

# Estimation of age from human sternum: an autopsy study on a sample from South India

H. V. Chandrakanth · Tanuj Kanchan · Kewal Krishan · M. Arun · G. N. Pramod Kumar

Received: 24 May 2012 / Accepted: 31 July 2012 / Published online: 9 August 2012  
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**Abstract** Age estimation is one of the main parameters in the evaluation of skeletal remains in forensic anthropology casework. The present investigation is an attempt to study the fusion of manubrium and xiphoid process with mesosternum in 118 sterna (67 males and 51 females) of known age obtained during autopsy in South Indian population. The male samples were aged between 25 and 74 years and the females between 20 and 80 years. The fusion is studied to derive standards for the estimation of age from sternum. The results indicate that, with advancing age, the proportion of sternum with fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions increases in males and females. A larger proportion of sterna showed fusion of mesosterno-xiphisternal junction than manubrio-mesosternal junction in different age groups. Fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions was proportionately commoner in males than females. None of the sterna aged below 30 years showed fusion of mesosterno-xiphisternal junction. Nonfusion of mesosterno-xiphisternal junction was reported till the age of 48 years in males and 46 years in females. Manubrio-mesosternal

junction was observed to be very variable with regard to fusion status as the joint remained unfused even in the elderly ages. Based on the variability of the fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions observed in the study, it can be concluded that the sternum alone is not reliable for estimation of age in South Indian population.

**Keywords** Age estimation · Manubrium · Mesosternum · Xiphoid process · Manubrio-mesosternal junction · Mesosterno-xiphisternal junction · Forensic anthropology

## Introduction

One of the crucial aims of a medicolegal investigation is to establish the identity of a deceased, especially in cases where skeletal remains and dismembered or mutilated body parts are recovered and brought for examination. In these cases, it is vital to estimate age, sex, stature, as well as ancestry and thus helps in establishing the biological profile of the remains. Age estimation is one of the foremost criteria in the evaluation of unknown and commingled human remains. A careful analysis of the appearance and fusion of ossification centers of the bones can provide an estimate of the age of the deceased [1]. Researchers have developed methods of age estimation using developmental changes in cranial sutures [2, 3], teeth [4–7], and various bones of the human body including ilium and clavicle [8–15].

In the past, sternum has been used by researchers for estimation of sex and stature [16–23] and to provide valuable clues on the age of the deceased. A sternum comprises of three distinct parts: a manubrium superiorly, a mesosternum or the main body in the middle, and a xiphoid process placed inferiorly. The manubrium joins with mesosternum by a primary or secondary cartilaginous joint (manubrio-mesosternal junction), and the xiphoid similarly unites with

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H. V. Chandrakanth · M. Arun · G. N. Pramod Kumar  
Department of Forensic Medicine, JSS Medical College,  
JSS University,  
Mysore, India

T. Kanchan (✉)  
Department of Forensic Medicine, Kasturba Medical College,  
Manipal University,  
Light House Hill Road, Mangalore 575001, India  
e-mail: tanujkanchan@yahoo.co.in

T. Kanchan  
e-mail: tanuj.kanchan@manipal.edu

K. Krishan  
Department of Anthropology, Panjab University,  
Chandigarh, India

the mesosternum by either a primary or a secondary cartilaginous joint (mesosterno-xiphisternal junction). The ossification of human skeleton follows definite timings of appearance as well as fusion. Age estimation from sternum is, thus, based upon the analysis of the fusion of manubrium with mesosternum and fusion of xiphoid with mesosternum [24–28] as well on the morphological characteristics of sternum [29].

A number of studies are available on the estimation of age from sternum based upon the ossification of manubrium and xiphoid with the main body in different population groups. Some of the significant studies in this regard have been conducted by Singh et al. [24], Gautam et al. [25], Garg et al. [26], Dwight [27], Trotter [28], Sun et al. [29], Patterson [30], Ashley [31, 32], Jit and Bakshi [33], and MacLaughlin and Watts [34]. All these studies observed different timings for the fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions.

The adult sternum is a highly variable structure due to its distinct embryological development. Two types of studies have been conducted for estimation of age from sternum: one based on the direct inspection/visual examination of the fusion on the bone, and the other based on the radiographic analysis of the fusion on the bone. The objective of the present research is to study the sterna of South Indian population for the fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions by direct inspection method and explore its validity for estimation of age in the study population.

## Material and methods

The sample for the present study consisted of 118 sterna (67 males and 51 females) of South Indian origin. The sterna were obtained from autopsied bodies aged above 20 years at the Department of Forensic Medicine, JSS Medical College, Mysore in South India. The exact age of the deceased was obtained from the information furnished by the police in the inquest documents and was further verified from the birth certificates and other legal documents for age obtained from the legal heirs. An informed consent was obtained from the legal heirs prior to the conduction of medicolegal autopsy, explaining to them the purpose of the study and that the sternum will be preserved in the department for further analysis. Unidentified bodies and sterna with acquired or congenital abnormalities were excluded from the study.

A primary “T” incision was given, extending from the chin to the pubis and the skin; underlying subcutaneous tissues, fats, and muscles were separated. Ribs were dissected laterally to the costochondral junction, and the sternum was removed after disarticulating sternoclavicular joints

bilaterally. After obtaining the sterna, soft tissues were removed by placing the bone in water for 4 weeks. The sterna were then cleaned, dried, and examined visually for fusion of xiphoid with mesosternum and manubrium with mesosternum. A thorough maceration of sternum was performed to ensure precision in visual inspection of the joints for fusion status. Radiological examination was performed to comment on the state of fusion in four sterna where visual examination was inconclusive.

The data obtained were analyzed using Statistical Package for Social Sciences (SPSS) version 11.0 computer software (SPSS, Inc., Chicago, IL, USA). Level of significance was set at standard *p* value of less than 0.05.

## Results

In the present study, 118 sterna were examined to observe the fusion status at the manubrio-mesosternal and mesosterno-xiphisternal junctions. Males included in the study were aged between 25 and 74 years, and the females, between 20 and 80 years. In the study sample, mean age of males and females was  $45.9 \pm 12.2$  years and  $39.1 \pm 14.1$  years, respectively.

On direct inspection of manubrio-mesosternal junction, fusion of the joint was observed in 33.9 % ( $n=40$ ) sterna. Earliest fusion of manubrio-mesosternal junction was observed at the age of 35 years in males and 31 years in females. Nonfusion of manubrio-mesosternal junction was reported till the age of 70 years in males and 75 years in females. Fusion of manubrium with mesosternum in various age groups among males and females are shown in Table 1. It is observed that, with advancing age, the proportion of sterna with fused manubrio-mesosternal junction increases in both the sexes. A higher proportion of male sterna (40.2 %) showed fusion of manubrio-mesosternal joint than female sterna (25.5 %) in the study sample.

**Table 1** Fusion of manubrium and mesosternum in various age groups among males and females

Age (years)	Male			Female		
	Number	Fused (%)	Not fused (%)	Number	Fused (%)	Not fused (%)
<30	03	00 (–)	03 (100)	13	00 (–)	13 (100)
30–39	19	05 (26.3)	14 (73.7)	17	02 (11.8)	15 (88.2)
40–49	19	07 (36.8)	12 (63.2)	12	03 (25.0)	09 (75.0)
>49	26	15 (57.7)	11 (42.3)	09	08 (88.9)	01 (11.1)
Total	67	27 (40.2)	40 (59.7)	51	13 (25.5)	38 (74.5)

Fusion of mesosterno-xiphisternal junction was observed in 63.6 % ( $n=75$ ) of all the sterna included in the study. Earliest fusion of mesosterno-xiphisternal junction was observed at the age of 30 years in males and females. Non-fusion of mesosterno-xiphisternal junction was reported till the age of 48 years in males and 46 years in females. Fusion of xiphisternum with mesosternum in various age groups among males and females are shown in Table 2. It is observed that, with advancing age, the proportion of sterna with fused mesosterno-xiphisternal junction increases in males and females. Fusion of mesosterno-xiphisternal joint was observed in a larger proportion of male sterna (77.6 %) than females (45.1 %) in the study sample. When nonfusion was coded as “1” and fusion as “2,” statistically significant male–female differences were observed for fusion at mesosterno-xiphisternal joint ( $p<0.001$ ). The same, however, was not observed to be statistically significant ( $p=0.122$ ) for manubrio-mesosternal joint.

On visual examination of the fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions in each decade, it is observed that there was a gradual increase in proportion of sterna showing fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions with age. A proportionately larger number of sterna showed fusion of mesosterno-xiphisternal in different age groups than manubrio-mesosternal junction. Number of sterna with fusion of manubrium with mesosternum and xiphisternum with mesosternum in each age group are shown in Fig. 1.

## Discussion

Dwight [27] studied 46 male and 26 female sterna for estimation of age and observed that the union of manubrio-mesosternal and mesosterno-xiphisternal junctions was extremely variable. He concluded that the sternum was of little value in determining the age of an individual. Trotter [28] studied age changes in sternum of 435 White males and 307 Negro males in the age group of 30–80 years and found no correlation with respect to age and manubrio-mesosternal union. Girdany and Golden [35] studied sterna and concluded that manubrio-mesosternal fusion occurred

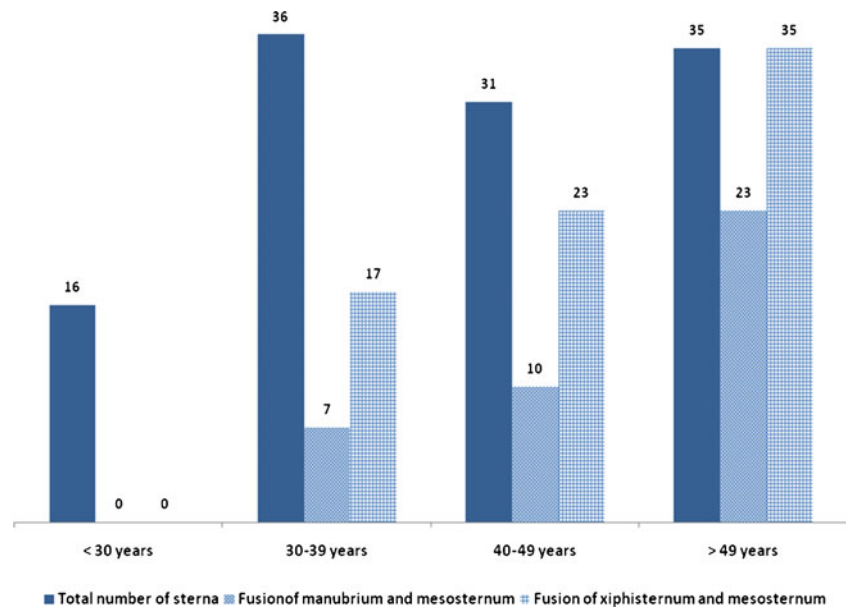
in old age, and the fusion of mesosterno-xiphisternal junction may or may not occur at all. McKern and Stewart [36] in a study conducted on 450 American soldiers opined that manubrium and mesosternum fuse occasionally. Garg et al. [37] on the radiographic investigation of manubrio-mesosternal joint observed that, in a sample of 192 participants aged between 35 and 65 years, manubrio-mesosternal joint was fused only in 14 % males and 22 % females. Fusion of xiphisternal joint was observed in nearly 50 % cases in the same population by Garg et al. [26]. In the present study, the fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions was observed in around 34 % and 64 % of the total sterna, respectively. The results of the present investigation indicate that the proportion of sternum with fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions increases with advancing age in both males and females. Similar observations are reported by Cameron and Fornasier [38] who observed an increase in fusion at manubriosternal joint with increasing age.

Singh et al. [24] studied the time of fusion of mesosternum with manubrium and xiphoid process in 524 male and 228 female sterna obtained from autopsy samples in the northwestern part of India. The age of their study sample ranged between 5 and 85 years. They concluded that the commencement and complete fusion of manubrium and xiphoid with the mesosternum was quite variable and, therefore, not a reliable age indicator. Gautam et al. [25] in another autopsy-based study on 100 sterna (56 males and 44 females) from Gujarat State of Western India studied the lengths of the specimens as well as the pattern of fusion of manubrium and xiphoid with mesosternum in males and females and concluded that, in most of the cases, the fusion of the xiphoid process with the mesosternum starts after 30 years of age, and complete fusion occurs after 50 years of age. They also observed that the fusion of the manubrium with the mesosternum starts at the age of 40 years and is completely fused after 50 years of age. Jit and Bakshi [33] studied 980 sterna with respect to naked eye changes and radiological fusion at the manubrio-mesosternal and mesosterno-xiphisternal junctions. They observed fusion of manubrium and mesosternum only after the age of 21 years

**Table 2** Fusion of mesosternum and xiphisternum in various age groups among males and females

Age (years)	Male			Female		
	Number	Fused (%)	Not fused (%)	Number	Fused (%)	Not fused (%)
<30	03	00 (–)	03 (100)	13	00 (–)	13 (100)
30–39	19	11 (57.9)	08 (42.1)	17	06 (35.3)	11 (64.7)
40–49	19	15 (78.9)	04 (21.1)	12	08 (66.7)	04 (33.3)
>49	26	26 (100)	00 (–)	09	09 (100)	00 (–)
Total	67	52 (77.6)	15 (22.4)	51	23 (45.1)	28 (54.9)

**Fig. 1** Age distribution of the study sample and number of sterna with fusion of manubrium with mesosternum and xiphisternum with mesosternum in each age group



in both sexes, though nonfusion could be seen even above the age of 60 years. With respect to mesosterno-xiphisternal junction, they observed that the fusion occurred after the age of 18 years in males and after 21 years in females, though nonfusion could be seen at any age. They concluded that, after the age of 18–20 years, the ossification of the sternum was of no help in estimating the age of an individual. Researchers have, thus, expressed different opinions on the variability and time of fusion at the manubrio-mesosternal and the mesosterno-xiphisternal junctions [24–28, 32–34]. Our findings in the present investigation on the high variability of the fusion of mesosternum with manubrium and xiphoid process are consistent with the observations made in the earlier studies. In the present research, fusion of manubrium and mesosternum was observed earliest at the age of 30 years in females and 35 years in males, while mesosterno-xiphisternal fusion occurred only after the age of 30 years in both sexes. Nonfusion of manubrio-mesosternal junction was reported till the age of 70 years in males and 75 years in females, while nonfusion of mesosterno-xiphisternal junction was observed latest at the age of 48 years in males and 46 years in females. No correlation was observed between the age and fusion status of manubrio-mesosternal and mesosterno-xiphisternal junction, and thus, the practical utility of utilizing sternum as an indicator of age appears limited. In our study, fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions was proportionately commoner in males than females, and a larger proportion of sterna showed fusion of mesosterno-xiphisternal junction than manubrio-mesosternal junction in different age groups.

Ashley [39] observed that the synostosis of manubriosternal joint cannot be considered as a senile change as the fusion is seen in all age groups after the age of 30 years.

Garg et al. [37] made similar conclusions in a radiographic investigation of manubrio-mesosternal joint based on the observations that the joint was not fused in more than 60 % cases in the 60–65 years age group. Manubriosternal junction is a symphysis where the manubrium and the sternum are connected by a fibrocartilage. According to Gray's Anatomy [40], in about 10 % of the subjects aged over 30 years, the manubrium is joined to the sternum by bone, but the intervening cartilage may be only superficially ossified. However, in the fibrocartilaginous plate, the centers for the manubrium and the sternum at manubriosternal joint may become juxtaposed, and union of the centers occurs. This may lead to matrical synostosis of the manubriosternal joint. In such cases, there is an incomplete demarcation between the manubrium and the sternal body which can be appreciated radiographically [41]. The manubriosternal fusion is about the formation of a lamina in the fetus, and the fusion can sometimes be seen in very young children. Synostosis at the manubriosternal joint can be primary or matrical synostosis and secondary or sclerotic synostosis. The matrical synostosis results from an obliteration of primary cartilaginous joint between manubrium and mesosternum during early life and is presumably inevitable. The sclerotic synostosis, on the other hand, is an obliteration of a secondary cartilaginous joint between manubrium and mesosternum during late adult life and is, presumably, the result of pathological processes [39]. Thus, while the matrical fusion is quite common in juvenile cases, the sclerotic synostosis is related to the advancing age, and the sclerotic form of this fusion is predominantly seen in females of advancing age [41]. Ashley [32] attributed the early synostosis to a persistent synchondrosis in place of symphysis. Due to the developmental phenomenon [34], sclerotic fusion is degenerative in nature and cannot be confused with



matrical synostosis. In the present study, the sternum was macerated, and the fusion status was analyzed by direct inspection method. Direct inspection method is the most frequently used method in forensic anthropology in developing countries primarily due to its cost-effectiveness. Radiography could not be conducted on all the dead bodies/sternum in the present research owing to financial constraints and limited facilities. This may be considered a limitation of the present investigation along with a smaller sample size of the present investigation. Hence, our observations with regard to fusion of manubriosternal joint should be read with caution and should not be compared with findings of radiological investigations per se. We propose that radiological examination should be preferred for the analysis of manubrio-mesosternal junction as it can distinguish between the matrical and sclerotic fusion at the joint more effectively. When visual method is employed for estimation of age from the joint, the observations on the nonfusion state should be considered more reliable than those on the fusion state.

## Conclusion

The present study shows that the sternum is of limited value as an accurate indicator of age. A general observation of the present study is that, as the age progresses, the proportion of male and female cases, showing fusion at mesosterno-xiphisternal and manubrio-mesosternal junctions, increases. However, it may not be extrapolated in any way that manubriosternal or mesosterno-xiphisternal fusion is well correlated with age. The pattern of fusion of the manubrio-mesosternal and mesosterno-xiphisternal junctions is extremely variable in both sexes and is observed from the younger to the older age group. The practical utility of the applicability of fusion status at mesosterno-xiphisternal and manubrio-mesosternal junctions in age estimation remains limited as the manubrio-mesosternal and the mesosterno-xiphisternal junctions may not fuse even until old age. A larger proportion of male sterna showed fusion of the manubrio-mesosternal and mesosterno-xiphisternal junctions. Hence, it can be concluded that fusion was commoner in males than females.

Manubrio-mesosternal junction was observed to be very variable with regard to fusion status as the joint remained unfused even in the elderly ages. Thus, the analysis of manubrio-mesosternal junction is of limited significance in establishing age from sternum. With regard to mesosterno-xiphisternal junction, the earliest fusion was observed at the age of 30 years in males and females, and nonfusion, of what was reported till the age of 48 years in males and 46 years in females. Thus, if the mesosterno-xiphisternal junction is fused, it can be assumed that the individual

sternum is not likely to be below 30 years, while in case of nonfusion of mesosterno-xiphisternal junction, it can be assumed that the sternum is not likely to be above 48 years in males and 46 years in females. Further research on a larger sample in different ethnic groups is proposed using radiological investigations to know the exact cause of the variability of the fusion as well as the precise pattern of ossification at manubrio-mesosternal and mesosterno-xiphisternal junctions.

**Conflict of interest** None.

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