

Morphology of the human xiphoid process: dissection and radiography of cadavers and MDCT of patients

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Abstract

Purpose The purpose of this study was to evaluate the morphology of xiphoid process by dissection and using radiography of cadavers and multidetector computed tomography (MDCT) in patients.

Methods The xiphoid processes of 41 cadavers were dissected and taken by radiography. Other 902 patients examined by MDCT were revealed by image post-processing used with multiple planar reconstruction, maximum intensity projection and volume rendering.

Results Xiphoid processes displayed pointed shape in 422 cases (44.75 %), oval shape in 387 cases (41.04 %), and forked shape in 134 cases (14.21 %). The sagittal shape of the xiphoid process was observed as ventrally deviated in 217 cases (23.01 %), dorsally deviated in 191 cases (20.25 %), S-shaped (ahead ventral, then dorsal) in 21 cases (2.23 %), and resembling a hook in 14 of ventral deviated patients and in 19 of those dorsal deviated patients. The foramen of xiphoid processes was found in

544 cases (57.69 %). The pattern L (a large foramen with a diameter of more than 5 mm) appeared in 302 cases (55.51 %), pattern S (a small foramen with a diameter of no more than 5 mm) in 155 cases (28.49 %), pattern LS (a mixture of a large and a small foramina) in 37 cases (6.80 %), and pattern SS (two or more small foramina) in 50 cases (9.19 %).

Conclusion Human xiphoid process appeared in morphological diversity. The anatomic structure and ossification degree of xiphoid process was well evaluated by MDCT. Our data may be used for diagnosis and surgical treatment of xiphoid process-related diseases.

Keywords Human xiphoid process · Morphology · Anatomic variations · Ossification · Multidetector computed tomography

Abbreviations

CT	Computed tomography
MDCT	Multidetector computed tomography
VR	Volume rendering
MIP	Maximum intensity projection
MPR	Multiplanar reconstruction
CPR	Curved planar reconstruction

Introduction

Human xiphoid process located in the lower part of the sternum is a thin and cartilaginous process. It offers many insertions points for ligaments and muscles, and becomes ossified ordinarily at its upper part as an adult [17]. The number of reports of xiphoid process diseases increased recently, and these reported diseases could be related to the

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morphology of the xiphoid process which has gotten increasing clinical attention [4, 9, 17, 21].

The xiphoid processes are partly composed of hyaline cartilage, and are invisible on radiographic images unless they have been calcified or ossified. It is difficult to reveal the structure of xiphoid process with conventional radiographic examination. In the frontal view, it is superimposed on the mediastinum, abdominal organs, and spine. On both the lateral radiographs and lateral tomograms, it is often visible but fine details are obscured by overlying structures. In the early 1980s, computed tomography (CT) was used to display the sternum and it could reveal the anatomic shape and ossification of xiphoid process by the axial images [6]. But routine axial CT scan displaying only axial images did not reveal the whole xiphoid process. With the development of multidetector CT (MDCT) and the imaging post-processing techniques including volume rendering (VR), maximum intensity projection (MIP), multiplanar reconstruction (MPR) and curved-planar reconstruction, revealing the whole shape and internal structures of xiphoid process from all aspects have become possible.

The aim of this study was to evaluate the morphology of xiphoid process including shape, foramen, and its ossified degree, by using radiograph in cadavers and MDCT in patients.

Materials and methods

The specimens and the patient information

The 41 cadavers came from bodies donated to Chonbuk National University Medical School for education and research, including 27 men and 14 women, from 33 to 101 years old, and the average age was 71.3 ± 17.7 years old. Each donation was reviewed by a Medical Ethics Committee, and the study was approved by an Internal Review Board.

In all of 902 adult patients (563 men and 339 women, age range 20–97 years, mean 62.8 ± 12.4 years), 592 cases (men 378, women 214) came from the Taishan Hospital of Taisan Medical University, China. 310 cases (men 185, women 125) came from the Chonbuk National University Hospital, Korea. This study followed the principles of the Declaration of Helsinki, and was conducted in accordance with the guidelines of our Institution's Research Committee.

The dissection of the anatomical specimens and radiograph

All the samples were removed from the cadavers containing the whole anterior chest wall, and then all the soft tissues were removed. Only costal cartilage, sternum, xiphoid

process and 2-cm long ribs have remained from each sample. All the samples were taken X-ray films in the same digital radiography machine (VDI 150B-40, Shimadzu, Japan) with the digital imaging and communications in medicine, under the same exposed condition of 50 kV and 5 mAs. The distance from tube focus to image plate was 100 cm, which was to avoid the sample from being magnified.

The patients MDCT scanning

There was no specific disease in these patients involving the xiphoid process. MDCT scanings were performed with a 128-slice MDCT scanner (SOMATOM Definition AS⁺, Siemens, Germany). The minimum of reconstructed slice thickness was 0.6 mm, and all the images were transferred to workstation (Syngo 2010, Siemens, Germany) for post-processing. MPR and MIP images on coronal and sagittal planes were obtained. The coronal curved MPR images and three-dimensional VR images were acquired. The reconstructed images were evaluated in consensus by three radiologists with over 10 years of experience in computed tomography diagnosis, respectively. The following anatomical morphology and ossification of the xiphoid process including anatomic shape

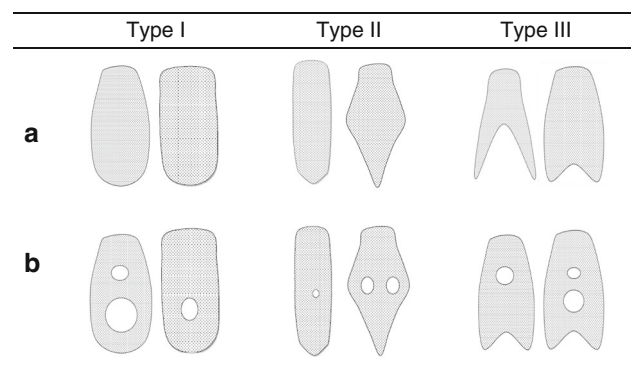


Fig. 1 The classification of xiphoid process. Type I means *oval shape*, type II means *pointed shape*, type III means *forked shape*. Subtype **a** means no foramen, subtype **b** means one foramen or more

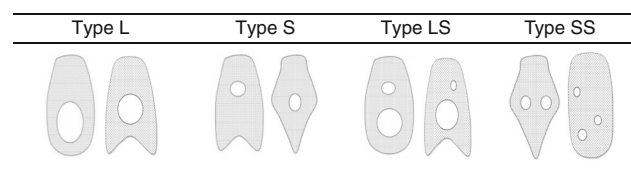


Fig. 2 The patterns of the xiphoidal foramen according to its size and distribution. Pattern L is a single large foramen which diameter is 5 mm or more. Pattern S is a single small foramen, <5 mm. Pattern LS is a mixture of a large and a small foramen. Pattern SS is two or more small foramina

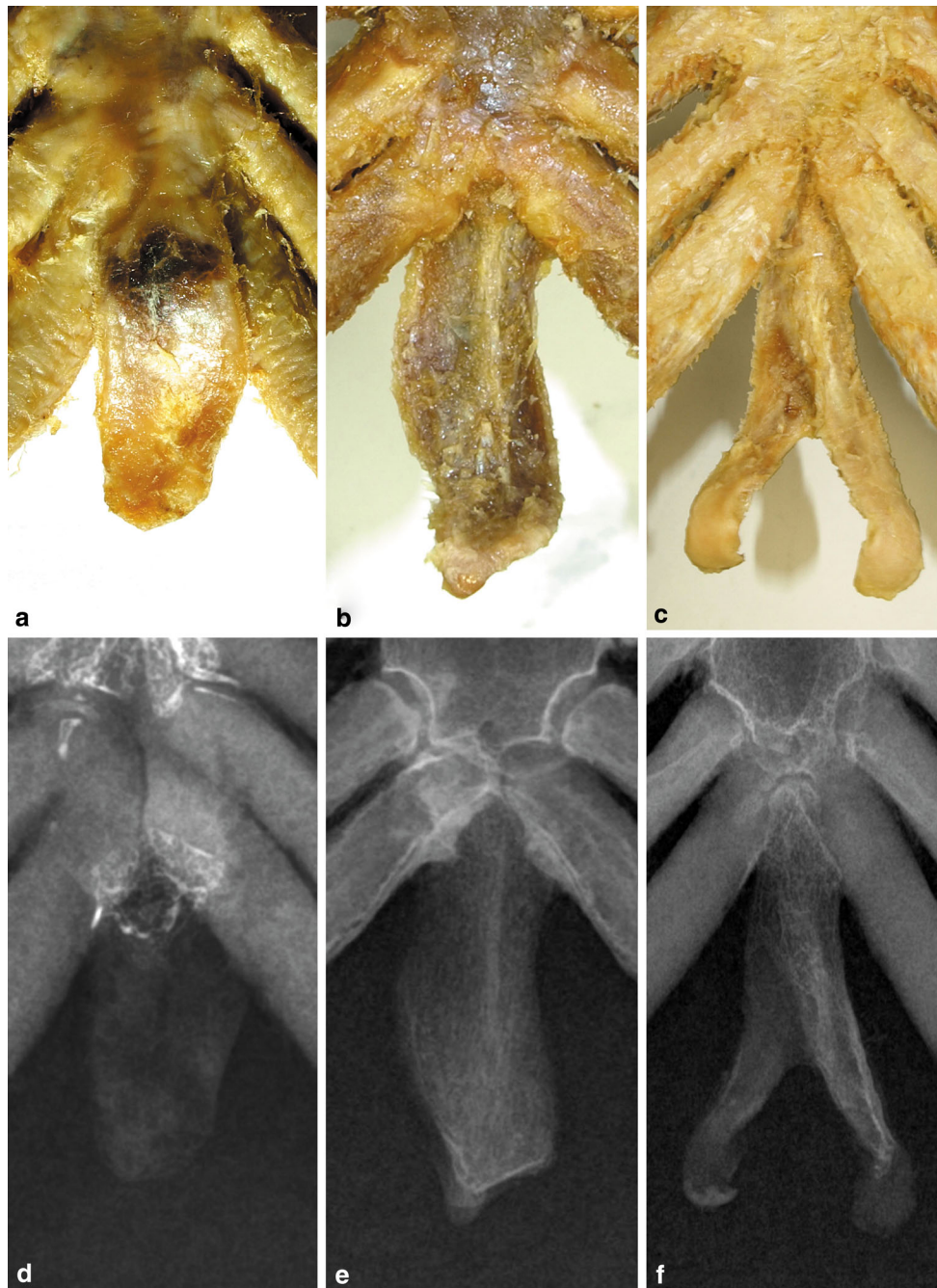


Fig. 3 The photographs of xiphoid process in Korean cadavers. **a, d** A 90-year-old woman, the type I of xiphoid process with *oval shape*; **b, e** A 61-year-old man, the type II of xiphoid process with *pointed*

shape. **c, f** A 75-year-old man with the type III of xiphoid process in *forked shape*. (**a, b, c** specimens; **e, d, f** X-ray files)

classification, the size and distribution of foramen and ossification degree were evaluated.

The classifying standard of the anatomic shape and foramen pattern of xiphoid process

According to the shape and outline, xiphoid processes were divided into three types: type I (oval shape), type II

(pointed shape), and type III (forked shape). If there was no foramen in the xiphoid process, it was named as subtype a; if there was a foramen or more, it was subtype b (Fig. 1).

The foramen was classified into four patterns by its size, number and position (Fig. 2). The pattern L meant that there was a single large foramen and its diameter was more than 5 mm on the xiphoid process. Pattern S meant that the foramen was a single small one which the diameter was no

Table 1 The number of every type of human xiphoid process in Chinese and Korean multidetector computed tomography (MDCT), and Korean cadavers

	Sex	Type I	Type II	Type III	Total
Chinese MDCT ^a	Men	143	191	44	378
	Women	82	107	25	214
	Total	225	298	69	592
	%	38.01	50.34	11.65	
Korean MDCT ^b	Men	84	66	35	185
	Women	56	48	21	125
	Total	140	114	56	310
	%	45.16	36.77	18.06	
Korean cadavers ^c	Men	14	7	6	27
	Women	8	3	3	14
	Total	22	10	9	
	%	53.66	24.39	21.95	
Type total		387	422	134	943
(%)		41.04	44.75	14.21	

Type I means *oval shape*, type II means *pointed shape*, type III means *forked shape*

a compared with b: type I, $P = 0.014$; type II, $P < 0.001$; type III, $P = 0.004$

b compared with c: type I, $P = 0.305$; type II, $P = 0.239$; type III, $P = 0.616$

Men compared with women: type I, $P = 0.877$; type II, $P = 0.997$; type III, $P = 0.823$

more than 5 mm, located in the midline or the side. Pattern LS meant a mixture of a large and one or more small foramina. Pattern SS meant that there were two or more small foramina on the midline or that they were deviated from the midline.

Data processing

All data were statistically processed. The independent sample t test and χ^2 test were used by SPSS18.0 (Chicago, USA) and statistical significance was set at $P < 0.05$.

Results

The morphology of xiphoid process

In 41 specimens of cadavers and 926 cases on MDCT, the xiphoid process was well revealed (Fig. 3). Table 1 shows the details of the number and incidence of each type of the xiphoid process.

The sagittal shape of the xiphoid process was studied. The lower part of xiphoid process was aligned in the same or nearly the same axis (angle of deflection no $>15^\circ$) as the xiphoid body (Fig. 4a) in 514 cases (54.51 %), ventrally deviated in 217 cases (23.01 %, Fig. 4b), dorsally deviated

in 191 cases (20.25 %, Fig. 4c), and S-shaped (ahead ventral, then dorsal, Fig. 4d, e) in 21 cases (2.23 %). The distal portion of the xiphoid process resembled a hook was found in 14 of ventral deviation cases, and in 19 of dorsal deviation cases (Fig. 4f). And this hooked shape was detected only in the type II of xiphoid process.

The length, width, and thickness of xiphoid process were measured in all the cadavers and MDCT cases (Fig. 5). The mean length of xiphoid process was 60.31 ± 3.71 mm (range 30.6–80.7 mm), the mean width was 23.42 ± 2.37 mm (range 11.1–35.2 mm), the mean thickness was 8.25 ± 1.84 mm (range 6.3–11.5 mm). There was no significant difference in the length, width, and thickness between the Chinese and Korean, men and women, respectively.

Xiphoidal foramen was present in 544 cases (521 MDCT patients and 23 cadavers, 57.69 %). Table 2 shows the details of the pattern of xiphoidal foramen and the relationship with the type of xiphoid processes. There was no significant difference between men and women. The most common of foramen is pattern L (55.51 %, Fig. 6a, b), followed by patterns of S (28.49 %), SS (9.19 %, Fig. 6c), and LS (6.80 %, Fig. 6d, e) in that order. Some foramina were on the midline and some have been deviated from the midline. The biggest foramen was 25.9 mm in vertical diameter and 9.5 mm in transverse diameter. The minimum diameter of xiphoid process was 1.5 mm. The occurrence of this group and the reports of Yekeler et al. [20], Akin et al. [1], and El-Busaid et al. [3] were compared between each other, and significant differences were found (Table 3).

The ossification of xiphoid process

All the xiphoid processes of 41 cadavers and 902 clinical cases have been found with ossifications. The dual density which consists of the bone density and calcification-like density was found in 459 (77.80 %) men and 305 (86.40 %) women. The bone density is in the original ossification center of xiphoid process and it was found in all the cases. The calcification-like density is located in the lower part of the ossified center like a close rod or a free small globule.

The relationship between the ossification degree and ages (Fig. 7) reveals an obvious increase with the age, and there is significant difference between men and women in the ages from 40s to 80s.

Discussion

Xiphoid process is a kind of hyaline similar to costal cartilage. But it has not been paid as much attention as the



Fig. 4 The images of multidetector computed tomography in patients. **a** The lower part (*arrow*) was aligned in the same axis as the xiphoid body, **b** the lower part of xiphoid process was ventrally deviated with an angle of >15 degree (*arrow*), **c** the lower part was

dorsally deviated (*arrow*), **d** the reversed S-shape (*arrow*) of the distal portion of xiphoid process, **e** the S-shape (*arrow*) of the distal portion of xiphoid process, **f** the distal portion of the xiphoid process resembled a hook (*arrow*)

costal cartilage and other cartilages in the morphology, orthopedic surgery, and forensic science [10–12, 16, 18, 19]. Recently, there were a few papers published only

about xiphoid process disease and morphologic viewing by CT [1, 4, 9, 17, 20, 21]. The evaluation of xiphoid process with conventional radiography might be troublesome due

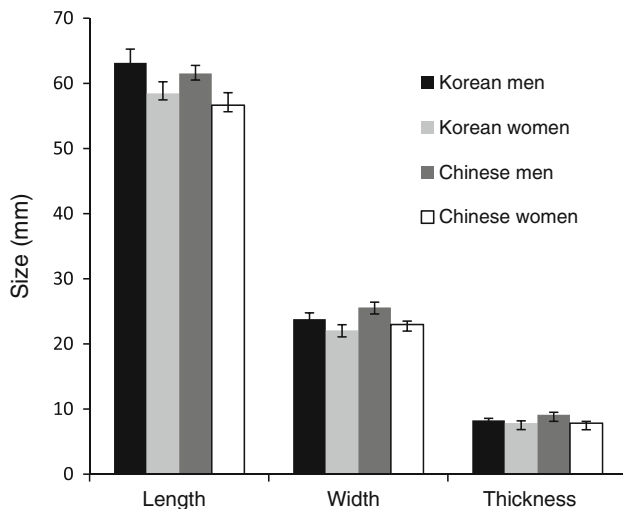


Fig. 5 The means and standard errors of length, width, and thickness of xiphoid process

Table 2 The number of the foramen patterns related to type of xiphoid process

Pattern ^b Type ^a	L	S	LS	SS	Total	%
Type I	212	42	27	34	315	57.90
Type II	81	109	8	15	213	39.15
Type III	9	4	2	1	16	2.94
Total	302	155	37	50	544	
%	55.51	28.49	6.80	9.19	100	

^a Type I means *oval shape*, type II means *pointed shape*, type III means *forked shape*

^b Pattern L is a single large foramen which diameter is 5 mm or more. Pattern S is a single small foramen, <5 mm. Pattern LS is a mixture of a large and a small foramen. Type SS is two or more small foramina

to technical limitations. In the frontal view, it was superimposed on the mediastinum, abdomen tissues, and spine. On both the lateral radiographs and lateral tomograms, it was often visible but fine details were obscured by overlying structures.

Computed tomography has settled the problems of displaying the xiphoid process. In the early years, Goodman et al. [6] began viewing the xiphoid process only with the axial scanning images. But routine axial CT scanning did not give the xiphoid the whole evaluation. Rapid developments in MDCT technology have facilitated the evaluation of xiphoid process because of its higher spatial resolution which offers comprehensive evaluation by performing post-processing tools such as MPR, MIP, curved MIP, and three-dimensional VR. These techniques have been used well in many cases to evaluate the xiphoid process in the studies of Yekeler et al. [20] and Akin et al.

[1]. In present study, all the xiphoid processes were displayed well by MDCT using the VR, MPR, and MIP, displaying not only ossifications or calcifications but also cartilage tissue.

In morphology, the xiphoid process is presented to be a flat and partly ossified cartilage. Its variation can be bifurcated, and sometimes with a foramen. These variances in morphology are inheritable, which can help group family members together when dealing with burial remains.

The fact that the shape of xiphoid process varies from rhomboid to triangular or to oval was first described by Goodman et al. [6] using axial CT images. Goodman et al. [6] also found that the distal xiphoid often showed a clumpy, irregular calcification or bifid appearance. Akin et al. [1] studied 577 patients and found that the xiphoidal ending consists of three different types: single, double or triple. In our study, according to the xiphoid process shape and outline, it was divided into three types: type I (oval type, 41.04 %); type II (pointed type, 44.75 %); type III (forked type, 14.21 %). Each type was divided into two sub-types according to the existence of foramen. This classification illustrated not only the xiphoid process shape, but also structure and outline. In this study, there was no significant difference between Korean cadaver and Korean patient in the each type of xiphoid process. It was demonstrated that MDCT was consistent with autopsy in evaluating morphology of xiphoid process. Type I was the most common in Korean (patients 45.16 %, cadavers 53.66 %), and type II was the most common in Chinese (50.34 %).

The sagittal shape of xiphoid process was observed in this study. The lower part of xiphoid process aligned in the same or nearly the same axis as the xiphoid body was found in 514 patients (54.51 %). The lower part of xiphoid process was ventrally deviated in 217 patients (23.01 %), dorsally deviated in 191 patients (20.25 %), and S-shaped (ahead ventral, then dorsal) in 21 patients (2.23 %). The distal portion of the xiphoid process resembling a hook was found in 14 of ventral deviated patients, and in 19 of those dorsal deviated patients, and this hooked shape was detected only in the type II of xiphoid process. This condition might mimic an epigastric mass, especially in the case of a long xiphoid process [9]. The tip of the xiphoid process curved like a hook or a S-shape has only been found in a report of Akin et al. [1] with the rate of only 0.6 % with dorsal curved and 0.8 % with S-shape. Maigne et al. [9], using MDCT, reported three cases that the abnormal anterior prominence of xiphoid process caused the mechanical discomfort and the local inflammation. Hence, MDCT is useful to display the abnormality of xiphoid process.

The xiphoidal dimensions of all the cadavers and clinical patients were measured. The mean length of xiphoid

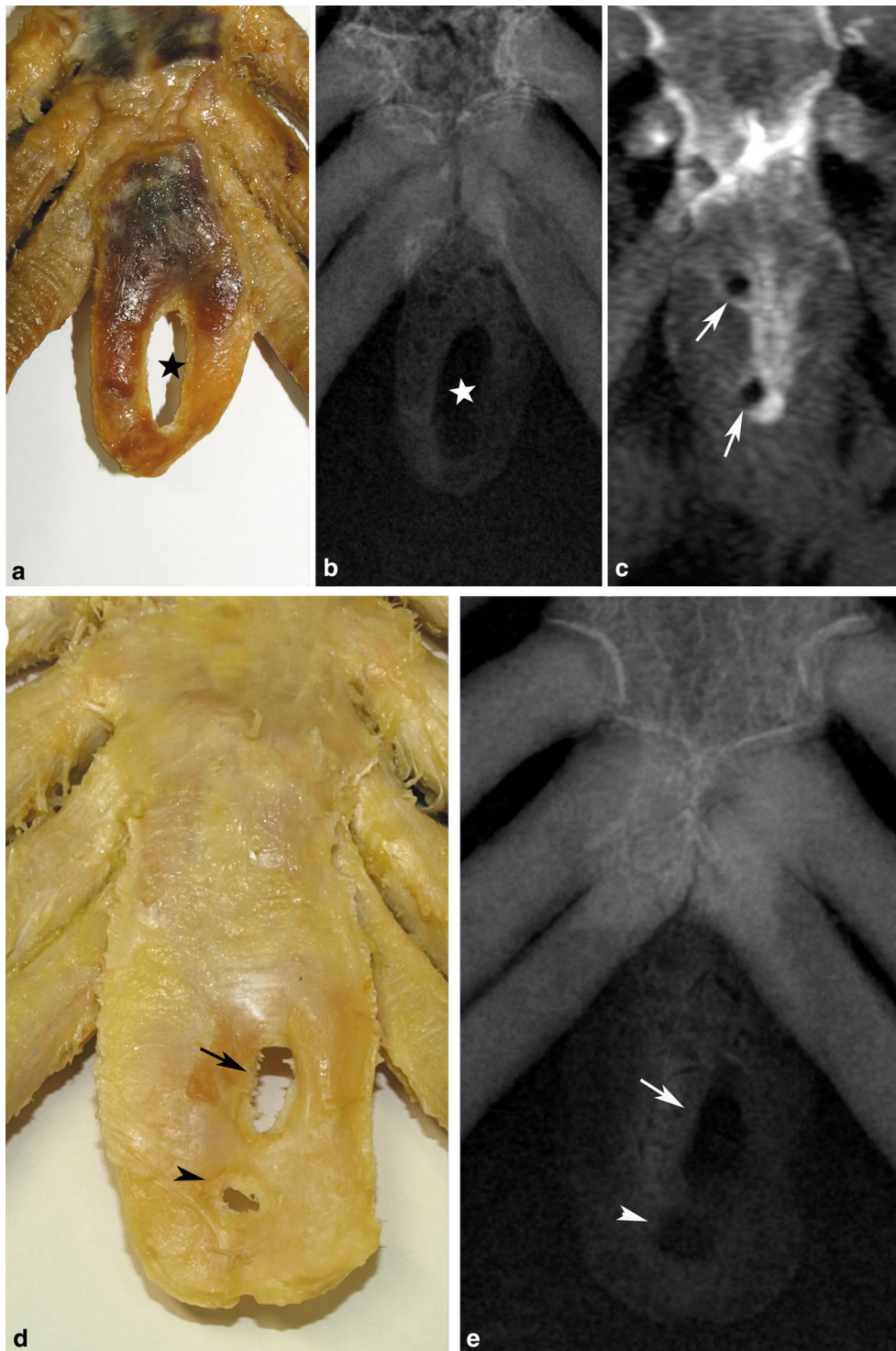


Fig. 6 **a, b** The photographs of foramina in human xiphoid process. An oval-shaped xiphoid process with large foramen (*star*) in an 85-year-old man. **c** An oval shape xiphoid process with two small foramina (*arrow*). **d, e** An oval-shaped xiphoid process with a mixture

of a large and a small foramina (*arrows*: a big foramen, *arrowheads*: a small foramen) from 60-year-old man cadaver. (**a, d** specimens; **b, e** X-ray films; **c** image of multidetector computed tomography in patient)

process was 60.31 ± 3.71 mm, mean width was 23.42 ± 2.37 mm, and mean thickness was 8.25 ± 1.84 mm. The result was similar to the report of Akin et al. [1]. There

were no significant differences in the length, width, and thickness between the Chinese and Korean, men and women, respectively. Enomoto et al. [4] reported a patient

Table 3 The xiphoidal foramen occurrence of this study compared with other studies

Reports	Populations	Total cases	Foramen cases	%
Present study**	Korean*	351	202	54.55
	Chinese	592	342	57.77
Yekeler et al. [20]	Turks	1,000	274	27.4
Akin et al. [1]	Turks	577	216	43.2
EI-Busaid et al. [3]	Kenyan	80	2	2.5

* Korean compared with Chinese ($P = 0.947$)

** Present study compared with other author's ($P < 0.001$)

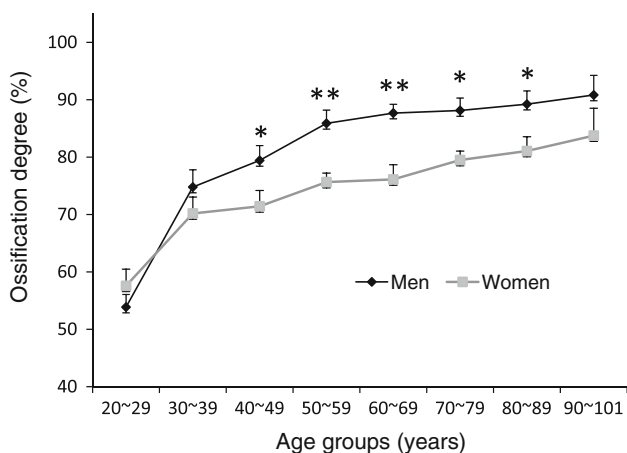


Fig. 7 The ossification degrees of xiphoid process in men and women were increasing with the ages, and the men's was higher than the women's. **a** compared with **b** * $P < 0.05$, ** $P < 0.01$

with chest pain and an abnormal elongation of the xiphoid process that was surgically resected. Hence, it is important to know the shapes and sizes of xiphoid process for the diagnosis of xiphoid process-related disease.

The foramen of xiphoid process is a result of improper development during embryogenesis [8]. In the 7th week of gestation, the sternal bars meet along the midline and begin to fuse and finish with the formation of the xiphoid process in the 9th week. The sternal bars ossify in the cranio-caudal succession from the 5th month until shortly after birth, producing the definitive bones of the sternum: the manubrium, the body, and the xiphoid process [8]. Any failure in this developmental process about the inferior end of the sternum results in fissure or foramen [2, 5, 13, 14]. Yekeler et al. [20] studied 1,000 sternums using MDCT, and found that xiphoidal foramen was seen in 27.4 %. Akin et al. [1] reported that the xiphoidal foramen was present in 43.2 %, and the most common type was single foramen (34.2 %), whereas 6.2 % patients had two, 1.4 % had three, and 1.4 % had four or more. But EI-Busaid et al. [3] found that only 2.5 % has foramen in 80 cadavers of Kenyan

population. In present study, the foramen of xiphoid process was found in 544 cases (57.69 %), including 23 cadavers by autopsy and 521 clinical patients by MDCT, and the number was higher than the former reports. Compared to the reports of Yekeler et al. [20] ($P < 0.001$), Akin et al. [1] ($P < 0.001$), and EI-Busaid et al. [3] ($P < 0.001$) there were significant differences in this study. Maybe the differences are related with ethnicity.

In this study, the foramen of xiphoid process was classified into four patterns. The most common pattern of foramen was pattern L (302 cases, 55.51 %), which only had a single large foramen. 155 cases (28.49 %) were pattern S, 37 cases (6.80 %) were pattern LS, and 50 cases were pattern SS. The foramen can be on the midline or deviated from the midline. The biggest foramen is 25.9 mm in vertical diameter and 9.5 mm in transverse diameter. The minimum diameter of foramen is 1.5 mm.

Ossification of the cartilaginous xiphoid process generally starts from proximal portion at about the age of three [7]. Odita et al. [15] reviewed the lateral chest radiographs of 200 Nigerian newborn infants to study the pattern of ossification of sternal segments. Authors found that any infant with two ossified sternal segments, including the manubrium, was at least 30 weeks gestated and those with three and four segments were 34 and 37 weeks gestated, respectively, and authors also found that ten infants had ossification of xiphisternum. This was one of the very few literatures about the xiphoid process ossification in the newborn infants. Authors also emphasized that there was no difference in the pattern of sternal ossification between the sexes. The xiphoid processes of 41 cadavers and 902 adult patients were all found with ossifications in this study. The ossification degree was evaluated as increasing with the ages, and there was significant difference between men and women in the ages from 40 to 80s (40s: $P < 0.05$, 50–70s: $P < 0.01$, 80s: $P < 0.05$), the men's is higher. Our data showed that the fastest ossified progress was in the 20–30 s age range. The ossification presented the dual density which the upper part was bone density and lower was similar to concentrated calcification density, and it was found in 77.80 % men and 86.40 % women. The original ossification center presented bone density, and mainly extended downward to the point of xiphoid process with age. The higher density like rod or globule might be the calcified original state of second ossification center, but this needs histological evidence. The increasing of the ossification degree with age means the decreasing of its flexibility.

In our opinion, xiphoid process showed morphologic diversity. MDCT can evaluate the outline, shape, and structure well from multi-aspect of it. Knowing the morphologic informations is helpful to understand and diagnose the disease of xiphoid process, particularly to surgery if the operation or injection is needed.

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Conflict of interest We declare that this manuscript entitled “Morphology of the human xiphoid process: dissection and radiography of cadavers and MDCT of patients” has not been published or submitted for publication elsewhere. Also, there is no conflict of interest in any financial support or relationships.

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