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Estimation of Sex from Sternum Measurements and Comparative Analysis using Machine Learning Based Feature Selection Algorithm

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Abstract: This prospective study utilized multi-detector computed tomography (MDCT) to examine the morphological characteristics and sex-related variations of the sternum in 150 adult patients (92 males and 58 females) aged 20–80 years. The sternum, a skeletal component is a strong bone that doesn't deform easily therefore, it can be used for age and sex prediction by researchers for sex determination. Sternum images were reconstructed using the Volume Rendering (VR) technique, and measurements of different sternal parts were obtained from sagittal and coronal images. Statistical analyses, including independent sample t-tests and discriminant analysis, revealed significant differences in sternum measurements between male and female groups ($p<0.001$), with body length and manubrium width emerging as the most crucial parameters. The study demonstrated the reliability and utility of sternal morphometric analysis for accurate sex estimation. Machine learning-based feature selection algorithms were utilized for comparative analysis of selected features. The findings emphasize the importance of employing scientifically validated methodologies, highlighting manubrium length/width and body length as key parameters for accurate gender determination using sternum measurements.

Keywords: Forensic, Manubrium, Mesosternum, Nearest neighbour classifier, ROC curve, Sternal area, Sternal cleft, Sternal foramen, Sternal index.

I. Introduction

Computed Tomography (CT) revolutionized medical imaging upon its invention in 1972 by Sir Godfrey Hounsfield and Allan Cormack, earning them the Nobel Prize for their contributions. This technology, characterized by its rapid advancements, has significantly enhanced imaging speed, patient comfort, and resolution [1]. CT operates on the principle of computerized X-ray imaging, wherein an X-ray beam rotates around the body, producing cross-sectional images or "slices" processed by the machine's computer. Helical or spiral CT, facilitated by slip ring technology, allows continuous rotation of the X-ray tube around the patient, improving imaging efficiency. Multidetector CT (MDCT) systems, a later development, collect multiple slices of data rapidly and reconstruct images within seconds, providing

enhanced visualization of tissues, particularly bone tissue [2].

The present study focuses on the application of sternum measurements for sex determination, especially beneficial in challenging identification scenarios. Forensic examiners analyse bone metrics to generate a biological profile encompassing age, sex, stature, and lineage [3].

Skeletal remains such as the pelvis, long bones, and skull traditionally aid sex determination, but in cases of trauma or degradation, the sternum emerges as a reliable alternative due to its resilience and accessibility. Various methods, including osteometry, odontometric data analysis, and DNA analysis, are employed for sex determination, with osteometry favoured for its simplicity and accuracy [4]. Previous research highlights sexual dimorphism in sternum measurements, enabling forensic professionals to predict sex accurately. Understanding sternal sexual dimorphism enhances identification processes in forensic settings. "Hyrtl's law," indicating differences in sternum length between males and females, serves as a foundation for sex determination as it states that the manubrium of the female sternum extends beyond half the length of the body, whereas the body length in the male sternum is approximately double that of the manubrium [5]. Imaging techniques such as Multiplanar reformation (MPR) aid in measuring sternum parameters accurately and with the help of a measurement tool all the measurements were calculated for an individual like manubrium length, Mesosternum length, sternum width, sternal index and whole sternum length of an individual patient [6].

A. Anatomy of Sternum

The sternum is a central component of the thoracic cage and is located in the front wall. It is divided into three sections: the manubrium, the body (corpus), and the xiphoid process. Because of its simplicity of use, it can be employed in the field of forensic medicine for assessing age as well as gender using imaging techniques.

Secondary cartilaginous joints connect these components, with hyaline cartilage and fibrocartilaginous discs acting as intermediaries. The manubrium is a flat, quadrilateral structure that widens superiorly. The body is a rectangular, flat bone with facets or grooves along its lateral edge that allow the ribs to be attached. It measures around 20 cm long, 3-4 cm wide, and 1 cm thick. Finally, the xiphoid process is a thin, inferiorly protruding structure.

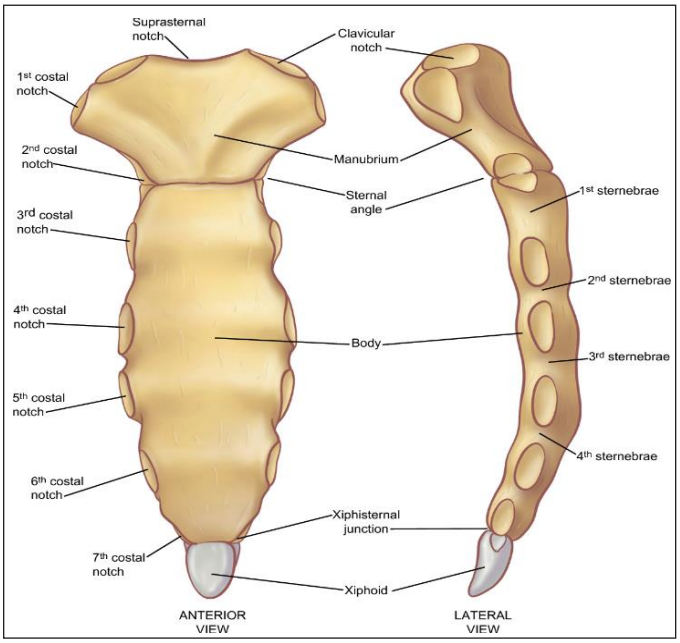

Fig. 1: Sternum Anatomy (Anterior & Lateral View)

B. Hypothesis

The measures obtained from a Multi-Detector Computed Tomography (MDCT) scan of the sternum can assist distinguish males and females. Various sternum dimensions, such as length, width, and total sternal length, as well as other characteristics, may be accurate markers for determining an individual's sex. It is predicted that by analysing these measurements and their statistical significance, a clear separation between male and female sternums can be made. If the measurements regularly show statistically significant variations between the sexes, it would imply that sternum measurements can be used to determine an individual's sex.

II. Aim and Objectives

A. Aim

The study aims to estimate the sex of an individual from sternum bone measurement by using Multidetector computed tomography.

B. Objective

- To investigate sternum ossification and anatomical changes based on age and gender.
- To ascertain the role of computed tomography scans in sex estimation.
- To comprehend the significance of 3D reconstruction and the measurement technique utilised to calculate sternum measurements.
- To assess the accuracy of gender determination using sternum measurement in a multi-detector computed tomography scan.
- To determine the measurement discrepancy according to the system software.

III. Material and Methods

A. Source of Data

Hospital based cross-sectional study that was carried out in Department of Radio-Diagnosis at Shree Guru Gobind Tricentenary (SGT) Hospital and Research Institute for CT chest examination.

B. Study Duration

This study was carried out over a period of 2 year. The data was collected from August 2022 to June 2023 in the department of Radio-Diagnosis of SGT Medical College and Hospital and Research Institute, Gurugram.

C. Study Type and Design

This study was designed to be a prospective, quantitative and comparative study about the determination of sex from various measurements of the sternum bone by using an MDCT scan in adult patients of 20-80 years of age. A patient who underwent CT chest scan, a sternum reconstructed image is created and different measurement is taken according to efficacy and study demand. No participant was made to undergo a CT scan for the sole purpose of this study.

D. Study Area

CT area of Department of Radio-Diagnosis of SGT Medical College and Hospital and Research Institute, Gurugram.

E. Inclusion Criteria

- Patients who have ages from 20 yrs to 80 yrs.
- Both sexes were included in this study.
- Only CECT examination of selected patient will be included in this study.

F. Exclusion Criteria

- If a patient doesn't have a fused sternum.
- Any patient who has a history of trauma and deformity related to the sternum.

G. Sample Size

A convenient sample of 150 patients of all age group were taken who underwent CECT & HRCT Thorax on 16 slices SOMATON SIEMENS. This study sample was included from a section of the population that is effortlessly accessible or readily available.

IV. Methodology of Data Collection

With the support of SGT University's Radio-Technologist, CT sternum images were taken, and overall data was collected. The information was gathered in the form of daily benefits. For the CT chest Imaging of the adult patients, our hospital uses routine sequences of thorax CECT and HRCT. After collecting data, for taking a measurement of the sternum Radian 3.0 software was used and measurement are done on sagittal and coronal images 3D reconstructed image of sternum. Data is filled

and expressed in excel sheet. A master chart is made which is attached with this study.

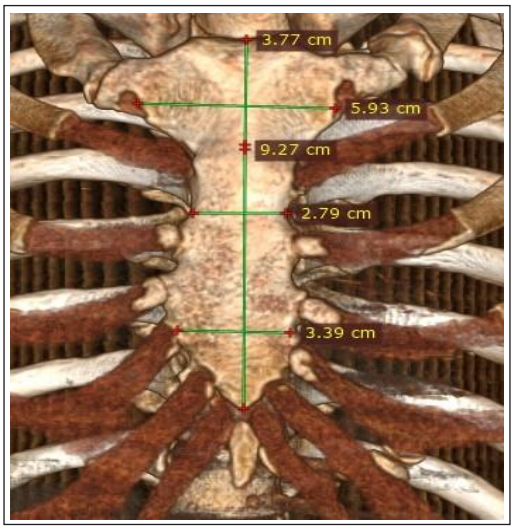

Fig. 2: MDCT Reformatted Image Shows MW (Manubrium Width), Sternebra 1 Width (S1W) and Sternebra 3 Width (S3W). Manubrium Length. (ML) and Mesosternum Length (MSL)

V. Results

Estimation of gender by using sternum measurement was well entrenched in this study. In current study, a total number of 150 patient's samples (92 males and 58 females) were included. The descriptive analysis and independent t-test was utilized to show the mean, standard deviation and significance of the sample. Each extracted feature is analysed statistically and for the comparison purpose a machine learning based feature selection algorithm is applied where AUC value of each feature subset is calculated. After t-value calculation the parameter with least t-value is more relevant and the same verification of extracted feature is done using wrapper-based feature selection [10]. Each feature vector has an AUC value, among the highest AUC value we select a feature vector again to calculate AUC values if new AUC is less than previous highest value than the previous feature vector is best vector otherwise calculate another AUC value for new feature vector. Total 6 feature vector outcome as final feature subset. The AUC curve is generated using the NN classifier for the simplicity and normalization of each feature is done before value generation. Order of features according to AUC:(3)> (7)> (6)> (1)> (9)> (5)> (8)> (2)> (4) Base feature vector: top AUC rankers taken as base set 5 features are selected, F_{base1} = [F3, F7, F6, F1, F9], Subset F_{base2} = [F3, F7, F6, F1, F9, F5] is the final subset because AUC value of subset 3 reduced as shown in Fig. 3 and we add feature in the previous until new value of AUC is not less than the last one [9].

Tabel I: Table for Selected Features using Two Algorithms

Unreduced or Raw Data	AUC Based Feature Selection
9 Extracted features [1,2,3,4,5,6,7,8,9]	Feature subset 2 [3,7,6,1,9,5]

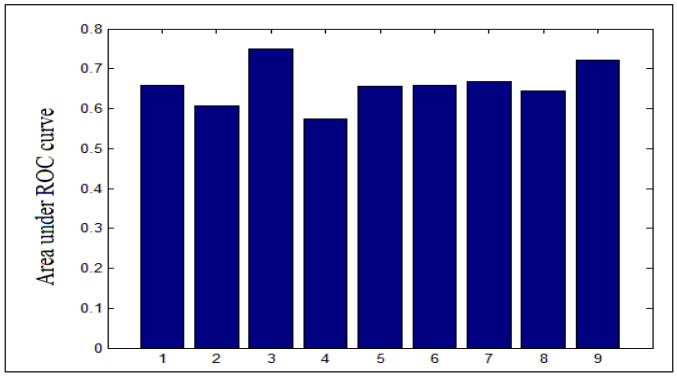

Fig. 3: Comparison of AUC Values of Each Extracted Features

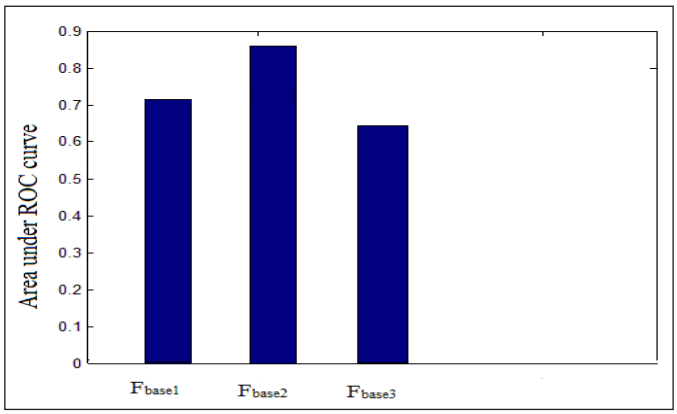

Fig. 4: AUC Value for Different Feature Subsets

Tabel II: Table for Selected Features (T-Value)

Measurements	Extracted Features	Calculated (t-Value)
1	Manubrium Length	6.25
2	TSL	10.86
3	Age	0.582
4	Manubrium Width	8.02
5	Sternal Area	10.76
6	SW1	2.88
7	Sternal Index	1.51
8	Mesosternum Length	8.73
9	SW2	3.14

After applying statistical t-test and machine learning AUC value, we can conclude that both algorithms showing the same features approximately. The order of selected features according to AUC value is Age > Sternal Index > SW1 > Manubrium length > SW2 > Sternal area.

VI. Discussion

Among all the radiological modality, CT is the pioneer choice for the evaluation of sex. Identification of skeletal remains is crucial because the estimation can be compared with antemortem data and other information that aids in the identification process. Moreover, sex assessment serves as a foundation for developing other aspects of a biological profile [7]. The current study affirms that sex differences in the sternum can be witnessed, however, these changes are peculiar to specific populations. Data from the study were compared to prior studies that covered varied populations from throughout the world, including Europe, India, Turkey, Jordan, and others. It is vital to notice that these differences change not just physically but also temporally. The study found that in the presence of an intact anterior thoracic cage, the sterna of the sample demonstrated significant sexual dimorphism to allow for a high degree of sex identification. Women's sternums were usually smaller than men's, which supports earlier findings in diverse populations. (Changani *et al.,* 2014): Indians (Singh and Pathak 2013), South Africans (Macaluso, 2010), Spaniards (Macaluso and lucena, 2014): West Australian (Franklin *et al.,* 2012) and Americans (Bongiovanni and Spradley, 2012). The initial evidence of sexual dimorphism in the sternum dates back to the late 18th century, when Wenzel conducted investigations comparing the lengths of the manubrium and corpus sterni in males and females. Building upon Wenzel's work, Dwight and Hyrtl conducted similar studies and arrived at a concept known as 'Hyrtl's law'. According to this law, there were observable differences in body shape between sexes, with men exhibiting a larger anterior thoracic cage and women displaying a longer manubrium to sternal body ratio. Even, researcher concluded that sternal index would be 50 in females. However, it has been noticed that the sternal index, which was previously utilised as a sexing criterion, is unreliable due to considerable sex overlap and accompanying sex bias. In different populations, different rules have been developed for sexing the sternum. Ashley, for example, devised the "149 rule" for sexing Europeans, which specifies that male sternal length is 149 mm and female sternal length is less than 149 mm [5]. Various criteria have been devised for various populations, such as the "136 rule" for East Africans, the "129 rule" for India's Marathwada region, the "131 rule" for West Indians, and the "142 rule" for Anatolians. In our investigation, we observed that the "144 rule" applied to the sample population, with a total sternum length greater than 144 mm indicating a male and a length less than 144 mm indicating a female. Notably, our data demonstrated that the total length of the sternum was more reliable as a measure for diagnosing sternum sex than the other factors studied.

VII. Conclusion

CT is a pioneer choice for sex evaluation among radiological modalities. The sternum exhibits sexual dimorphism specific to populations, and its assessment aids in identification processes. Various rules and indices have been formulated to determine sex based on sternal measurements, although some parameters may show overlap between sexes. Additionally, the sternum can exhibit anatomical variations and anomalies, and awareness of these variations is crucial for accurate diagnosis. Multiplanar and volume-rendering

reconstructed images are excellent tools for visualizing sternal anatomy and properly describing sternal variations and anomalies. These cutting-edge imaging techniques are extremely successful at revealing the delicate details of the sternum from various angles. Medical practitioners can observe the sternal structure in sagittal, coronal, and axial planes using multiplanar reconstruction, allowing for a more comprehensive assessment. Furthermore, volume-rendering reconstruction approaches allow for the fabrication of three-dimensional representations, which improves comprehension of sternal complexity. With these invaluable instruments, healthcare practitioners can acquire vital insights into the sternum's particular traits and anomalies, allowing for precise diagnosis and educated treatment recommendations. CT imaging plays a significant role in revealing the anatomy and variations of the sternum, enabling reliable assessments and avoiding diagnostic uncertainties.

Estimating gender is essential for identifying victims of terrorist acts, catastrophe victims, and legal cases involving medicine. In this present study, Males had greater mean and standard deviation values than females. The gender of an individual subject may be established with 91.4% accuracy using sternum measurement. The current study concluded that measuring manubrium width or length and body length can be used to accurately estimate gender in this sample. However, sternal area is not that reliable parameter for differentiation.

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