PHOTON
Journal of Natural Sciences and Technology
p-ISSN: 2087-393X | e-ISSN: 2579-5953
http://ejurnal.umri.ac.id/index.php/photon

Forensic Anthropology: Morphometric Study of the Sternum Using Computed Tomography Scan to Differentiate Sex Across Various Countries (Literature Review)

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Received 11 January 2025 | Accepted 1 August 2025 | Published 30 November 2025
DOI: https://doi.org/10.37859/jp.v16i1.7769

Keywords:

Forensic Anthropology; Computed Tomography Scan; Gender; Morphometric Study; Sternum

Abstract. The discovery of bodies in Indonesia is a frequent occurrence. Identifying these bodies requires determining the gender, height, and other physical characteristics to narrow down the search for the victim's identity. Computed tomography (CT) is the modality of choice for evaluating the anatomical details and pathological conditions of the sternum, sternoclavicular joints, and surrounding soft tissues. Given this issue, the researchers were interested in conducting a literature review on morphometric studies of the sternum using computed tomography scans to differentiate gender in various countries. The research method employed was descriptive observational, utilizing a literature review design from several articles published within the last 15 years. The articles selected for this study were based on specific inclusion and exclusion criteria set by the researchers. A total of 20 articles were used in this study. The literature review shows that the increasing number of morphometric studies, particularly in different populations, provides valuable data for researchers. CT can be utilized for the morphometric analysis of living subjects or discovered bones. If parts of the skeleton, such as the pelvis or skull, are not found or are damaged, forensic specialists and forensic anthropologists can accurately estimate gender using the sternum.

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1. Introduction

Indonesia is one of the most disaster-prone countries in the world due to its geographical position on the Pacific *Ring of Fire*, where three major tectonic plates the Indo-Australian, Eurasian, and Pacific plates converge. This unique geotectonic setting makes the country highly susceptible to natural disasters such as earthquakes, tsunamis, volcanic eruptions, and landslides (Mutaqin *et al.*, 2020). Additionally, hydrometeorological hazards such as floods and droughts occur frequently, exacerbated by the effects of climate change. These disasters often lead to large numbers of fatalities, and in many

cases, the victims are found in severely damaged, decomposed, or fragmented conditions, complicating the process of identification.

Beyond natural disasters, unidentified human remains are also frequently discovered under unusual and challenging circumstances whether buried, submerged, burned, or in advanced stages of decomposition. In such cases, conventional identification methods such as facial recognition, fingerprint analysis, or dental comparison are often rendered ineffective, necessitating the application of forensic sciences (Rutty *et al.,* 2013).

One of the primary fields employed in this context is forensic anthropology, a subdiscipline of biological anthropology that specializes in analyzing human skeletal remains to estimate biological profiles such as sex, age, stature, ancestry, and signs of trauma for legal and investigative purposes (Cattaneo, 2015). Among the biological parameters, sex estimation is considered foundational, as it significantly narrows the scope of possible identities and influences the methods used to estimate other biological traits.

One of the skeletal elements commonly studied for sex estimation is the sternum, a flat bone located in the center of the chest, composed of three parts: the manubrium, the body (corpus sterni), and the xiphoid process. Several studies have demonstrated that the sternum exhibits measurable sexual dimorphism, making it a valuable bone for morphometric analysis (Torimitsu *et al.,* 2017). In recent years, technological advancements have enabled the use of computed tomography (CT) scanning for three-dimensional imaging and precise measurement of skeletal elements. CT-based anthropometric analysis offers a non-destructive and reproducible method for evaluating skeletal remains in forensic investigations (Utsuno *et al.,* 2014).

While DNA analysis is the gold standard for identification with the highest degree of accuracy, it is not always feasible due to factors such as sample degradation, contamination, high costs, and limited laboratory access in certain regions. Moreover, environmental conditions in tropical and post-disaster settings often compromise DNA integrity (Amorim et al., 2021). As a result, combining genetic approaches with morphometric and radiological methods offers a practical alternative that enhances the accuracy of identification, especially in mass disaster contexts or when only partial skeletal remains are available.

Therefore, the integration of forensic anthropology, morphometric analysis of the sternum, and radiological imaging presents a reliable and efficient approach to human identification in forensic casework. This methodology is particularly vital in a disaster-prone country like Indonesia, where the need for rapid, accurate, and resource-efficient identification tools is urgent and ongoing.

2. The Methods

2.1. Search strategy

This research is a systematic literature review (Systematic Literature Review), a specific research and development methodology used to gather and assess various studies relevant to a particular focus topic (Triandini *et al.,* 2019). The steps include determining the data search strategy and/or information sources, selecting studies by assessing their quality according to eligibility criteria and using quality assessment instruments, as well as synthesizing data and extracting information. The keywords and Boolean operators used in the literature search were “morphometric study” and “computed tomography” and “gender” and “forensic anthropology”.

2.2. Information sources

The database sources used to search for literature in this study were Google Scholar, SpringerLink, DOAJ, and PubMed.

2.3. Eligibility criteria

The eligibility criteria for this study include both inclusion and exclusion criteria. The inclusion criteria are as follows: 1) Literature in the form of scientific journals and/or proceedings, 2) Sources of scientific journals and/or proceedings such as Google Scholar, SpringerLink, DOAJ, and PubMed, 3) Open access scientific journals and/or proceedings, 4) Articles available in full text, 5) Scientific journals and/or proceedings written in English or Indonesian, 6) Publication years between 2010-2023, 7) The discussion in scientific journals and proceedings must include morphometric studies, computed tomography, gender, and forensic anthropology. Additionally, to narrow the scope of the research, the researcher uses the PICO method (Population/Problem, Intervention, Comparison, Outcomes), as shown in the following table:

Table 1. Summary of PICO

Component	Description
Population/Problem	Morphometric Study of the Sternum Using Computed Tomography Scan
Intervention	Description of Morphometric Study of the Sternum Using Computed Tomography Scan for Gender Differentiation Across Various Countries
Comparison	n/a
Outcomes	Morphometric Study of the Sternum Using Computed Tomography Scan for Gender Differentiation Across Various Countries, Including International Comparisons and Validity of the CT Scan Method

2.4. Study selection

The process of literature selection was carried out in three systematic stages to ensure relevance, quality, and consistency with the research objective:

2.4.1. Identification

Relevant studies were identified through comprehensive database searches and were imported into the Mendeley Desktop reference management system. During this stage, duplicate entries were automatically detected and removed. Additionally, non-journal sources such as books and conference abstracts were excluded to maintain focus on peer-reviewed journal articles.

2.4.2. Screening

Titles and abstracts of the collected studies were screened for relevance. Studies that did not involve the use of a single bone (e.g., those that analyzed multiple bones simultaneously or used whole skeletons) were excluded. Further, studies that did not focus on population-specific analysis of the sternum or other single bones were also removed to ensure consistency in the scope of comparative analysis.

2.4.3. Inclusion

The final selection included studies that specifically investigated sex determination using morphometric analysis of single bones primarily the sternum within defined populations. Inclusion criteria also required that the studies be published in English, fully accessible for review, and ranked at least Q3 in recognized journal indexing systems. These studies formed the core dataset for comparative evaluation in this literature review.

2.5. Quality assessment

Literature selection utilized the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method. The PRISMA flow diagram for this study is presented in Figure 1.

Based on the PRISMA method applied, the results are as follows: Out of a total of 149 journal articles and proceedings identified, 28 were excluded due to duplicate data. Additionally, 87_ did not

meet the inclusion and exclusion criteria, resulting in only 20 journal articles being used in the literature review. The quality of articles in this study was assessed using the Standards for Reporting Qualitative Research (SRQR) Checklist. The SRQR Checklist includes 21 quality assessment components. A total of 20 scientific journals and/or proceedings utilized this instrument. These journals were used as literature sources for this research. Based on the quality assessment conducted, 20 (twenty) journals and/or proceedings met the minimum criteria and were thus deemed suitable for use as literature sources in this study.

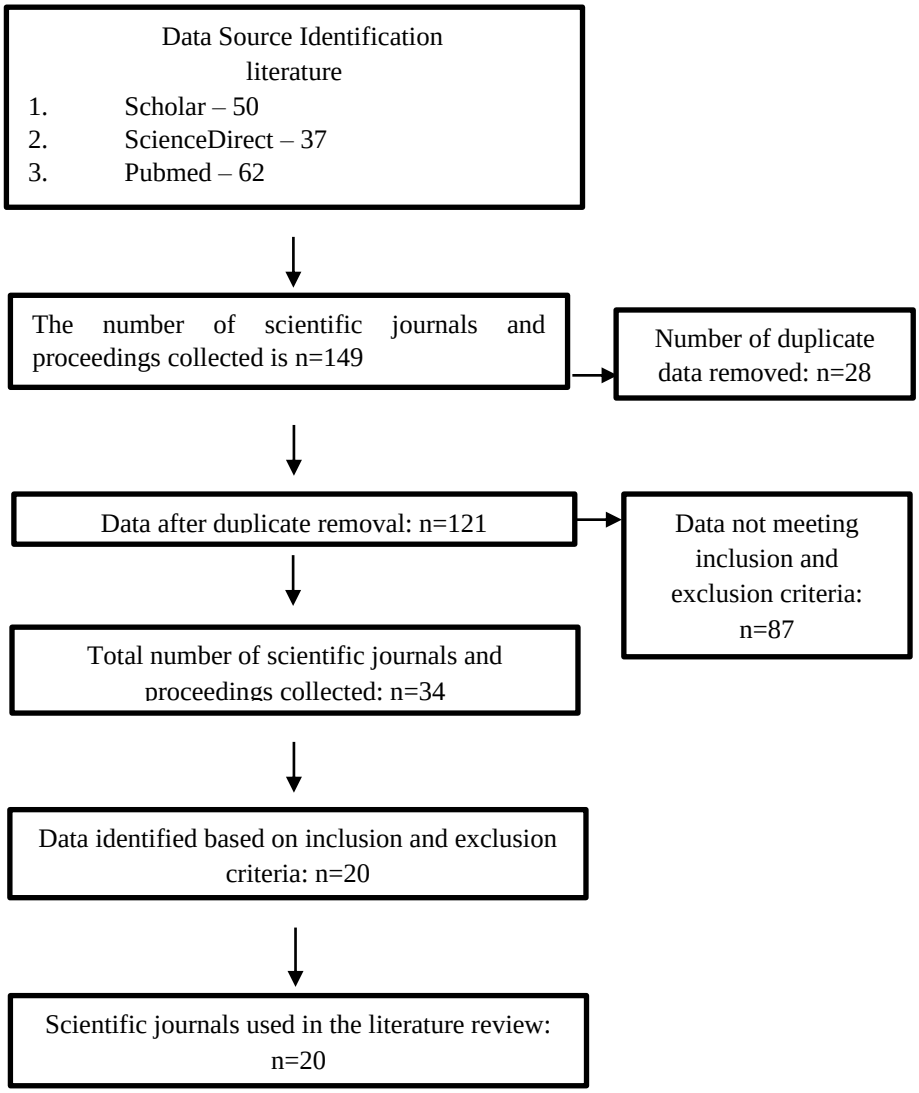

Figure 1. Research flowchart.

2.6. Data synthesis

The data synthesis process in this study was carried out by comparing literature that met the quality assessment criteria as well as the inclusion and exclusion criteria. Data synthesis refers to the research objective of understanding the use of computed tomography scans (CT scans). The use of CT scans in gender differentiation and determining gender based on human bones is the focus of this analysis.

2.7. Data extraction

The data extraction output is presented in a table that includes the study name, country of origin, study title, research results, and the accuracy level of using computed tomography scans (CT scans). This table focuses on the use of CT scans for gender differentiation and determining gender based on human bones.

3. Result and Discussion

3.1. Results

The results of the literature quality assessment and data extraction revealed that out of 15 sources, 12 focus on the use of computed tomography scans for gender differentiation and 8 address gender determination using human bones. This study included literature from various countries. The cases reported in the research articles were identified from the years 2010 to 2023.

Table 2. Literature review on morphometric methods using CT scan of the sternum in various countries.

Author (Year)	Country	Title	Results	Accuracy Level
Ghorbanlou *et al.* (2022)	Iran	Morphometric study of sternum by computed tomography in an Iranian population: A method to discriminate between male and female.	This study found significant differences in sternum measurements between men and women. Men had notably higher measurements for the manubrium and the body of the sternum.	92.3%
Torimitsu *et al.* (2015)	Japan	Estimation of sex in Japanese cadavers based on sternal measurements using multidetector computed tomography.	Descriptive statistics for ten variables showed significant differences between men and women. Discriminant function analysis demonstrated that sternum measurements are effective in predicting gender.	87%
Daniel Franklin *et al.* (2012)	Australia	Estimation of sex from sternal measurements in a Western Australian population	The results show the mean, standard deviation, and range of 8 sternum measurements. Men are significantly larger ($P < 0.001$) than women in all compared variables, explaining 9.8–47.4% of the variation in the sample.	84.5%
J. Singh *et al.* (2012)	India	Morphometric sex determination from various sternal widths of Northwest Indian sternums collected from autopsy cadavers: A comparison of sexing methods	Effective cutoff points identify 72–75% of men and 62–67% of women. Cutoff points classify 60–80% of sterna, with higher accuracy for men. Discriminant function analysis classifies approximately 84% of sterna (men = 82.1%, women = 89.0%).	84%
Ahmed *et al.* (2017)	Arab Saudi	Estimation of sex in a contemporary Saudi population based on sternal measurements using multidetector computed tomography	Significant differences were observed in the sternum area, sternum body length, and manubrium width. Gender prediction accuracy ranges from 62.5% to 89.5%, with the most	90.5%

			distinct variables providing the highest accuracy.	
Myint tun *et al.* (2015)	Thailand	Sex determination from different sternal measurements: A study in a Thai population	This study found that men generally have higher average values than women for all parameters, except for the sternum index. This difference is highly significant ($p < 0.01$) for all parameters, except for the sternum width index, which did not show a significant difference ($p = 0.176$).	85.8%
Koşar *et al.* (2022)	Turkiye	Sex and stature estimation based on multidetector computed tomography imaging measurements of the sternum in Turkish population	The averages of all sternum measurements in men are significantly higher compared to women ($p < 0.001$).	85%
Macaluso (2010)	South Africa	The efficacy of sternal measurements for sex estimation in South African blacks	This study found significant differences in sternum dimensions between men and women. Men have higher average values, except for the sternum index, which is higher in women.	86.9%
Ali *et al.* (2021)	Egypt	Sternum as an indicator for sex and age estimation using multidetector computedtomography in an Egyptian population.	All measurements are larger in the male group, except for the Sternum Index (SI), which is larger in the female group. All variables show statistical significance with $p < 0.05$.	88.3%
Monum *et al.*, (2020)	Japan	Age estimation from ossification of sternum and true ribs using 3D post-mortem CT images in a Japanese population	The accuracy of the model was tested on 26 male and 24 female subjects, with accuracy rates in the initial SEE of 57.69% and 70.83%, respectively. This rapid and non-invasive age estimation method for the sternal region is superior to conventional methods and can be useful for estimating the age at death in Japanese populations.	60.26%
Baca *et al.*, (2022)	US	Three-dimensional geometric morphometric sex determination of the whole and modeled	The results of the fragmentary analysis models consisted of 164 combinations showing 90% or higher accuracy in gender prediction, and twelve combinations demonstrating 96%	95.35%

		fragmentary human pubic bone.	or higher accuracy. Specifically, two markers located around the ventral arc of the pubic bone exhibited the best performance, indicating that this is the most sexually dimorphic part of the bone.	
Ahmidan *et al.*, (2023)	Libya	Identification of Sex from Clavicle Bone Morphometry through 3D CT in Libyan Population	All measurements examined on the left clavicle showed a statistically significant increase in men compared to women. C4 is the most sexually dimorphic dimension of the left clavicle with 90% accuracy. Stepwise discriminant analysis of clavicle variables (C2, C4, and C6) resulted in high accuracy of 99% (cross-validated at 99%).	99 % (Klavikula kiri)
Bedalov *et al.*, (2019)	Croatia	Sex estimation of the sternum by automatic image processing of multi-slice computed tomography images in a Croatian population sample: a retrospective study	All sternum measurements showed significant differences between men and women. The difference between manual and automated measurements ranged from 2.8% to 3.6% of the average values obtained with the automated approach. The most accurate single-variable discriminant function was the sternum body length (82.8%), the most accurate index was the sternum area (89.1%), and the discriminant function with three variables.	90.6%.
Ekizoglu *et al.*, (2014)	Turkiye	Sex Estimation From Sternal Measurements Using Multidetector Computed Tomography	The sternum measurements for men are significantly higher compared to women, while the Sternum Index (SI) is significantly lower in men. In discriminant analysis, the Mid-Sternum Length (MSL) shows high accuracy with 80.2% for women and 80.9% for men. MSL also has the best sensitivity (75.9%) and specificity (87.6%). Accuracy levels are above 80% in the three-step discriminant analysis for both sexes.	80%

Chowdhuri *et al.,* (2019)	India	A Study for the Determination of Sex by Multidetector Computed Tomography of Sternum using Discriminant Function and Logistic Regression	This study was conducted on 108 adults who underwent chest examination for various medical reasons. Measurements were taken by studying CT scans. Of these cases, 73 were men and 35 were women. The discriminant function equation (Df) = 0.071×Manubrio−SternalLength+ 0.075×Sterno−ManubrialLength+ 0.036×WidthatS1+0.037×Widthat S3−11.367 (Constant).	80.6%
Mukhopadhyay PP. (2010)	India Bengali	Determination of Sex from Adult Sternum by Discriminant Function Analysis on Autopsy Sample of Indian Bengali Population: A New Approach	The results of this preliminary study indicate that the sternum exhibits considerable sexual dimorphism, and this variable contributes to the discrimination between the two sexes in the research population. Therefore, the determination of gender from the sternum of adult humans can be performed with reasonable accuracy using discriminant functions on samples from this population, with this approach employing a linear combination of new parameters.	100%
Sassi *et al.,* (2020)	Brazil	Sex determination in a Brazilian sample from cranial morphometric parameters - a preliminary study	Two mathematical models for gender prediction were developed for each pair: one logistic regression model and one conditional inference tree model, with respective accuracy rates of 78.5% and 77.42%, and 68.28% and 72.04%.	68.28-78.5%
Ahmed *et al.,* (2021)	Sudan	Multi-detector computed tomography for the estimation of sex from sternal medullary cavity measurements in Sudanese individuals	MDCT scans of 180 living adult subjects (87 men, 93 women; age range 18-90 years) were studied. For gender determination, binary logistic regression outperformed discriminant function analysis. The best model predicted gender with an accuracy rate of 82.8% and a gender bias of 2.3%. Therefore, the dimensions of the mediolateral diagonal length can be used for high-accuracy gender	82.8%

			determination when more accurate body parts are unavailable.	
Weaver *et al.*, (2014)	North Carolina, US	Morphometric Analysis of Variation in the Sternum With Sex and Age	The size of the sternum increases from birth until around 30 years of age and maintains a consistent size from 30 to 100 years. The manubrium extends laterally from birth to 30 years of age, becoming wider relative to the body of the sternum. In infants, the manubrium is 1.1 to 1.2 times the width of the sternum body, and this width ratio increases to 1.6 to 1.8 in adults.	-
Khartade *et al.*, (2022)	Middle India	Anthropometry of the sternum: An autopsy-based study for sex determination	The sternum can be useful for determining gender, especially when bones such as the skull, pelvis, or long bones are unavailable or fragmented. Additionally, the average body ratio with the manubrium in men and women, according to Hyrtl's law, is not statistically significant ($p > 0.05$).	-

3.2. Discussion

Sex estimation through skeletal morphometry has become a critical approach in forensic anthropology, particularly in cases where commonly used bones such as the pelvis or skull are missing or fragmented. Among various bones, the sternum has been extensively studied due to its protective anatomical location, which offers resistance to degradation and fragmentation (see Figure 2). The reviewed studies reveal varying degrees of accuracy, methodologies, and outcomes depending on the population sampled, imaging techniques used, and statistical approaches applied.

3.2.1. Accuracy and effectiveness of the sternum for sex estimation

Most studies agree that the sternum demonstrates a high degree of sexual dimorphism, making it a reliable element for sex estimation. Reported accuracy rates range from 80% to over 92%. For example, Ghorbanlou *et al.* (2022, Iran) achieved 92.3% accuracy using measurements of the manubrium and sternal body, while Ahmed *et al.* (2017, Saudi Arabia) reported up to 90.5% accuracy based on variables such as sternal body length and manubrium width. Research from Turkey (Koşar and Ekizoglu), Egypt (Ali *et al.*), and Thailand (Myint Tun *et al.*) consistently shows that males tend to have significantly larger sternal dimensions than females. Interestingly, the Sternal Index (SI) is often higher in females, which provides an inverse indicator useful in discriminant analysis.

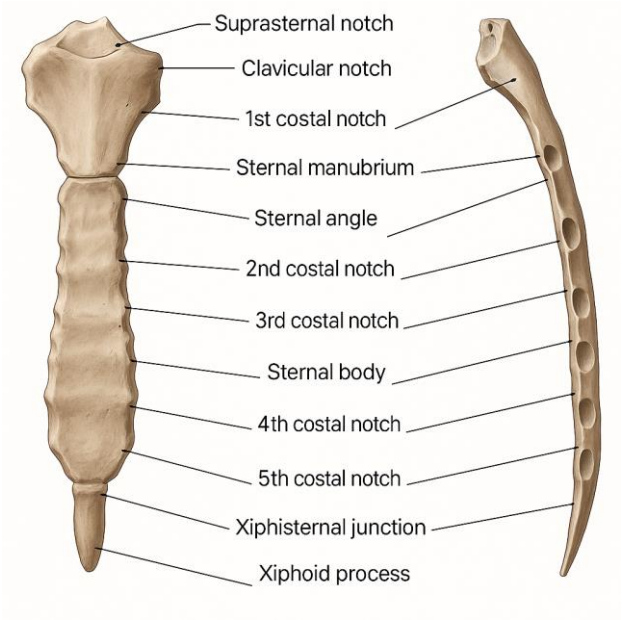

Figure 2. Human sternum (lateral and anterior views).

3.2.2. Methodology and statistical analysis influence

The use of Multidetector Computed Tomography (MDCT) significantly improves the precision and accuracy of skeletal measurements. MDCT enables high-resolution 3D visualization, reducing human measurement error. Most studies employed Discriminant Function Analysis (DFA) or Logistic Regression to develop sex estimation models. Some studies, such as Ahmed *et al.* (2021, Sudan), found that logistic regression produced more accurate results than DFA, emphasizing the importance of choosing the appropriate statistical technique in forensic models.

3.2.3. Comparison with other bones (clavicle and pubis)

Interestingly, bones such as the clavicle and pubic bone have shown even higher accuracy rates for sex estimation. Ahmidan *et al.* (2023, Libya) achieved 99% accuracy using morphometric analysis of the left clavicle, while Baca *et al.* (2022, USA) reported up to 96% accuracy using 3D geometric morphometrics of the pubic bone. However, these bones may not always be available in forensic cases, especially in decomposed or fire-damaged remains. In such cases, the sternum remains a valuable alternative.

3.2.4. Population-specific variability and sexual dimorphism

Sexual dimorphism is not universal across populations, as demonstrated by lower accuracy rates in Japanese samples (e.g., Monum *et al.,* 2020: 60.26%), in contrast with Middle Eastern or African populations where higher accuracy is often achieved. This highlights the need for population-specific models and suggests that universal applications may lead to misclassification. Additionally, Weaver *et al.* (2014) noted that sternum dimensions change with age, growing until around age 30 and remaining constant thereafter. Therefore, age must also be considered, especially in subadult populations.

3.2.5. Limitations and critical observations

Studies reporting extremely high accuracy, such as Mukhopadhyay (2010, India Bengali) with 100%, should be interpreted cautiously. Such results may reflect small sample sizes, population homogeneity, or model overfitting rather than true predictive power. Furthermore, studies such as those by Khartade and Weaver did not provide explicit accuracy values, limiting their use for quantitative comparison.

Personal identification is a nuanced perception and often one of the most significant priorities in criminal investigations, mass disasters, and forensic issues. Gender determination is a crucial step in personal identification, which can be performed through bone examination, either from metric

measurements or radiographic images, especially in challenging identification cases such as those involving dismemberment, mutilation, and explosions. In such cases, forensic examiners can rely on bone measurements. The best results for gender determination are achieved when the entire skeleton is accessible. However, skeletal remains traditionally used for gender identification (pelvis, long bones, and skull) are often recovered in fragmented or deteriorated conditions. When a complete skeleton is available, age and gender identification can be performed with an accuracy ranging from 80% to 100%.

The sternum is one of the bones commonly used for gender identification, whether through direct measurements of the dry sternum from cadavers or indirect measurements from images obtained via chest X-rays. Studies on the length of the sternum for gender determination have primarily been conducted on cadaver dissections, and more recently, several studies have also employed radiological measurements. Computed tomography (CT) is the preferred modality for evaluating anatomical details as well as pathological conditions of the sternum, sternoclavicular joints, and surrounding soft tissues. While radiographic approaches were used previously, computed tomography has been developed as a medical diagnostic tool; its application in forensic anthropology has become both comprehensive and significant. A CT scan is a form of tomography (imaging using sections) that combines multi-directional X-ray images processed by a computer to produce cross-sectional images of the desired object.

New technologies such as CT and two-dimensional (2D) and three-dimensional (3D) scanning offer advantages in estimating gender. These methods are user-friendly, quickly implemented, and more objective compared to those evaluating qualitative characteristics. Therefore, specimens can be viewed as 2D images or as a stack of rendered 3D images. Traditionally, research using CT scans focused on employing 2D images to investigate various morphological features, while more contemporary studies use multi-slice CT (MSCT) 3D images. The sternum exhibits various variations and anomalies. Reconstructed multi-planar and curved-planar images from multi-slice CT (MSCT) are useful in revealing the anatomy of the sternum and illustrating its variations and anomalies. Awareness of multi-detector CT (MDCT) imaging in relation to these variations and anomalies enhances differential diagnosis of pathological conditions. MDCT scanning can provide rapid and accurate results in identifying victims of mass disasters and legal investigations. It can be effectively used for skeletal structure analysis, offering clear and unmistakable images of various areas without distortion or interference with other anatomical structures. It is capable of distinguishing fine details that conventional radiography may miss and can provide slices with a clear depiction at thicknesses of 1 mm or less.

Determining sex in human skeletal remains is crucial for narrowing down the pool of potential matches in forensic investigations. Morphometric methods reveal significant differences in sternal parameters between men and women as showed in Figure 3. In males, measurements for the manubrium (ML – manubrium length, MW – manubrium width, MT – manubrium thickness) and the body of the sternum (BL – body length, S1W, S2W, S3W – segmental widths, BT – body thickness) are significantly higher compared to females. Additionally, two parameters of the xiphoid process—xiphoid length (XL) and xiphoid width (XW)—also show greater values in males. These differences are statistically significant and serve as reliable indicators in sex estimation (Utsuno *et al.,* 2014). In studies of the sternum among the Iranian population, Jalili *et al.* (2020) demonstrated that sternal parameters in males, including the manubrium and sternal body, are significantly larger than in females. This study also explored parameters of the xiphoid process and identified the sternal area (SA) and manubrium-body length (MBL) as the most discriminative variables for sex estimation. Despite anatomical variation among individuals, their findings defined sex-specific morphometric characteristics of the sternum within the Iranian population.

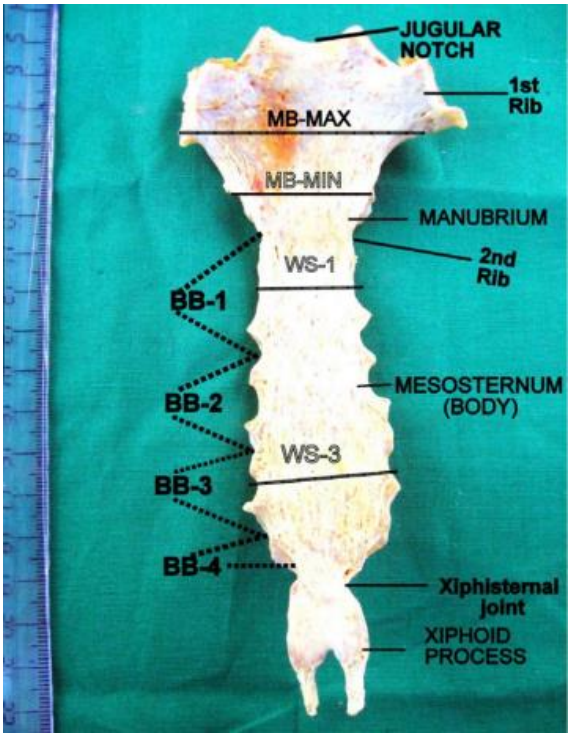

Figure 3. Human sternum showing markers for measuring sternum width (Utsuno *et al.*, 2014).

Similarly, research involving Japanese subjects revealed that the male sternum is generally longer, narrower, and thicker than that of females, reinforcing earlier findings (Utsuno *et al.*, 2014). This study emphasized that objective metric measurements, such as manubrium width (MW) and sternal body width (B), provide high accuracy in sex estimation. Multivariate statistical methods that combine various measurements further enhance classification performance. The combined length (CL) of the sternum, for example, has proven to be a reliable parameter for this purpose. Supporting these observations, Kanchan and Krishan (2016) conducted a CT-based study in the Indian population and concluded that thoracic index and sternal dimensions are highly effective for sex determination. They also underscored the critical role of population-specific standards to ensure forensic reliability. Additionally, Villa et al. (2020) confirmed the robustness of postmortem sternal measurements obtained via CT scans in European samples, emphasizing the advantages of modern imaging modalities like Multi-Detector Computed Tomography (MDCT) in forensic practice.

Furthermore, De Boer *et al.* (2018) highlighted the integration of forensic anthropology with MDCT technology as essential in mass disaster victim identification. Their work demonstrated the value of sternal morphometry as a non-invasive and accurate method, especially when skeletal remains are fragmented or decomposed. The sternum, due to its compact and flat structure, is often well preserved in extreme trauma cases and remains a key element in forensic anthropological analysis. As a flat bone capable of withstanding high levels of compression, the sternum continues to be widely used in forensic anthropology—not only for sex determination but also for estimating age and stature. With the ongoing advancement of CT imaging and 3D reconstruction technology, sternal measurements offer enhanced objectivity, reliability, and precision, making them a cornerstone in modern forensic identification techniques.

4. Conclusion

This literature review highlights the potential of morphometric analysis of the sternum using computed tomography (CT) as a reliable method for sex estimation, particularly when primary skeletal elements such as the pelvis or skull are missing or damaged. Numerous studies across different countries have

demonstrated that the sternum exhibits notable sexual dimorphism, with relatively high accuracy in various population-based analyses. However, several key challenges remain. One of the primary concerns is the variability in CT scanning methods, including differences in image resolution, body positioning, and software tools used for morphometric measurements, all of which can influence the consistency and reliability of results. Additionally, small sample sizes and the lack of standardized methodologies across studies limit the generalizability and comparability of findings.

Many studies are confined to specific regional or ethnic populations, raising questions about their applicability in broader forensic contexts. Therefore, there is a strong need for larger, multiethnic studies that can provide more representative datasets and support the development of universal reference standards. Future research should also focus on establishing internationally standardized measurement protocols for CT-based morphometry. Importantly, the integration of artificial intelligence (AI) and machine learning techniques into CT image analysis offers a promising avenue to improve the speed, accuracy, and objectivity of sex determination processes. By addressing these challenges and fostering interdisciplinary and cross-national collaboration, morphometric studies of the sternum can become an increasingly valuable tool in modern forensic science.

References

Ahmed, A. A., Alshammari, F. O., Alrafiaah, A. S., Almohaisani, A. A., Al-Mohrej, O. A., & Alkubaidan, F. O. (2017). Estimation of sex in a contemporary Saudi population based on sternal measurements using multidetector computed tomography. *HOMO*, 68(6), 411–421. https://doi.org/10.1016/j.jchb.2017.11.001

Ahmed, A. A., Koko, A. O., & Elsayed, M. M. (2021). Multi-detector computed tomography for the estimation of sex from sternal medullary cavity measurements in Sudanese individuals. *Forensic Science International: Reports*, 4, 100244. https://doi.org/10.1016/j.fsir.2021.100244

Ahmidan, S. M. M., Ali, M. W. M., & Gad, M. A. M. A. (2023). Identification of sex from clavicle bone morphometry through 3D CT in Libyan population. *The Egyptian Journal of Hospital Medicine*, 90(2), 3534–3539. https://ejhm.journals.ekb.eg/article_291965.html

Ali, M. I., Mosallam, W., Mostafa, E. M., Aly, S. M., & Ali, N. M. (2021). Sternum as an indicator for sex and age estimation using multidetector computed tomography in an Egyptian population. *Forensic Imaging*, 27, 200457. https://doi.org/10.1016/j.fri.2021.200457

Amorim, A., van Oorschot, R. A. H., & Caldas, I. M. (2021). Interpreting forensic DNA evidence in the presence of uncertainty. *Forensic Science International: Genetics, 54*, 102563. https://doi.org/10.1016/j.fsigen.2021.102563

Baca, K., Bridge, B., & Snow, M. (2022). Three-dimensional geometric morphometric sex determination of the whole and modeled fragmentary human pubic bone. *PLoS ONE*, 17(4), e0265754. https://doi.org/10.1371/journal.pone.0265754

Bedalov, A., Basic, Z., Marelja, I., Dolic, K., Bukarica, K., Missoni, S., Slaus, M., Primorac, D., Andjelinovic, S., & Kruzic, I. (2019). Sex estimation of the sternum by automatic image processing of multi-slice computed tomography images in a Croatian population sample: A retrospective study. *Croatian Medical Journal*, 60(3), 237–245. https://pubmed.ncbi.nlm.nih.gov/31187951/

Cattaneo, C. (2015). Forensic anthropology: Developments of a classical discipline in the new millennium. *Forensic Science International, 254*, 136–141. https://doi.org/10.1016/j.forsciint.2015.07.014

Chowdhuri, S., Roy, P., Dey, A., Das, S., & Ghosh, R. (2019). A study for the determination of sex by multidetector computed tomography of sternum using discriminant function and logistic regression. *Arab Journal of Forensic Sciences & Forensic Medicine*, 1(10), 1445–1454.

De Boer, H. H., Berger, C. E. H., Blau, S., & Delabarde, T. (2018). Multidetector computed tomography and forensic anthropology: A powerful combination for victim identification. *Forensic Science International, 290*, 263.e1–263.e8. https://doi.org/10.1016/j.forsciint.2018.06.040

Franklin, D., Flavel, A., Kuliukas, A., Cardini, A., Marks, M. K., Oxnard, C., & O'Higgins, P. (2012). Estimation of sex from sternal measurements in a Western Australian population. *Forensic Science International*, 217(1–3), 230.e1–230.e7. https://doi.org/10.1016/j.forsciint.2011.11.008

Ghorbanlou, M., Moradi, F., & Asgari, H. R. (2022). Morphometric study of sternum by computed tomography in an Iranian population: A method to discriminate between male and female. *Forensic Imaging*, 28, 200501. https://doi.org/10.1016/j.fri.2022.200501

Jalili, P., Mirfeizi, M., & Nazem, M. (2020). Sex determination using sternal measurements in Iranian population: A study by multi-slice CT scan. *Egyptian Journal of Forensic Sciences, 10*(1). https://doi.org/10.1186/s41935-020-0176-2

Kanchan, T., & Krishan, K. (2016). Estimation of sex from thoracic index: A CT-based study on an Indian population. *International Journal of Legal Medicine, 130*(5), 1363–1369. https://doi.org/10.1007/s00414-016-1401-7

Koşar, M. İ., Uğuz Gençer, C., Tetiker, H., Yeniçeri, İ. Ö., & Çullu, N. (2022). Sex and stature estimation based on multidetector computed tomography imaging measurements of the sternum in Turkish population. *Forensic Imaging*, 28, 200495. https://doi.org/10.1016/j.fri.2022.200495

Macaluso, P. J. (2010). The efficacy of sternal measurements for sex estimation in South African blacks. *Forensic Science International*, 202(1–3), 111.e1–111.e7. https://doi.org/10.1016/j.forsciint.2010.07.019

Monum, T., Makino, Y., Prasitwattanasere, S., Yajima, D., Chiba, F., Torimitsu, Y., Hoshioka, Y., Yoshida, M., Urabe, S., Oya, Y., & Hirotaro, I. (2020). Age estimation from ossification of sternum and true ribs using 3D post-mortem CT images in a Japanese population. *Legal Medicine*, 43, 101663. https://doi.org/10.1016/j.legalmed.2019.101663

Mukhopadhyay, P. P. (2010). Determination of sex from adult sternum by discriminant function analysis on autopsy sample of Indian Bengali population: A new approach. *Journal of Indian Academy of Forensic Medicine*, 32(4), 321–324.

Mutaqin, M., Delinom, R., & Sugianto, S. (2020). Natural disaster risk in Indonesia: Current status and future directions. *Indonesian Journal of Geography, 52*(2), 155–164. https://doi.org/10.22146/ijg.50471

Myint Tun, S., Das, S., Ruengdit, S., Singsuwan, P., & Mahakkanukrauh, P. (2015). Sex determination from different sternal measurements: A study in a Thai population. *Journal of the Anatomical Society of India*, 64(2), 155–161. https://doi.org/10.1016/j.jasi.2015.10.004

Rutty, G., Robinson, S., & Morgan, L. (2013). The role of forensic imaging in mass fatality incidents. *International Journal of Legal Medicine, 127*(3), 559–566. https://doi.org/10.1007/s00414-012-0771-x

Sassi, C., Picapedra, A., Alvarez-Vaz, R., Schmidt, C. M., Ulbricht, V., Junior, E. D., & Junior, L. F. (2020). Sex determination in a Brazilian sample from cranial morphometric parameters – a preliminary study. *Journal of Forensic Odontostomatology*, 38(1), 8–17.

Singh, J., Pathak, R. K., & Singh, D. (2012). Morphometric sex determination from various sternal widths of Northwest Indian sternums collected from autopsy cadavers: A comparison of sexing methods. *Egyptian Journal of Forensic Sciences*, 2(1), 18–28. https://doi.org/10.1016/j.ejfs.2011.12.002

Torimitsu, S., Makino, Y., Saitoh, H., Sakuma, A., Ishii, N., Inokuchi, G., Motomura, A., Chiba, F., Hoshioka, Y., & Iwase, H. (2015). Estimation of sex in Japanese cadavers based on sternal

measurements using multidetector computed tomography. *Legal Medicine*, 17(4), 226–231. https://doi.org/10.1016/j.legalmed.2015.01.003

Torimitsu, K., Makino, N., Ishii, M., Shintani-Ishida, T., & Yoshida, H. (2017). Sex estimation in a contemporary Japanese population using multidetector computed tomography of the sternum. *Forensic Science International, 270*, 108–112. https://doi.org/10.1016/j.forsciint.2016.11.016

Triandini, E., Jayanatha, S., Indrawan, A., Werla Putra, G., & Iswara, B. (2019). Metode systematic literature review untuk identifikasi platform dan metode pengembangan sistem informasi di Indonesia. *Indonesian Journal of Information Systems*, 1(2), 63–74. https://doi.org/10.24002/ijis.v1i2.1916

Utsuno, H., Tsubota, A., Kageyama, I., & Fukunaga, T. (2014). Sex estimation from the sternum in a Japanese population using multidetector computed tomography. *Legal Medicine, 16*(4), 219–222. https://doi.org/10.1016/j.legalmed.2014.03.006

Villa, C., Buck, U., Muggenthaler, H., & Guglielmi, G. (2020). Sternal measurements by postmortem CT scan and their reliability for sex determination: A European study. *Forensic Imaging, 20*, 100321. https://doi.org/10.1016/j.fri.2020.100321

Weaver, A. A., Schoell, S. L., Nguyen, C. M., Lynch, S. K., & Stitzel, J. D. (2014). Morphometric analysis of variation in the sternum with sex and age. *Journal of Morphology*, 275(11), 1284–1294. https://doi.org/10.1002/jmor.20302