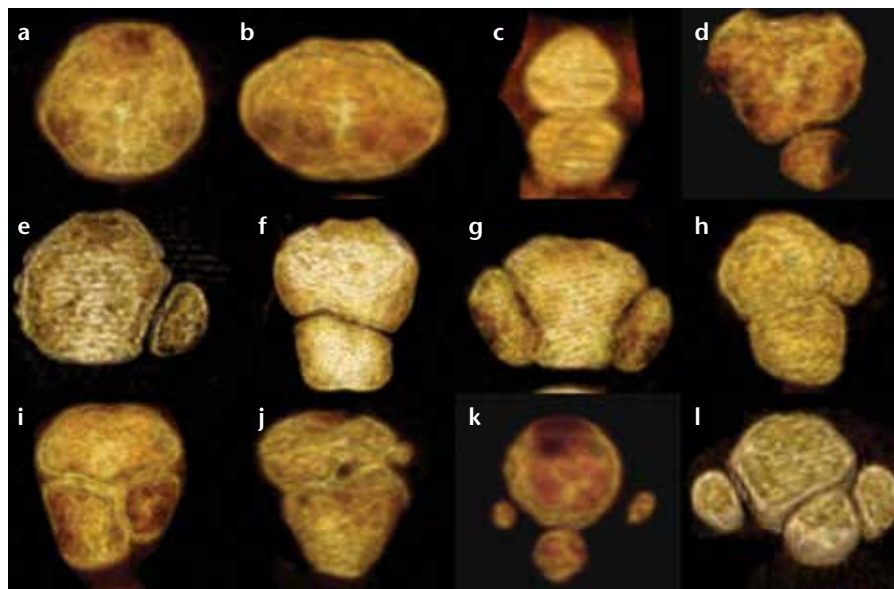


Figure 2. a–l. Three-dimensional MDCT images show the type and number of ossification centers in the manubrium in 12 cases: a circular and ovoid ossification center of the manubrium (a, b), two ossification centers of the manubrium (c–f), three ossification centers of the manubrium (g–i), and four ossification centers of the manubrium (j–l).

Ossification centers, sternebrae fusion, and shape and developmental variations in the body

The patients in the age group of 0–15 years ($n=150$) were evaluated to determine whether the ossification centers and the sternebrae had fused partially or completely. In our cases, the sternebrae had one to four ossifications centers that were localized on either side of the midline. The female patients had significantly less sternebrae than the male patients. Two sternebrae in three female patients, three sternebrae in 50 female patients, and four sternebrae in 13 female patients were observed. Three sternebrae were observed in 47 males, and four sternebrae were observed in 37 males. In our study, fusion of the third and fourth sternebrae

and the second and third sternebrae was fully complete in patients 16–20 years of age; however, non-fusion of the first and second sternebrae had occurred in four cases 21–25 years of age. The number of sternebrae according to age and gender, and the ages when fusion of the sternebrae occurred are shown in Table 3.

Sternal hypoplasia due to the absence of the development of the third sternebrae was observed in the age groups of 0–5 years (three females) and 23–24 years (one male).

Manubriosternal structures were evaluated morphologically to determine whether ossification was partially or totally complete in 100 cases 16–25 years of age. The flat shape was the most common shape of the sternum (68%). The longitudinal oval shape

Table 2. Manubrium characteristics according to age and gender

Age (years)	Manubrium shapes				Number of ossification centers						Manubriosternal fusion				Variation and anomalies				
	Spherical		Trapezoid		2		3		4		Total		Partial		SSB		SST		
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	
0–5	11	8	20	11	6	5	1	2	1	1	-	-	-	-	-	-	-	-	-
6–10	4	7	21	18	3	5	-	1	-	1	1	-	-	-	-	-	-	1	1
11–15	6	-	23	21	1	-	-	-	-	-	-	-	1	-	-	-	-	2	-
16–20	-	-	31	19	1	-	-	-	-	-	-	2	1	3	-	-	-	2	1
21–25	-	-	41	9	-	-	-	-	-	-	3	-	-	1	2	3	-	2	1
Total	21	15	136	78	11	10	1	3	1	2	4	2	1	5	2	3	-	7	3
	36		214		21		4		3		6		6		5		10		

f, female; M, male; SSB, suprasternal bone; SST, suprasternal tubercle. Data are given as number of patients.



Figure 3. a–d. Three-dimensional and MIP MDCT images show one-sided suprasternal bone (SSB-1) (a), bilateral suprasternal bone (SSB-2) (b), a one-sided suprasternal tubercle (SST-1) (c), and a fused bilateral suprasternal tubercle (SST-2) (d).

was the second most common shape, and the O shape was the third most common shape (Fig. 4).

Foramina were detected in 15 cases. In one case, a foramen was observed in the manubrium (Fig. 5a). Thirteen foramina were localized in the distal sternum (Fig. 5b), and two foramina were

localized in the middle of the sternum (Fig. 5c, 5d). A pseudo-foramen was detected at the sternoxiphoidal junction in three cases. A cleft was observed in 10 cases, of which five had a foramen that was usually localized in the distal part of the sternum (Fig. 5e, 5f). In one case, the cleft was located on the ver-

tical and horizontal planes (Fig. 5g), and, two cases had wide clefts between the second and third sternebrae that were accompanied by a foramen in the middle of the sternum (Fig. 5h).

Direction, calcification, termination, and developmental variations of the xiphoid process

The XP calcification, partial or total, was observed in 15 cases aged 0–5 years. In total, calcification was observed in 116 cases. Of the patients with XP calcification, eight had total calcification, and the other cases had partial calcification. The termination of the XP was identified in a calcified XP. A single XP was observed in 101 cases, and a double-ended XP was observed in 15 cases. Triple-ended XPs were not observed in our study. The deviation of the XP was identified in calcified and noncalcified XP. Ventral deviation was observed in 135 XPs, whereas no deviation was observed in 115 cases. Dorsal deviation was not observed in any of our cases. Sternoxiphoidal fusion was observed in 12 cases in the age group of 21–25 years. The deviation, calcification, end termination, and variations of XP according to age and gender are shown in Table 4.

Discussion

This study was performed with MDCT and is the most extensive research about the postnatal development, maturation, and ossification centers of the sternum and sternal variations. Knowing the postnatal development, maturation, and anatomy of the sternum is important for treating several bone,

Table 3. Characteristics of the body of the sternum according to age and gender

Age (years)	Number of sternebrae						1–2 fusion				2–3 fusion				3–4 fusion				Variations and anomalies					
	2		3		4		Fused		Nonfused		Fused		Nonfused		Fused		Nonfused		Foramen		PseudoF		Cleft	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
0–5	-	3	17	15	11	4	1	1	27	21	5	3	27	15	5	1	6	2	1	1	-	-	1	-
6–10	-	-	14	20	13	3	1	5	25	19	5	8	20	17	3	2	6	2	2	1	-	-	2	-
11–15	-	-	16	15	13	6	5	4	24	17	11	14	16	8	4	5	5	1	2	1	1	1	1	1
16–20	-	-	8	4	11	-	16	17	15	2	26	19	4	5	-	-	-	-	2	3	1	-	2	2
21–25	1	-	6	-	5	1	34	12	4	-	35	12	2	-	-	-	-	2	-	-	-	-	1	

F, female; M, male; PseudoF, pseudo-foramen. Data are given as number of patients.

Table 4. Characteristics of XP according to age and gender

Age (years)	XP deviations						XP ossification								XP termination						S/XP fusion					
	No D		Vtrl D		Total		1/3 Sup		2/3 Sup		1/3 Mid		Mid-inf		MOF		Single		Double		Triple		F of XP		S/XP fusion	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
0–5	11	6	19	14	-	-	3	1	3	1	4	1	3	-	-	-	12	3	-	-	-	-	-	-	-	-
6–10	14	15	11	10	-	-	-	2	2	3	1	-	1	2	1	0	4	7	-	-	-	-	-	-	-	-
11–15	16	11	13	10	-	-	3	2	2	-	5	5	1	2	-	-	10	10	-	-	-	-	-	-	-	-
16–20	21	10	10	9	2	-	3	4	10	3	-	-	1	1	1	-	17	10	1	-	-	-	-	-	-	-
21–25	10	1	30	9	4	2	8	1	16	5	1	1	1	-	2	2	19	9	12	2	-	-	1	8	4	
Total	72	43	83	52	6	2	17	10	33	12	11	7	7	5	4	2	62	39	13	2	-	-	1	8	4	
	115		135		8		27		45		18		12		6		101		15		-		1		12	

F of XP, foramen of the xiphoid process; Mid, middle; Mid-inf, middle inferior; MOF, multiple ossification foci; No D, No deviation; S/XP fusion, sternum/xiphoid process fusion; Sup, superior; Vtrl D, ventral deviation; XP, xiphoid process. Data are given as number of patients.

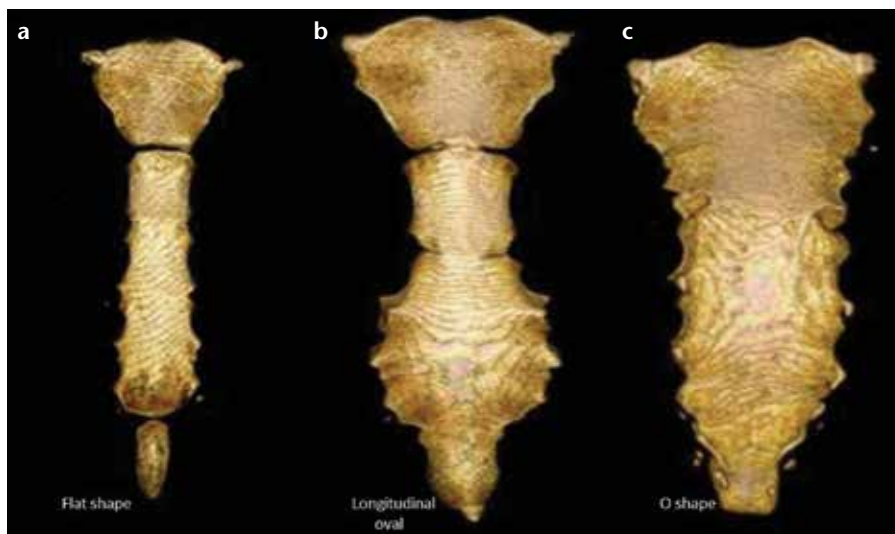


Figure 4. a–c. Three-dimensional MDCT images of three different sternal body types: the flat shape (a), the longitudinal oval shape (b), and the O shape (c).

hematological, and developmental diseases and for planning thoracic surgery, identifying possible postsurgery complications, preventing mediastinal organ injury, and performing intraosseous transfusions in pediatric popula-

tions. In addition, knowledge about the sternum is important in forensic medicine and anthropology.

The sternum begins to form in the lateral mesoderm plates during the sixth week of the prenatal period. These

plates are located in the anterior chest wall and are shifted toward the midline. During the sixth week, the fused bilateral sternal plates (the presternum) and the developing shoulder girdle appear simultaneously. Later, a pair of supra-sternal cartilages appears in the cranium lateral to the presternum, and these cartilages form part of the manubrial articulation with the clavicle. During the seventh week, the plates that extend across from the upper point to complete the convergence in the craniocaudal direction by fusing. Lastly, the XP forms during the ninth week.

The sternum is formed from bilateral sternal plates that chondrify and begin to fuse with the ribs at approximately 10 weeks of gestation. Similar to other axial and appendicular skeletons, the sternum must chondrify before ossification. Similar to the ribs, the clavicle, the skull, and the facial bones, sternal bone ossifies the cartilaginous segment of the sternum during endochondral ossification. The ossification centers of

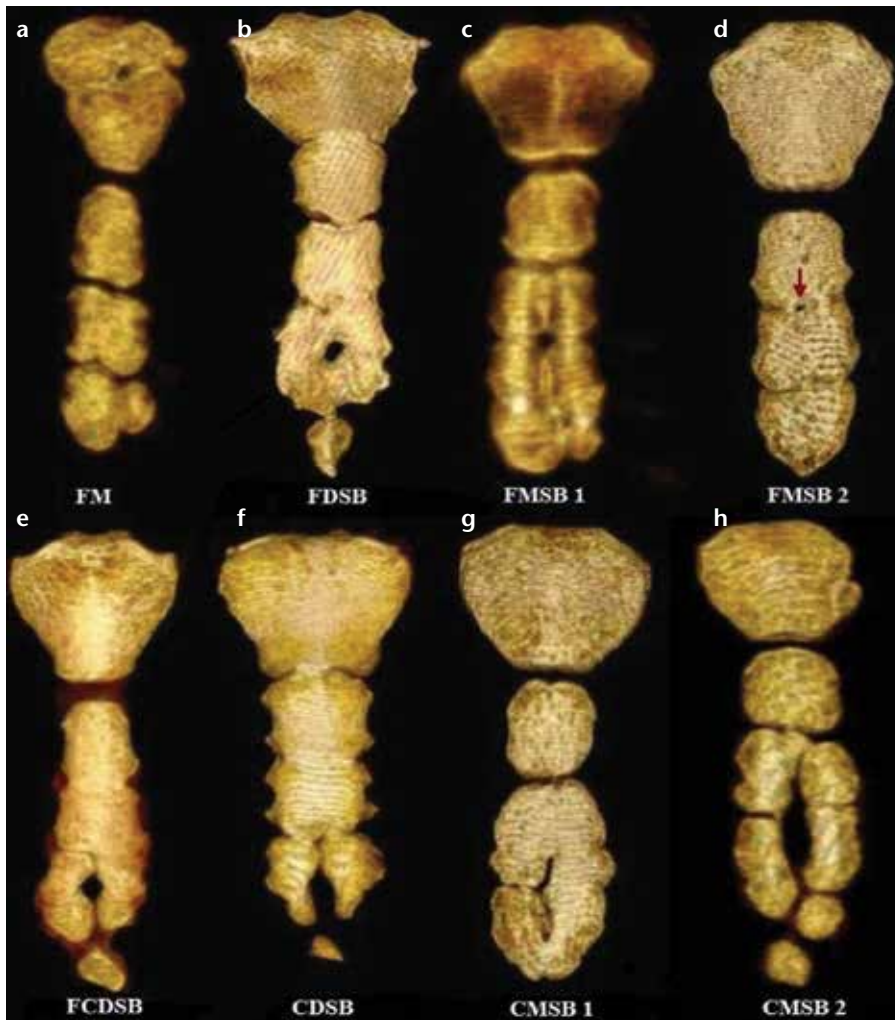


Figure 5. a–h. Foramina and clefts identified in the sternal body in different cases: a foramen of the manubrium (FM) (a), a foramen of the distal sternal body (FDSB) (b), a foramen of the medial sternal body 1 and 2 (red arrow) (FMSB 1 and 2) (c, d), a foramen and cleft of the distal sternal body (FCDSB) (e), a cleft of the distal sternal body (CDSB) (f), and a cleft of the medial sternal body 1 and 2 (CMSB 1 and 2) (g, h).

the sternum are more similar to the ossification centers of the vertebrae than those of the long bone, and each of the centers are enveloped by a spherical plate.

Components of the sternum (the manubrium, the body, and the XP) are formed in the cartilage structures of the sternal plates that are located on each side of the midline after merging. The sternal cartilage plates that are located on both sides of the midline begin to calcify in the craniocaudal direction during the 15th week of the prenatal period. Calcification continues into the postpartum period. At birth, calcified areas can only be observed in the manubrium and the mesosternum. XP calcification appears at six years of age (6, 9). Sternal ossification centers are

monitored at the intercostal space in the midline, the manubrium, and the mesosternum. The manubrium usually has one ossification point, and the mesosternum has three ossification points.

The segments of the mesosternum are known as sternebrae. Accessory ossification centers are frequently found in the manubrium and the mesosternum. Multiple ossification centers form as a result of endochondral ossification, especially in the cartilage segments of the mesosternum that are located on both sides of the midline. These points of ossification can be symmetrically positioned on both sides of the midline. Additionally, these points may be arranged in an irregular manner due to the asymmetry

of the costal joints. Two or more ossification centers that develop in the cartilage structures merge over time in the craniocaudal direction as endochondral ossification continues. The fusion of the sternebrae occurs in the caudocranial direction. After fusion is complete, the sternebrae form in the body. The fusion of the manubrium and the body cannot occur even at later ages because of the fibrocartilaginous tissue between them (1, 2, 6, 10–16).

The three different ossification pattern types are described according to the ossification of the manubrium and the body during the postnatal period. The type 1 pattern is characterized by one ossification center in the manubrium and one ossification center in the three sternebrae of the mesosternum. The type 2 pattern is defined by one ossification center in the manubrium, one ossification center in the first sternebrae of the mesosternum, and two ossification centers in the other sternebrae. In the type 3 pattern, only one ossification center in the manubrium and two ossification centers in the sternebrae of the mesosternum occur. The type 2 pattern is the most commonly observed pattern in the literature (13, 17). In a study by Ashley (13), the incidence rates of the different ossification patterns were as follows: 22% for type 1, 60% for type 2, and 18% for type 3. In our study, the type 2 ossification pattern was the most common pattern among the 139 cases, which occurred in 97 cases (67%). The type 1 ossification pattern occurred in 39 cases (28%), and the type 3 ossification pattern was detected in seven cases (5%). These findings were consistent with the values reported in the literature.

Measurements of the manubrium, the body of the sternum, and the manubriosternal structures were obtained to assess the postnatal development and the maturation of the sternum, and the differences between the age groups were statistically significant. No differences were observed in the TM and SDM measurements between the genders, but statistically significant differences were found in the SDB and TSDS measurements between the genders. These results are consistent with the differences in the number of

sternebrae in males versus females. The thickness of the body was not assessed due to the many developmental variations from person to person. In the literature, the postnatal development of the sternum has not been evaluated using measurements obtained with MDCT, and our study will contribute to additional studies in this area of research.

One ossification center is usually found in the manubrium after birth; however, several studies have demonstrated that more than one center may occur in rare cases (6, 12). In our study, 28 cases 0–10 years of age had two to four ossification centers in the manubrium even though several cases had partial fusion. Overall, 36 patients 0–15 years of age had spherical ossification centers in the manubrium. Morphological structure changes occur due to the mechanical forces of the joint and the surrounding structures, which are associated with the developing manubrium. Spherical ossification centers acquire a trapezoidal shape over time. In our study, spherically shaped manubrium was not observed in any of the age groups older than the age group of 10–15 years.

A sternal foramen is rarely observed in the manubrium (18). In one case, a foramen was observed in the manubrium due to inadequate fusion of ossification centers.

The accessory bone, known as the suprasternal bone or the episternal bone, is observed in the upper and posterior part of the manubrium in 1.5% of cases in the population (2). The suprasternal bone was observed in five of our cases (three cases were bilateral and two cases were unilateral). Suprasternal tubercles result from the bony fusion of the suprasternal bone to the manubrium (8, 19). In this study, 10 cases had tubercles that were fused to the upper part of the manubrium and were localized in the midline (nine cases were bilateral and one case was unilateral). Their appearances were similar to vascular calcification, calcified lymph nodes, fracture fragments, and foreign bodies in a radiographic study; however, MDCT can clearly identify these conditions.

Manubriosternal fusion does not occur at later years of age due to the fibro-

cartilaginous tissue located between the manubrium and the body. In our study, full fusion occurred in six cases, and partial fusion occurred in six cases. The earliest fusion occurred in the age group of 6–10 years. No comparison was performed with the rates in the literature because our study evaluated cases according to the stage of development and maturation.

Three to four ossification foci, known as sternebrae, have been observed in the mesosternum in the period immediately after birth (6, 16). Of the cases in the age group of 0–15 years ($n=150$), female patients had significantly less sternebrae compared with the males. Two sternebrae were observed in three females. Three sternebrae were observed in 50 females, and four sternebrae were identified in 13 females. Three sternebrae were found in 47 males, and four sternebrae were identified in 37 males. These results demonstrate the differences in the dimensions of the sternum between males and females.

The development of the sternum body was analyzed in the age group of 0–15 years, and at least two ossification centers, as described in previous studies, and potentially a total of four ossification centers were observed in the sternebrae, which were localized on each side of the midline. Previous studies determined that ossification centers generally fuse in the cranio-caudal direction from 6–12 years of age. Our study included several rare cases with incomplete fusion up to the age of 15; however, fusion of the ossification centers in our cases was largely consistent with the literature. Past studies have reported that fusion in the sternebrae occurred in the caudocranial direction, and fusion was complete before 25 years of age. In our cases, fusion of the third and fourth sternebrae and the second and third sternebrae was fully complete from 15–20 years of age. Fusion of the first and second sternebrae was complete from 20–25 years of age. In four cases, fusion did not occur.

The sternum has one of three morphological shapes in adults (flat, longitudinal oval, or O shape) as defined in the literature. The flat type is the most commonly observed shape (20). In our

study, the findings were consistent with those reported in the literature. Sternal hypoplasia was observed due to the absence of the development of the third sternebrae in four cases. Sternal developmental anomalies include foramina, pseudo-foramina, and clefts. Sternal foramina are usually localized in the distal sternum, and form as a result of the incomplete fusion of ossification centers (8). A foramen was observed in 15 cases. Thirteen of the foramina were localized in the distal sternum. One foramen was localized in the middle of the sternum, and one foramen was localized in the manubrium. Five cases had a cleft associated with the foramen. A pseudo-foramen was observed at the sternoxiphoidal junction in three cases. A cleft was observed in 10 cases. Five of the cases occurred in conjunction with a foramen, and most of the clefts were localized in the distal part of the sternum. In one case, a cleft was observed in the vertical and horizontal planes. In two cases, wide clefts were observed between the second and third sternebrae, which were accompanied by a foramen in the middle of the sternum.

The XP is the third part of the sternum and forms the most distal section of the sternum. The direction, calcification, and termination of the XP and the developmental variations in the XP were evaluated. Ventral deviation occurred more frequently in previous studies (21). In our study, ventral deviation was observed in 135 cases, and no deviation was observed in 115 cases. Dorsal deviation was not observed. Initial ossification of the XP was reported to occur after six years of age in the literature; however, partial XP calcification was observed in 15 cases in the age group of 0–5 years in our study. Calcification was observed in a total of 116 cases. Eight of the cases had complete XP calcification. Partial calcification was observed in the remaining cases. Fusion of the sternal XP was found in 12 cases in the age group of 20–25 years. A pseudo-foramen was found in only one of our cases. The incidence of foramina, pseudo-foramina, and fusion of the sternal XP was lower than those in previous studies that evaluated adults because our study included a younger population.

Knowledge of the sternal foramina, clefts and non-ossified chondral regions is important to prevent fatal complications, such as hemorrhage and cardiac tamponade. A risk of cardiopulmonary resuscitation is a fracture of the sternum, which may lead to severe heart injuries and patient death. Knowledge of the postnatal development, maturation, and anatomy of the sternum is important for preventing misdiagnoses, such as traumatic fissures or fractures and lytic lesions. MDCT images clearly depict sternal variations and the pathological conditions. Intraosseous transfusions from the medullary portion of the sternum are rarely used in the pediatric population because of a high risk of complications. The medullary portion of the tibia is more often used.

The postnatal development and maturation of the sternum result in a range of variations and anomalies, such as sternal foramina, manubrium shapes, fusion (manubriosternal, sternabraes, body, and XP), ossification, and clefts. All these variations, especially differences in ossification, have crucial importance in the misdiagnosis of developmental sternal anomalies and tumors. MDCT produces high-resolution images and enables the anatomical evaluation of the skeletal system and the morphogenesis of the sternum.

In conclusion, the postnatal development and the morphogenesis of the sternum can be adequately assessed using MDCT. Our study included a limited number of cases and different cases. We believe more accurate results can be achieved if the number of cases is increased and the same cases are studied to determine the maturation and the development of the sternum over the years.

Conflict of interest disclosure

The authors declared no conflicts of interest.

References

- Gray H, Williams PL, Bannister LH. Gray's anatomy: the anatomical basis of medicine and surgery. New York: Churchill-Livingstone, 1995.
- Restrepo CS, Martinez S, Lemos DF, et al. Imaging appearances of the sternum and sternoclavicular joints. *Radiographics* 2009; 29:839–859. [\[CrossRef\]](#)
- Williams PL, Warwick R, Dyson M, Bannister LH. Gray's anatomy. 37th ed. New York: Churchill-Livingstone, 1989.
- Kozielec T. A roentgenometric study of the process of ossification of the human sternum. *Folia Morph (Warsz)* 1973; 32:125–148.
- O'Rahilly R, Muller F. Human embryology and teratology. New York: Wiley-Liss, 1992.
- O'Neal ML, Dwornik JJ, Ganey TM, Ogden JA. Postnatal development of the human sternum. *J Pediatr Orthop* 1998; 18:398–405. [\[CrossRef\]](#)
- Larsen WJ. Human embryology. 2nd ed. New York: Churchill-Livingstone, 1997; 77–78.
- Yekeler E, Tunaci M, Tunaci A, Dursun M, Acunas G. Frequency of sternal variations and anomalies evaluated by MDCT. *AJR Am J Roentgenol* 2006; 186:956–960. [\[CrossRef\]](#)
- Skandalakis JE, Gray SW, Ricketts R, Skandalakis LJ. The anterior body wall. In Skandalakis JE, Gray TW, eds. *Embryology for surgeons*. Baltimore: Williams and Wilkins, 1994; 540–544.
- Riach ICF. Ossification in the sternum as a means of assessing skeletal age. *J Clin Pathol* 1967; 20:589–590. [\[CrossRef\]](#)
- Odita JC, Okolo AA, Omene JA. Sternal ossification in normal newborn infants. *Pediatr Radiol* 1985; 15:165–167. [\[CrossRef\]](#)
- Ogden JA, Conlogue GJ, Bronson ML, Jensen PS. Radiology of postnatal skeletal development. II. The manubrium and sternum. *Skeletal Radiol* 1979; 4:189–195. [\[CrossRef\]](#)
- Ashley GT. The relationship between the pattern of ossification and the definitive shape of the mesosternum in man. *J Anat* 1956; 90:87–105.
- Kohli V, Nooreyazdan S, Das BN, Kaul S, Singh J, Parmar V. Surgical reconstruction for absence of sternum and pericardium in a newborn. *Indian J Pediatr* 2006; 73:367–368. [\[CrossRef\]](#)
- McCormick WF, Nichols MM. Formation and maturation of the human sternum. I. Fetal period. *Am J Forensic Med Pathol* 1981; 2:323–328. [\[CrossRef\]](#)
- Rush WJ, Donnelly LF, Brody AS, Anton CG, Poe SA. "Missing" sternal ossification center: potential mimicker of disease in young children. *Radiology* 2002; 224:120–123. [\[CrossRef\]](#)
- Wong M, Carter DR. Mechanical stress and morphogenetic endochondral ossification of the sternum. *J Bone Joint Surg Am* 1988; 70:992–1000.
- Cooper PD, Stewart JH, McCormick WF. Development and morphology of the sternal foramen. *Am J Forensic Med Pathol* 1988; 9:342–347. [\[CrossRef\]](#)
- Ogawa K, Fukuda H, Omori K. Suprasternal bone. *Nihon Seikeigeka Gakkai Zasshi* 1979; 53:155–164.
- Selthofer R, Nikolić V, Mrcela T, et al. Morphometric analysis of the sternum. *Coll Antropol* 2006; 30:43–47.
- Akin K, Kosehan D, Topcu A, Koktener A. Anatomic evaluation of the xiphoid process with 64-row multidetector computed tomography. *Skeletal Radiol* 2011; 40:447–452. [\[CrossRef\]](#)