A Study for the Determination of Sex by Multidetector Computed Tomography of Sternum using Discriminant Function and Logistic Regression

Soumeek Chowdhuri 1,*, Priyam Roy 1, Arkadeep Dey 1, Saikat Das 1, Ritwik Ghosh 1

1,* Department of Forensic and State Medicine, Calcutta National Medical College, Kolkata, India.

Received 29 Jul. 2019; Accepted 18 Nov. 2019; Available Online 31 Dec. 2019

Abstract

Post-mortem investigations of skeletal remains as well as radiographs from living individuals provide useful information for the discrimination of sex. Our study aimed to find out a mathematical model to differentiate gender based on greater degree of accuracy than the anthropological measures taken from the sternum obtained from cadaver dissection.

The study was performed on 108 adults who were brought for examination of chest due to various medical reasons. Their age ranged between 18 and 80 years. The cases were selected randomly after considering the inclusion and exclusion criteria. Sternal measurements were taken by studying CT (Computed Tomography) scans.

Of these cases, 73 were males and 35 were females. The discriminant function equation (Df) = 0.071 Manubrial Length +0.075 Manubrio-Sternal Length +0.036 Width at S1 +0.037 Width at S3 -11.367 (Constant). Overall 80.6% of the sample was correctly classified into their group.

This study revealed that measurements from CT scan of sternum can be used to differentiate between sex of individuals which adds to a great advantage in forensic anthropology.

Keywords: Forensic Science, Sternum, radiology, sex estimation, CT scan thorax, identification.

* Corresponding Author: Soumeek Chowdhuri
Email: smk_kep@gmail.com
doi: 10.26735/16586794.2019.035
1. Introduction

In forensic investigation, identification plays one of the most important parts. Bones when they are available are an important element of identification. There are number of differences between males and females among which skeletal differences along with hormonal and physiological differences are in total known as sexual dimorphism. When a skeleton is partially recovered, it is necessary that the diagnosis can be made from the available parts. In these cases, fine differences also assume importance [1]. In various cases of dubious identity, where fragments of bones or only some of the bones are found; it becomes important to identify the individuals from these remnants. The sternum plays an important role being a flat bone which can survive a great degree of compression. Sex determination is well studied in forensic medicine. Determination of sex plays an important role in the process of identification for medico-legal cases [2]. Post-mortem investigations of skeletal remains as well as radiographs from living individuals provide useful information for the discrimination of sex [3-9]. Explosions, putrefaction, traumatic damage, and geographic factors may hinder investigations of the pelvis and skull bones. However, the integrity of the sternum is well preserved even in advanced skeletal destruction. Differences in ethnic groups are prominent as shown by studies as early as Hyrtl’s and Ashleys [10]. The sternum has drawn considerable attention in studies related to sexual dimorphism [11-14].

Previously studies on sternal lengths for sex determination was done on various populations like Spaniards [15], South African Blacks [16], Japanese [17], Egyptian [18]. Studies on sternal length for sex determination were done mostly on cadaveric dissections and recently some studies have utilized radiological measurements also. The accuracy of radiological measurements which have been done on different ethnic populations can only be utilized in practical forensic medicine when we have obtained validated data from different populations of the world. In this relevance, the authors have named in the present work to assess the reliability of HRCT of chest measurements of sternum and to build a mathematical model for accurately predicting sex of an individual from measurement of sternal parameters from multislice computed tomography.

2. Methodology

2.1 Study Subjects

Multidetector Computed Tomography (MDCT) images were taken from 108 subjects, of which 73 were male and 35 were female, between the age group of 18 and 80 years. The cases were randomly selected from the general population who came for HRCT Scan of thorax for various medical conditions and informed consent was obtained from them before participation in this study. Ethical clearance (No. CM/CNMC/2017) was taken from Ethics Committee of Calcutta National Medical College; no additional radiation exposure was given to study subjects. Patients showing congenital, pathological or traumatic lesions of the chest wall were excluded.

2.2 Methods

The CT scan was performed on 16 slice Alexion Machine (Toshiba, Japan) at the CT scan centre of Calcutta National Medical College campus. A routine thoracic CT protocol was followed. All scans were obtained with the following parameters: tube voltage 120 kV, effective mA 120 and slice thickness 1mm. All images were transferred to a commercially available workstation. On the workstation, multiplane reformatting (MPR) of images in the sagittal and coronal planes was obtained using commercially available software (RadiAnt DICOM Viewer).

Our study was conducted at the CT Scan Centre of Calcutta National Medical College from June, 2018 to August, 2018 on 108 subjects of age ranging from 18 years to 80
years.

The following measurements were taken for this study:

- **Manubrium length (ML):** the distance from the jugular notch to the sagittal midpoint of the manubriosternal joint (Figure-1).
- **Mesosternum length (MSL):** the distance from the sternal angle to the sagittal midpoint of the xiphisternal joint (Figure-1).
- **Sternebra 1 width (S1W):** the distance between the left and the right first sternebra (depressions between the articulation notches for the second and third costal cartilage) (Figure-2).
- **Sternebra 3 width (S3W):** the distance between the left and right third sternebra (depressions between the articulation notches for the fourth and fifth costal cartilage).
- **Sternal index:** (manubrium length/mesosternum length) x 100.

### 2.3 Statistical Analysis

Discriminant function analysis was performed on the data entering all the variables together with sex as the grouping variable. The variables were entered together as the sample size was 108 of which 73 were males and 35 were females. The mean and standard deviation of the variables are seen in the chart in Table-1. ROC curve was first done on the variables to see the discriminating power of the variables. The Wilk’s lambda for the model is 0.621 which signifies a good discriminating power of the model as shown in Table-2. The Eigen value for this model is 0.609. Relative contribution of each variable to the discriminant equation is shown in Table-2. The discriminant function equation is, 

\[
D_f = 0.071 \text{Manubrial Length} + 0.075 \text{Manubrio-Sternal Length} + 0.036 \text{Width at S1} + 0.037 \text{Width at S3} - 11.367 \text{(Constant)}
\]

The cutoff point is 0.535 -1.117/2 = -0.291 as shown in Table-4. So above this value -0.291, the cases are male. Below this value -0.291, the cases are female. Overall 80.6% of the sample was correctly classified.
into their group by a model as shown in Table-4. At the individual group level, 80.0% of females and 80.8% of males were correctly classified. Cross-validated results showed 79.6% of the cases correctly classified by this model. After the results were used to get a discriminant equation, the formula was used on a separate sample of 20 cases to validate the results.

When age was correlated with the measured variables none of them showed any significant correlation as shown in Table-6. So, age could not be predicted with accuracy from this preliminary study. On doing logistic regression with the given variables we found that the Nagelkerke R Square was 0.551 (Table-5). The Hosmer and Lemeshow Test were also significant. The model was correctly able to predict sex overall in 82.4% cases, 87.7% in males and 71.4% in females (Table-6). This shows a good fit for this model (Table-7).

4. Discussion

Usually there is a considerable variability in the degree of sexual dimorphism even within closely related populations. This is due to genetic environmental and various socio-economic factors. It is therefore possible to produce images that are parallel, perpendicular or at an angle that suits the shape of the bone to obtain a one-to-one replicate image. Using the newest technology of MSCT makes it possible to form images that are very similar to the original of the bone shape that needs to be measured, in any axis and in a rapid manner [19]. The findings of the present study reemphasise the population variability in sternal dimensions (Table-8). When compared to the study by Ramadan et al [19]. Discriminant analysis of sternal parameter is a successful method of sex estimation studies as has been proved in previous studies [15] by Macaluso and Lacuna, on Spanish population and Western Australian sample done by Franklin et. al. [19], on comparison with Bon-giovanni and Spradley, who found the frequency of 61% for males and 55.6% for females which is in variation from our study. Direct measurement analysis can usually be performed on skeletal remains. However sometimes it may not be possible. Therefore the clinical diagnostic importance of radiological methods like CT and MRI which have high resolution and in which 3D images can be obtained can be used for morphometric studies. In 2012 the Royal College of Radiologists reported a 25.5% increase in radiological images in comparison to 2004/05 with 86% increase in use of CT and 125% use in MRI [20]. Thus, an increase in number of radiological based studies can be used for forensic anthropologic studies due to increase in radiological database. Population specific studies concluded that mean sterna measurements in South Africans [16] and Indians [14, 21-23] were lower than that of their European [24-28], US [7,29] and Canadian counterparts. Like studies in North and West Indian population reported larger female sternum measurement in North India and larger male sternum measurement in Western India [30,21-23]. Our study which has been done on an ethnically single population has shown difference between the west and north Indian population. All variables in this study had significant sexual dimorphism.

At the individual group level, 80.0% of females and 80.8% of male were correctly classified. Cross-validated
Table 1- Synopsis of statistical parameters of sternal measurements expressed in mm.

| Sex   | Sternal Index | ML     | MSL     | S1W    | S3W    |
|-------|---------------|--------|---------|--------|--------|
| Mean  | 56.10         | 48.22  | 87.84   | 25.31  | 26.66  |
| N     | 73            | 73     | 73      | 73     | 73     |
| Male  | Std. Deviation| 10.252 | 5.166   | 11.783 | 4.371  | 5.438  |
| Minimum | 33          | 40     | 50      | 17     | 15     |
| Maximum| 98           | 60     | 124     | 49     | 39     |
| Mean  | 63.11         | 44.15  | 71.22   | 23.51  | 25.12  |
| N     | 35            | 35     | 35      | 35     | 35     |
| Female| Std. Deviation| 9.333  | 5.253   | 11.177 | 5.915  | 9.969  |
| Minimum| 49           | 22     | 27      | 15     | 16     |
| Maximum| 86           | 54     | 89      | 40     | 76     |
| Mean  | 58.37         | 46.90  | 82.45   | 24.72  | 26.16  |
| N     | 108           | 108    | 108     | 108    | 108    |
| Total | Std. Deviation| 10.453 | 5.511   | 13.934 | 4.968  | 7.212  |
| Minimum| 33           | 22     | 27      | 15     | 15     |
| Maximum| 98           | 60     | 124     | 49     | 76     |

Table 2- Synopsis of the Canonical Discriminant Function Coefficients showing the degree to which, the variables contribute to the equation.

| Variables | Coefficient |
|-----------|-------------|
| ML        | 0.071       |
| MSL       | 0.075       |
| S1W       | 0.036       |
| S3W       | 0.037       |
| (Constant)| -11.367     |

Unstandardized coefficients

ML, Manubrium length; MSL, Mesosternum length; S1W, Sternebra 1 width; S3W, Sternebra 3 width

Table 3- Synopsis of the Group Centroid which provides the cut off point for the differentiation of sex.

| Sex     | Function coefficient |
|---------|-----------------------|
| Male    | 0.535                 |
| Female  | -1.117                |

Unstandardized canonical discriminant functions evaluated at group means
results showed 79.6% of the cases correctly classified by this model. This is different from those in Japanese (90.5%) [17], Western Australians (84.5%), South Africans (86.9%), North Indians (84.8%). Collectively all the results indicate that sternum can be used as a good indicator of sex determination in most regional populations.

The female to male ratio in the current work was 1:2 which is different from that reported by Wadhavan et al, 2009 [32] and Darwish et al, 2017 [18] where the ratio was 1:1. In this regard, there is an inequality between division of both sexes. Puttabanthi et al, 2012 [33] stated that the lengths of manubrium and sternal widths act as a good discriminator of female sterna. Our study found similar findings and agreed with them. On the other hand, Osunwoke et al, 2010 [27] who conducted the study on southern Nigerian population stated that the length of the body of sternum was sexually dimorphic whereas the manubrial length was not sexually dimorphic.
lights the necessity of such a study in an ethnic population like Bengalis who have some ethnic characters which are independent from other Indian populations. Therefore, this study has shown that it can be used for determination of sex in Bengali population.

### 4. Conclusion

When fragmentary remains are found as is often in cases of disasters or mass graves, it is difficult to find whole bones, especially of transverse flat bones like sternum. So, it is difficult to calculate stature or estimate sex from such fragmentary remains. Since our study uses a tool like MDCT for measurement of the lengths of the parts of the sternum, it should be effective to a great degree in finding out such data as sex because of its accuracy of measurement and predictability through a mathematical model with lesser chances of error. Integration of all the anthropometric measurements highlighted the necessity of such a study in an ethnic population like Bengalis who have some ethnic characters which are independent from other Indian populations. Therefore, this study has shown that it can be used for determination of sex in Bengali population.

### Table 8: Sternal variations between the study population and other populations.

| Study                        | Population          | Manubrium length (mean) | Mesosternum length (mean) | Sternebra 1 width (mean) | Sternebra 3 width (mean) |
|------------------------------|----------------------|--------------------------|----------------------------|--------------------------|--------------------------|
| Chowdhuri et al.             | Eastern Indian (Bengali) | 48.22                    | 87.84                      | 25.31                    | 26.66                    |
| (2019) Present Study         |                      | 44.15                    | 71.22                      | 23.51                    | 25.12                    |
| Macaluso et al (2014)        | Spaniards            | 51.85                    | 106.25                     | 28.31                    | 35.36                    |
| Macaluso et al (2010)        | South African Black  | 48.51                    | 98.74                      | 24.95                    | 31.77                    |
| Torimitsu et al (2015)       | Japanese Cadavers    | 50.21                    | 101.18                     | 29.16                    | 32.93                    |
| Darwish et al (2017)         | Egyptian adults      | 46.40                    | 103.00                     | 28.70                    | 35.10                    |
| Changani et al (2014)        | Gujarati             | -                        | -                          | 27.80                    | 32.25                    |
| Puttalbanthi et al (2010)    | Unknown human skeletal remains | 47.48                  | 92.36                      | 53.32                    | 33.41                    |
| Ramadan et al (2010)         | Turkish patients     | 53.90                    | 100.70                     | 28.70                    | 34.90                    |
| Ekizoglu et al (2010)        | Turkish patients     | 52.50                    | 104.90                     | 28.80                    | 34.10                    |

The calculated discriminant functions for a combination of three measurements, single measurement and indices, yielded an overall accuracy ranging from 63.3% to 90.6% [34] from different models that can be used to determine sex from these measurements performing logistic regression analysis. The accuracy of sex determination was 84.7% and 81.8% taking into account only sternal measurements with general accuracy rate being 82.9% [35]. A series of new forensic standards for the estimation of sex in that population were outlined; cross-validated expected classification accuracies range between 77.2 and 84.5% amongst the Australian population [36].

This study conducted in an ethnic regional population has shown similarity in predictability to studies conducted in other populations like Japanese, South Africans, Western Australians, Spaniards, but has also shown a variation which is indigenous and regional in character which highlights the necessity of such a study in an ethnic population like Bengalis who have some ethnic characters which are independent from other Indian populations. Therefore, this study has shown that it can be used for determination of sex in Bengali population.
pological data from regional populations can be utilize in development of data base, which can be utilized for various image-based techniques which can augment or may be in future replace traditional autopsy.

References

1. Hunnargi SA, Menezes RG, Kanchan T, Lobo SW, Binu VS, Uysal S, Kumar HR, Baral P, Herekar NG, Garg RK. Sexual dimorphism of the human sternum in a Maharashtrian population of India: a morphometric analysis. Leg Med. 2008;10(1):6-10. https://doi.org/10.1016/j.legalmed.2007.05.011
2. Rastogi P, Kanchan T, Menezes RG, Yoganasimha K. Middle finger length—a predictor of stature in the Indian population. Med Sci Law. 2009;49(2):123-6. https://doi.org/10.1258/rmsmsl.49.2.123
3. Chowdhuri S, Mukhopadhayay P. Estimation of stature from radiological measurement of sternal length with corroborating in living individuals a study in contemporary Bengali adults. J Indian Acad Forensic Med. 2015;37(4):388-91. https://doi.org/10.5958/0974-0848.2015.00101.3
4. Krogman WM, Iscan MY. The human skeleton in forensic medicine, Charles C. Thomas, Springfield, IL. 1986:413-57.
5. Byers S. Forensic Anthropology. A text book.
6. Bass WM. Human Osteology: A Laboratory and Field Manual. 5thedn. Columbia: Missouri Archaeological Society; 2005.
7. Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci. 2011;56(2):289-96. https://doi.org/10.1111/j.1556-4029.2010.01635.x
8. Haglund WD, Sorg MH. Advances in forensic taphonomy: method, theory, and archaeological perspectives. CRC Press; 2001. https://doi.org/10.1201/9781420058352
9. Phenice TW. A newly developed visual method of sexing the os pubis. Am J Phys Anthropol. 1969;30(2):297-301. https://doi.org/10.1002/ajpa.1330300214
10. Dahiphale VP, Baheete BH, Kamkhedkar SG. Sexing the human sternum in Marathwada region. J Anat Soc India. 2002;51(2):162-7.
11. Gautam RS, Shah GV, Jadav HR, Gohil BJ. The human sternum as an index of age and sex. J Anat Soc India. 2003;52(1):20-3.
12. Jit I, Jhingan V, Kulkarni M. Sexing the human sternum. Am J Phys Anthropol. 1980;53(2):217-24. https://doi.org/10.1002/ajpa.1330530206
13. Atal DK, Murari A, Naik SK. Gender differentiation from sternal width. J Indian Acad Forensic Med. 2008;30(4):198-201.
14. Hunnargi SA, Menezes RG, Kanchan T, Lobo SW, Binu VS, Uysal S, Kumar HR, Baral P, Herekar NG, Garg RK. Sexual dimorphism of the human sternum in a Maharashtrian population of India: a morphometric analysis. Legal Medicine. 2008;10(1):6-10. https://doi.org/10.1016/j.legalmed.2007.05.011
15. Macaluso PJ, Lucena J. Estimation of sex from sternal dimensions derived from chest plate radiographs in contemporary Spaniards. Int J Legal Med. 2014;128(2):389-95. https://doi.org/10.1007/s00414-013-0910-z
16. Macaluso Jr PJ. The efficacy of sternal measurements for sex estimation in South African blacks. Forensic Sci Int. 2010;202(1-3):111-e1. https://doi.org/10.1016/j.forsciint.2010.07.019
17. Torimitsu S, Makino Y, Saitoh H, Sakuma A, Ishii N, Inokuchi G, Motomura A, Chiba F, Hoshioka Y, Iwase H. Estimation of sex in Japanese cadavers based on
26. Torwalt CR, Hoppa RD. A test of sex determination from measurements of chest radiographs. J Forensic Sci. 2005;50(4):JFS2004425-6. https://doi.org/10.1520/JFS2004425

27. Osunwoke EA, Gwunireama IU, Orish CN, Ordu KS, Ebowe I. A study of sexual dimorphism of the human sternum in the southern Nigerian population. J Appl Biosci. 2010;26:1636-9.

28. Teige K. Morphometric studies of x-rays of the sternum. Zeitschrift fur Rechtsmedizin. J Legal Med. 1983;90(3):199-204. https://doi.org/10.1007/BF02116230

29. Bongiovanni R, Spradley MK. Estimating sex of the human skeleton based on metrics of the sternum. Forensic Sci Int. 2012;219(1-3):290-e1. https://doi.org/10.1016/j.forsciint.2011.11.034

30. Hunnargi SA, Menezes RG, Kanchan T, Lobo SW, Binu VS, Uysal S, Kumar HR, Baral P, Herekar NG, Garg RK. Sexual dimorphism of the human sternum in a Maharashtrian population of India: a morphometric analysis. Leg Med. 2008;10(1):6-10. https://doi.org/10.1016/j.legalmed.2007.05.011

31. Changani MV, Javia MD, Varma KA. Determination of sex from various measurements of human sternum and manubrium in Gujarat population. J Res Med Den Sci. 2014;2:59-65. https://doi.org/10.5455/jrmds.20142111

32. Wadhawan M, Murari A, Naik SK. Correlation between age and degree of fusion, between sternal joints. Indian J Forensic Med Pathol. 2009;2:83-7.

33. Puttabanthi S, Velichety SD, Padi TR, Boddeti RK, Priyanka JR. Sexing of unknown adult human sterna by metrical analysis. Int J Biol Med Res. 2012;3(2):1516-9.
34. Bedalov A, Bašić Ž, Marelja I, Dolić K, Bukarica K, Missoni S, Šlaus M, Primorac D, Andjelinović Š, Kružić I. Sex estimation of the sternum by automatic image processing of multi-slice computed tomography images in a Croatian population sample: a retrospective study. Croatian med J. 2019;60(3):237. https://doi.org/10.3325/cmj.2019.60.237

35. Ramadan SU, Türkmen N, Dolgun NA, Gökharman D, Menezes RG, Kacar M, Koşar U. Sex determination from measurements of the sternum and fourth rib using multislice computed tomography of the chest. Forensic Sci Int. 2010;197(1-3):120-e1. https://doi.org/10.1016/j.forsciint.2009.12.049

36. Franklin D, Flavel A, Kuliukas A, Cardini A, Marks MK, Oxnard C, O'Higgins P. Estimation of sex from sternal measurements in a Western Australian population. Forensic Sci Int. 2012;217(1-3):230.e1-5. https://doi.org/10.1016/j.forsciint.2011.11.008