Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Sex Estimation in the Haryana Population Using CT-Derived Sternal Morphometry: Development of a Population-Specific Formula

Sonia Beniwal

soniabeniwal99@gmail.com

Shree Guru Gobind Singh Tricentenary University

Prachi Saffar Aneja

Shree Guru Gobind Singh Tricentenary University

Susmita Saha

Shree Guru Gobind Singh Tricentenary University

Neeru Kapur

Shree Guru Gobind Singh Tricentenary University

Arjun Narula

Narula Diagnostic Center,

Sanjay Lathwal

Narula Diagnostic Center,

Research Article

Keywords: Computed Tomography, Sex Discrimination, Forensic anthropology, Sternum Morphometry, Logistic Regression, Population-specific Standards

Posted Date: June 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9894098/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Sex Estimation in the Haryana Population Using CT-Derived Sternal Morphometry: Development of a Population-Specific Formula

Abstract

Background: Accurate sex estimation is a fundamental step in forensic identification. The sternum is a durable skeletal element that often survives decomposition and trauma, making it valuable in medico-legal investigations. Computed tomography (CT) provides precise, non-destructive, three-dimensional assessment of sternal morphology. However, sex estimation standards are population-specific because skeletal dimensions vary with ethnicity, genetics, nutrition, and environment. No validated formula currently exists for the Haryana population.

Purpose: To analyze CT-derived sternal morphometry and develop a population-specific formula for sex estimation in the Haryana population.

Materials and Methods: This cross-sectional study included thoracic CT scans of 72 individuals (26–90 years) of known age and sex, obtained for indications unrelated to sternal pathology. Measurements of manubrium length, body of sternum length, xiphoid process length, combined manubrium-body length, and total sternal length were recorded using RadiAnt DICOM Viewer after multiplanar and three-dimensional reconstruction. Logistic regression analysis was performed to identify the most reliable predictors of sex and to derive a discriminant formula.

Results: All five morphometric variables showed significant association with sex on univariate logistic regression ($p<0.05$). Total sternal length demonstrated the highest discriminatory power (AUC=0.892), followed by body length (AUC=0.846). The multivariate logistic regression model incorporating all five variables showed excellent performance (AUC=0.919; McFadden $R^2=0.456$; $p<0.001$). Backward stepwise analysis generated the most robust prediction model with an AUC of 0.920, sensitivity of 85.7%, specificity of 89.7%, and overall accuracy of 87.3%. Xiphoid process length emerged as an important corrective variable, improving classification in females.

Conclusion: A reliable, Haryana-specific formula for sex estimation from CT-derived sternal morphometry was developed. The model demonstrates high diagnostic accuracy and may serve as a useful adjunct in forensic identification of North Indian adults. External validation on larger and ethnically diverse populations is recommended before routine application.

Keywords: Computed Tomography, Sex Discrimination, Forensic anthropology, Sternum Morphometry, Logistic Regression, Population -specific Standards

Introduction

Estimating sex and age are essential elements of forensic identification, especially when dealing with skeletal, burnt, decayed, or disfigured remains. These bones are frequently missing or injured in medico-legal instances, despite the fact that the pelvis and skull are regarded to be the most reliable skeletal elements for determining[1]. In such cases, the sternum may serve as an alternative skeletal component because to its safe anatomical positioning within the thoracic cage and better possibility of preservation [2]. The sternum consists of the manubrium, the sternum body, and the xiphoid process. These constituents exhibit age-related changes and sexual dimorphism, which could be useful in forensic investigations. Previous anatomical observations, particularly Hyrtl's law, revealed that, while the manubrium is larger in females, the body of the sternum is proportionally longer in males [3]. According to recent morphometric study, sex can be estimated using measurements of the manubrium, body of the sternum, xiphoid process, and overall sternal length [4]. In recent years, computed tomography (CT) has emerged as an important tool for skeletal morphometric study. CT imaging, which does not harm the specimen, enables exact assessment of osseous structures, high-resolution images, and three-dimensional reconstructions. CT-based analysis is more repeatable than classic osteometric procedures on dry bones and may be applied to both living people and previously recorded radiological information [5].Several studies have found that males frequently have significantly larger sternal proportions than females. Significant sexual dimorphism has been observed in several populations using measurements such as manubrial length, sternal body length, xiphoid process length, and total sternal length [6, 7]. Sternal morphometry has been studied extensively, however much of the research has been done on populations in Europe, Africa, Turkey, and East Asia [4,6]. Forensic identification requires population-specific standards since skeletal dimensions are altered by environmental factors, genetics, nutrition, and ethnicity. There is still little information available about sternal morphometry in the North Indian population, especially in Haryana. Additionally, only a small number of studies have combined typical sternal measurements with the xiphoid process . In order to assess the morphometry of the manubrium, body of the sternum, xiphoid process, and total sternum length in the Haryana population using CT imaging, the current study was conducted.

Materials and Methods

Study Design and Ethical Approval

This study is done on the sternum of CT Scans of 72, male (43) and female (29). Prior approval for the study was obtained from the Institutional Ethics Committee.

Study Population

MDCT scans of adults and old patients of known age (26 yrs to 90 yrs) and sex who had thoracic CT imaging for reasons unrelated to sternal disease throughout the study period were included in the study. To evaluate differences in sternal morphometry linked to age and sex, both male and female patients were included.

Inclusion Criteria

1. People who are eighteen years of age or older
2. CT scans that show the sternum fully visible from the jugular notch to the distal end of the xiphoid process
3. Sufficient image quality to enable precise morphometric analysis

Exclusion Criteria

- A history of sternal fractures, thoracic surgeries, or severe chest trauma, as shown by radiological evidence
- The existence of infections, sternal tumours, congenital abnormalities of the chest wall, or large pathological lesions

- CT scans that are incomplete or of low quality

Sample Size Calculation

The sample size for the present study was calculated using the formula for estimation of a population mean in morphometric studies:

$n= Z^2 \sigma^2/d^2$

Where:

n = required sample size

Z = 1.96 (95% confidence level)

σ = 12 mm (from previous CT studies)

d = 2.8 mm (allowable error)

n=(2.8)2(1.96)2×(12)2 n=3.84×1447.84=70.5≈71n = \frac{3.84 \times 144}{7.84} = 70.5 \approx 71n=7.843.84×144=70.5≈71

The calculated sample size was **approximately 71**, which was **rounded to 72 subjects** to obtain an equal representation of both sexes for analysis.

(Table 1)

Protocol for CT Acquisition

A multidetector computed tomography (MDCT) scanner in the Department of Radiology was used for all exams. Standard bone reconstruction algorithms were used to reconstruct axial images into sagittal and coronal planes after they were obtained with thin collimation. The sternum and its constituent parts were clearly defined anatomically by the creation of three-dimensional volume-rendered images.

Morphometric measurements and image analysis

RadiAnt DICOM Viewer software was used to analyse all CT images. To ensure accuracy and repeatability, morphometric measurements of the sternum were mostly carried out in the axial plane using digital electronic callipers that were included in the software following 3D reconstruction.
The following parameters were measured:

Every subject's morphometric and demographic features were recorded as follows:

Demographic Details

Age (in completed years)

Gender (male or female)

Measurements (in millimetres) (as shown in figure 1)

1. **Manubrium Length** is measured from the inferior border of the manubrium to the jugular notch.
2. **The length of the sternal body**, measured from the manubriosternal joint to the xiphisternal joint
3. **The length of the xiphoid process**, measured from the distal tip of the process to the xiphisternal junction
4. **Total sternal length**, measured from the jugular notch to the tip of the xiphoid process
Assessment of Joints

5. **Sternal Index –**Length of manubrium / Length of sternal body x 100

Statistical Analysis

Statistical analysis performed using Python (statsmodels, scikit-learn). Backward stepwise elimination by $p > 0.05$ criterion. ROC threshold optimised by Youden's J statistic.

Results

The current study included 72 participants in total, of which 29 were female (40.3%) and 43 were male (59.7%). The effectiveness of five sternal morphometric parameters—manubrium length, body of sternum length, sternal index, xiphoid process length, and total sternum length—in estimating sex was assessed. The predictive power of these variables for sex identification was assessed using logistic regression analysis.

Three methods for statistical modelling were used:
(i) Multivariate logistic regression analysis using all five factors at once,
(ii)Univariate logistic regression analysis utilising each variable separately, and
(iii) Backward stepwise logistic regression analysis to find the most economical and practical predictive model for clinical usage.

Univariate logistic regression

Initially, each morphometric parameter's independent predictive value was evaluated using univariate logistic regression analysis (Table 2). Each of the five variables separately resulted in sex discrimination, as evidenced by statistically significant relationships with sex ($p < 0.05$). With an area under the receiver operating characteristic (ROC) curve (AUC) of 0.892, entire sternum length demonstrated the best discriminatory performance among the variables assessed, demonstrating a greater ability to distinguish between males and females. With an AUC of 0.846, the body of the sternum length showed the second-best predictive performance. The remaining factors demonstrated a moderate capacity for discrimination, including xiphoid process length, sternal index, and manubrium length. These results support the known sexual dimorphism of the sternum by indicating that larger sternal dimensions were often linked to male sex.

Multivariate logistic regression model

All five morphometric characteristics were then simultaneously incorporated into a comprehensive multivariate logistic regression model (Table 3). With an AUC of 0.919 and a McFadden's R2 score of 0.456, the model as a whole showed exceptional discriminatory ability. The model was highly statistically significant ($p < 0.001$), according to the likelihood ratio test (LRT), indicating that all of the included variables strongly influenced sex prediction. Only whole sternum length remained a statistically significant independent predictor of sex ($p = 0.008$), despite the model's excellent overall performance. After controlling for the other predictors, the remaining variables lost statistical significance. Given the anatomical relationships and strong correlations between a number of sternal measures, this conclusion is probably due to multicollinearity. As a result, the independent contribution of the

remaining factors was diminished by the variables' overlapping predictive information. However, the model showed that, in the study population, entire sternum length was the most accurate morphometric measure for sex prediction.

Backward Stepwise Logistic Regression Analysis

Backward stepwise logistic regression analysis was used to create a more useful and straightforward predictive model. Using this method, variables with p-values higher than 0.05 were gradually eliminated from the complete model until only statistically significant predictors were left. Two predictors—xiphoid process length and total sternum length—were kept in the final stepwise model (Table 4). With an AUC of 0.920 and McFadden's R2 of 0.454 ($p < 0.001$), this simplified model showed outstanding discriminatory performance. Significantly, the reduced model's predictive performance was about the same as the complete five-variable model's (AUC 0.920 vs. 0.919), suggesting that these two factors captured almost all of the discriminatory information needed for sex estimate. Forensic and radiological applications benefited from the stepwise model's comparable predicted accuracy and lower measurement burden, which made it more practicable.

Sex Estimation Formula

Based on the final backward stepwise logistic regression model, the following equation was derived for sex estimation:

Step 1: Calculation of Logit Score

$$L = -24.2585 - (0.1346 \times \text{Xiphoid Process Length}) + (0.1706 \times \text{Whole Sternum Length})$$

Where:

- L = logit score
- Xiphoid process length and whole sternum length are measured in millimetres (mm)

The probability of male sex increases as sternum length increases, according to the positive coefficient for whole sternum length. On the other hand, following regression model adjustment, the negative coefficient for xiphoid process length suggests an inverse relationship.

Step 2: Calculation of Probability of Male Sex

The probability of an individual being male was calculated using the logistic regression equation:

$$P(\text{Male}) = 1 / (1 + e^{-L})$$

Where:

- e is the base of the natural logarithm
- $P(Male)$ represents the predicted probability of male sex

The measured probability falls between 0 and 1.

Step 3: Classification Rule

Youden's J statistic was used to establish the ideal probability threshold. The optimal ratio of sensitivity to specificity was achieved with a cut-off value of 0.573.

Accordingly:

- Individuals with a predicted probability ≥ 0.573 were classified as male.
- Individuals with a predicted probability < 0.573 were classified as female.

Worked Example

For an individual with a xiphoid process length of 30 mm and whole sternum length of 175 mm, the logit score was calculated as follows:

$\mathbf{L} = -24.2585 - (0.1346 \times 30) + (0.1706 \times 175)$

$= -24.2585 - 4.038 + 29.855 = \mathbf{1.559}$

The probability of male sex was then calculated:

$\mathbf{P(Male)} = 1 / (1 + e^{-\mathbf{1.559}}) = 1 / (1 + 0.2104) = \mathbf{0.826}$

The person was categorised as male since the estimated probability (0.826) was higher than the threshold value of 0.573.

Model Comparison and Diagnostic Performance

When the various logistic regression models were compared, it was found that the backward stepwise model required fewer predictor variables while achieving almost the same discriminatory performance as the full multivariate model (Table 5). As a result, the stepwise model was thought to be the most effective and useful approach for estimating forensic sex. The resulting model obtained 85.7% sensitivity, 89.7% specificity, and 87.3% overall classification accuracy at the ideal probability threshold of 0.573 (Table 6).

While the high sensitivity shows that the model reliably recognised males, the high specificity shows that the model correctly identified females. The final regression model exceptional prediction performance in the Haryanvi population of present study is demonstrated by its overall accuracy of 87.3%. In a modified model, xiphoid process length added discriminatory value, but overall, entire sternum length was the most reliable and strong predictor of male sex (Figure 2).

Discussion

The current work shows that sternal morphometry generated from multidetector computed tomography (MDCT) is a dependable and non-invasive method for sex assessment in a North Indian population. This study's outstanding diagnostic performance (AUC = 0.920) is comparable to previously reported CT-based studies, which typically have accuracy values of 80% to 90% [8,9]. This adds to the emerging consensus that radiographic methods can match or outperform traditional osteometric techniques in terms of accuracy [10,11]. Among all the measures examined, total sternum length was the most powerful and independent predictor of sex in current study. In previous CT-based study , İnci E found that overall sternal length was the most significant variable for sex discrimination [8]. Similarly, osteological studies on dry sternum samples have shown that overall sternal length has the greatest degree of sexual dimorphism, supporting reliability in both radiological and skeletal contexts [9,10]. However, some studies found slightly lower discriminatory power for particular factors, implying that population-specific variation may alter the amount of sexual dimorphism [9]. The biological basis for the substantial predictive value of entire sternum length is found in differences in skeletal growth patterns between males and females. Males often have more longitudinal bone growth due to longer growth periods and hormonal factors, particularly androgens [12]. This result is consistent with classical anatomical concepts detailed in conventional textbooks such as Gray's Anatomy, which emphasise sex-related variances in skeletal proportion. As a result, overall sternal size has become a reliable indication of sex across a wide range of populations [13]. In this study, some morphometric variables lost statistical significance in the multivariate model, most likely due to multicollinearity. Because different components of the sternum contribute cumulatively to its overall length, their effects tend to overlap when investigated concurrently.

Similar results have been reported in regression-based studies, in which the introduction of several correlated variables reduces each parameter's independent predictive contribution [9]. This underlines the need of carefully selecting variables in predictive modelling to avoid redundancy and overfitting. Interestingly, the backward stepwise model retained both the xiphoid process length and the overall sternum length, indicating that it contributes additional discriminatory information. Although the xiphoid process is known to have high morphological variability, its inclusion improved overall model performance. This result has been supported in part by prior study, which found that, while xiphoid measures alone may not be extremely reliable, they can improve forecast accuracy when paired with other characteristics [14]. As a result, the combination of size-related and region-specific characteristics appears to provide a more complete assessment of sexual dimorphism. This study's overall accuracy (87.3%), sensitivity (85.7%), and specificity (89.7%) are comparable or slightly greater than those reported in similar CT-based investigations [8,9]. Recent research in the Indian population has shown that MDCT-derived sternal measurements perform similarly, while modest discrepancies in results may be due to variances in methodology and sample makeup [9]. These findings support the validity of CT-based morphometric techniques in forensic applications. The current findings are also consistent with established forensic principles like Hyrtl's law, which explains proportional differences between the manubrium and body of the sternum [3]. Although ratio-based characteristics were not the primary focus of this investigation, the apparent relevance of overall sternal dimensions indirectly confirms these long-held anatomical findings. Earlier research by Ashley GT highlighted the importance of sternal morphology in forensic identification, particularly in terms of age and developmental changes [1]. In fact, MDCT imaging has major advantages over standard osteological techniques. It allows for exact, reproducible measurements in both living humans and skeletal remains, without the need for physical manipulation [8]. This is especially beneficial in disaster victim identification situations where remains may be fragmented or unavailable. Furthermore, CT-based techniques make it easier to develop population-specific standards, which is important considering the known variation in skeletal morphology between ethnic and geographic groups [9,15]. Despite these strengths, numerous limitations must be addressed. The small sample size and emphasis on a specific regional demographic may restrict the findings generalisability. Similar limitations have been observed in other morphometric studies, highlighting the significance of larger, multi-centric datasets to improve external validity. Future study should aim to validate the proposed regression model in larger and more diverse populations. The use of advanced analytical methodologies, such as artificial intelligence and machine learning, as researched by Oner Z, may improve predictive accuracy and allow for automated sex estimation in forensic practice [3].

Conclusion

The current study reveals that a reliable and objective approach for estimating sex in the Haryanvi population is multidetector computed tomography-based morphometric assessment of the sternum. Xiphoid process length provided more discriminatory value to the final regression model, while overall sternum length proved to be the most important and reliable predictor of sex among the assessed parameters. With simply the total sternum length and xiphoid process length, the backward stepwise logistic regression model revealed outstanding diagnostic performance with high sensitivity, specificity, and overall classification accuracy. By minimising measurement complexity without losing predictive accuracy, this model's simplicity improves its usefulness in forensic and medical applications. These results confirm the usefulness of sternal morphometry as an beneficial addition in medicolegal identification, especially when dealing with skeletal remains that are fractured, degraded, or only partially preserved, when traditional techniques might not be as trustworthy. The reliability of forensic analysis is increased by the added benefits of non-invasive assessment, repeatability, and accurate morphometric evaluation that multidetector CT imaging offers. Additionally, the current study offers baseline data specific to the Haryanvi population, which could enhance the precision of sex determination in local forensic practice. To confirm the applicability of the suggested regression model, more multicentric research with bigger and more ethnically varied populations is advisable.

Limitations

The current study has some limitations that should be addressed. The small sample size and single-center research approach may restrict the findings external validity and generalisability. The study has the unequal gender distribution, may have had an impact on the findings statistical reliability. Furthermore, just a few sternal morphometric measurements were included, while other possibly significant skeletal factors were not included.

Therefore, in order to validate and uniformly apply the suggested model for wider forensic use, more extensive multicentric investigations with ethnically varied populations are needed.

Abbreviations
CT – Computed Tomography
MDCT - Multidetector computed tomography
AUC – Area under the Curve
ROC – Receiver Operating Characteristics

Declarations

Ethical approval and consent to participate

This study was conducted with Prior approval for the study was obtained from the Institutional Ethics Committee IEC/FMHS /2026-20-A.Informed consent was waived because of the retrospective nature. All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and the Declaration of Helsinki. As this study involved retrospective analysis of anonymized computed tomography (CT) images, the requirement for informed consent to participate was waived by the Ethics Committee.

Consent to publish study

Not applicable.

Funding
No funding was received for conducting this study.

References

1. Ashley GT. The relationship between age and sternum fusion. Med Sci Law. 1956;4:227-235.

2. Vatzia K, Fanariotis M, Bugajski M, Fezoulidis IV, Piagkou M, Vlychou M, et al. Assessing sternal dimensions for sex classification: insights from a Greek computed tomography-based study. *Diagnostics.* 2025 Jun 27;15(13):1649. doi:10.3390/diagnostics15131649

3. Hyrtl J. *Handbuch der topographischen Anatomie.* Vienna: Wilhelm Braumüller; 1860.

4. İnci E, Hocaoğlu E, Bilgili MG, Can İÖ. Morphometric analysis of the sternum for sex determination in a Turkish population using multidetector computed tomography. Medicine (Baltimore). 2014;93(27):e240. doi:10.1097/MD.0000000000000240.

5. Bedalov A, Mišković V, Dujmović J, Biočina-Lukenda D, Petaros A. Sex estimation of the sternum by automatic image processing of multislice computed tomography images in a Croatian population. Croat Med J. 2019;60(3):237-245. doi:10.3325/cmj.2019.60.237.

6. Banyeh M, Abdulai AR, Annan EK, Mensah EK, Nkansah C, Nathan JA, et al. Assessing the reliability and accuracy of sex estimation models utilizing sternal morphometry derived from computed tomography in the Ghanaian population. Forensic Sci Int Rep. 2024;9:100368. doi:10.1016/j.fsir.2024.100368.

7. Troupis TG, Koutselini-Ioannidou A, Michalopoulos A, Kotsiomitis E, Kordalis A, Vasilopoulos G, et al. CT-derived sternal morphometry for sex estimation in a contemporary Greek population. Diagnostics (Basel). 2025;15(13):1649. doi:10.3390/diagnostics15131649.

8. Ekizoglu O, Hocaoglu E, Inci E, Bilgili MG, Solmaz D, Erdil I, et al. Sex estimation from sternal measurements using multidetector computed tomography. *Medicine (Baltimore).* 2014;93(27):e240. DOI: 10.1097/MD.0000000000000240

9. Sravan JS, Arora A, Yadav J, Vidua RK, Gayathri BH. Determination of sex from morphometry of sternum using multidetector computed tomography in Central Indian population. *Int J Appl Basic Med Res.* 2025;15(1):32–37.

10. Bongiovanni R, Spradley MK. Estimation of sex from the sternum in a contemporary American sample. *J ForensicSci.*2012;57(2):347–351.DOI: 10.1111/j.1556-4029.2011.01976.x

11. Macaluso PJ Jr. Metric sex determination from the sternum in a contemporary American sample. *J ForensicSci.*2010;55(4):859–864.DOI: 10.1111/j.1556-4029.2010.01363.x

12. Krogman WM, Iscan MY. *The human skeleton in forensic medicine.* 2nd ed. Springfield (IL): Charles C Thomas; 1986.

13. Standring S (ed). *Gray's Anatomy: The Anatomical Basis of Clinical Practice*. 42nd ed. Elsevier, London; 2021.

14. Khartade HK, Shrivastava S, Shedge R, Meshram VP, Garg SP. Anthropometry of the sternum: An autopsy-based study for sex determination. *Med Sci Law.* 2022;62(3):173–179. DOI: 10.1177/00258024211053174

15. Franklin D, Freedman L, Milne N. Sexual dimorphism and discriminant function sexing in indigenous South African crania. *Homo.* 2005;55(3):213–228. DOI: 10.1016/j.jchb.2004.08.001

Figure Legends

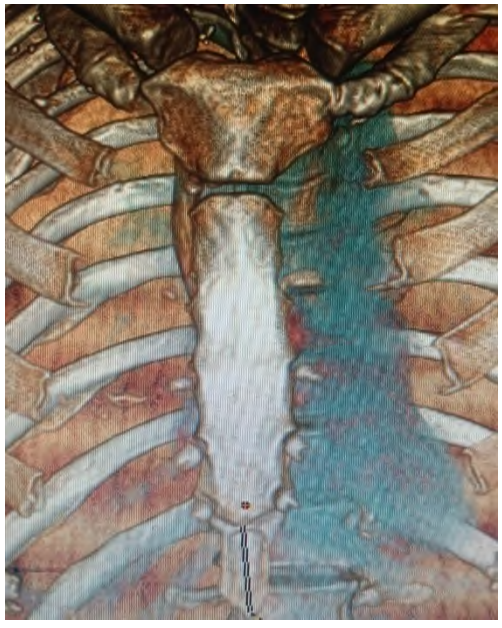


Figure 1 showing sternum morphometric parameters measurement

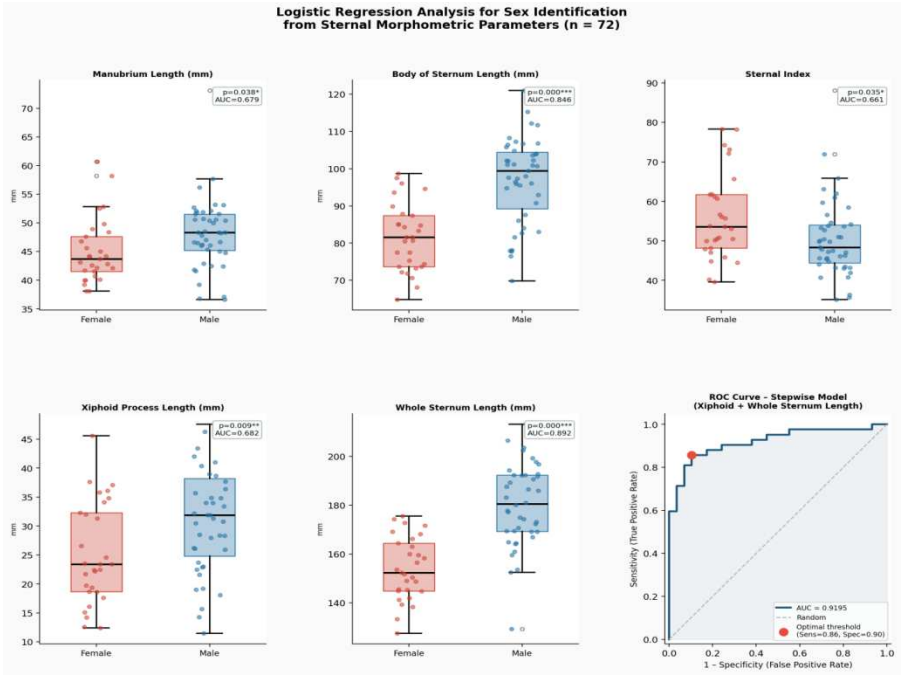


Figure 2. (Panels 1–5) Box-and-jitter plots showing sex-based distribution of each morphometric parameter. (Panel 6) ROC curve of the backward stepwise model (AUC = 0.920). The red dot marks the Youden's J optimal threshold.

Table Legends

Table 1: Sex Distribution of Study Participants (n = 72)

Sex	**Frequency (n)**
Male	43
Female	29
Total	**72**

Table 2. Univariate Logistic Regression Results (n = 72)

Variable	**β Coefficient**	**Odds Ratio**	**95% CI**	**p-value**	**Sig.**	**AUC**
Manubrium Length (mm)	0.0997	1.1048	1.0057 – 1.2138	0.0378	*	0.6792
Body of Sternum Length (mm)	0.1251	1.1332	1.0700 – 1.2001	<0.0001	***	**0.8464**
Sternal Index	-0.0524	0.9489	0.9038 – 0.9962	0.0347	*	0.6608
Xiphoid Process Length (mm)	0.0744	1.0772	1.0183 – 1.1395	0.0095	**	0.6820
Whole Sternum	0.1100	1.1163	1.0602 – 1.1753	<0.0001	***	**0.8920**

Length (mm)						

* p < 0.05; ** p < 0.01; *** p < 0.001. Outcome: Male = 1. OR > 1 indicates higher odds of being Male with increasing measurement.

Table 3. Full Multivariate Logistic Regression

Variable	β	SE	z	p-value	95% CI	Sig.
const (Intercept)	-19.6223	16.9609	-1.157	0.247	−52.865 to 13.621	—
Manubrium Length	0.1267	0.3736	0.339	0.734	−0.606 to 0.859	NS
Body of Sternum Length	-0.0404	0.1843	-0.219	0.826	−0.402 to 0.321	NS
Sternal Index	-0.0920	0.3029	-0.304	0.761	−0.686 to 0.502	NS
Xiphoid Process Length	-0.1238	0.0688	-1.799	0.072	−0.259 to 0.011	NS
Whole Sternum Length	0.1567	0.0595	2.635	0.008	0.040 to 0.273	**

Model fit: AUC = 0.919, McFadden R^2 = 0.456, Nagelkerke R^2 = 0.466, LRT p < 0.001

Note: Loss of individual significance despite high AUC is characteristic of multicollinearity among correlated sternal measurements.

Table 4. Backward Stepwise Logistic Regression — Final Model

Variable	β	SE	z	p-value	95% CI	Sig.
const (Intercept)	-24.2585	5.8065	-4.178	<0.001	−35.639 to −12.878	***
Xiphoid Process Length	-0.1346	0.0583	-2.307	0.021	−0.249 to −0.020	*
Whole Sternum Length	0.1706	0.0417	4.094	<0.001	0.089 to 0.252	***

Model fit: AUC = 0.920, McFadden R^2 = 0.454, Nagelkerke R^2 = 0.464; LRT p < 0.001. Removal sequence: Step 1 - Body of Sternum Length (p = 0.826); Step 2 - Sternal Index (p = 0.731); and Step 3 - Manubrium Length.

Table 5. Comparison of All Logistic Regression Models

Model	Predictors (k)	n	McFadden R^2	Nagelkerke R^2	AUC
Univariate – Manubrium	1	72	0.049	0.079	0.6792
Univariate – Body of Sternum	1	72	0.269	0.388	0.8464
Univariate – Sternal Index	1	72	0.040	0.058	0.6608
Univariate – Xiphoid Process	1	72	0.077	0.111	0.6820
Univariate – Whole Sternum	1	71	0.286	0.413	0.8920
Multivariate (all 5 predictors)	5	71	0.456	0.466	0.9187
Backward Stepwise (Xiphoid + WSL)	**2**	**71**	**0.454**	**0.464**	**0.9195**

WSL = Whole Sternum Length. Highlighted row = recommended model. Nagelkerke R^2 approximated from McFadden R^2.

Table 6. Classification Performance Metrics

Metric	Backward Stepwise Model	Full Multivariate Model	Best Univariate (WSL)	Interpretation
AUC (ROC)	**0.9195**	0.9187	0.8920	Excellent (>0.90)
Sensitivity	**85.7%**	87.5%	76.7%	True Male detection
Specificity	**89.7%**	89.7%	89.7%	True Female detection
PPV	**92.3%**	92.6%	86.8%	If predicted Male, is Male

NPV	**81.3%**	83.9%	77.8%	If predicted Female, is Female
Accuracy	**87.3%**	88.7%	81.7%	Overall correct classification
Optimal Threshold	**0.573**	0.573	0.500	Probability cutoff (Youden's J)

Positive Predictive Value (PPV); Negative Predictive Value (NPV); Whole Sternum Length (WSL) (best univariate predictor).