Study of Sexual Dimorphism from Sternal End of Ribs

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ABSTRACT

Background

Sex estimation is a fundamental component of the biological profile in forensic anthropology. The sternal ends of ribs exhibit significant sexual dimorphism.

Objective

This study evaluates sexual dimorphism of the sternal ends of ribs in a Nepalese population using discriminant function analysis.

Method

A cross-sectional analysis was performed on 90 autopsied individuals aged between 15 and 74 years. Sternal end measurements supero-inferior height and antero-posterior breadth from the 2nd to 7th ribs were taken with Vernier calipers. Data were analyzed using SPSS-26 with descriptive statistics, independent t-test and discriminant function analysis.

Result

The sample of 50 males and 40 females showed statistically significant sexual dimorphism in all rib measurements ($p < 0.05$). The supero-inferior height of the right fourth rib demonstrated the strongest discriminating power, evidenced by the highest canonical correlation (0.526), highest eigenvalue (0.382) and lowest Wilks' Lambda (0.723). Its classification accuracy was 96.9% for original cases and 71.9% after cross-validation, with consistent high accuracy of 96.9% in younger age groups (15-32 years) and 94.8% in older age groups (33-74 years). The antero-posterior breadth of the right second rib was the second most predictive variable.

Conclusion

Rib morphometry, specifically of the right fourth and second ribs, provides a reliable method for sex estimation in the Nepali population. The discriminant functions developed in this study offer valuable forensic applicability, especially in cases involving incomplete or fragmented remains where more sexually dimorphic bones are unavailable.

KEY WORDS

Anthropometry, Rib morphometry, Sex estimation, Sexual dimorphism, Nepal

INTRODUCTION

Identification establishes the uniqueness of an individual and is essential in both living people and deceased individuals. Identification is easier in case of living or when the body is intact. It becomes challenging when remains are decomposed, fragmented, or otherwise unrecognizable.[1] In such cases confirming identity becomes crucial for legal, investigative, and humanitarian purposes.[2,3] In forensic anthropology, forming a biological profile usually begins with estimating sex and age, followed by population affinity and stature.[4,5]

Sex estimation is crucial because many biological characteristics, such as epiphyseal fusion and stature differ between males and females. Traditionally, the pelvis, skull, and long bones are the most utilized elements for assessing sexual dimorphism.[1,6-8] However, recent studies show that elements of the axial skeleton, including the vertebrae, the sternum, and metacarpals, can also provide reliable sex indicators.[9-11] In many forensic scenarios, such as mass disasters, conflicts, airplane crashes, or terror attacks - remains may be incomplete or severely damaged, requiring experts to rely on any available skeletal fragments.[1,3,12]

While developing rib-based age estimation techniques, researchers observed that the sternal ends of ribs exhibit notable sexual dimorphism.[13,14] A study conducted by Iscan on 230 fourth ribs of the right side where the superior–inferior height, anterior–posterior breadth, and pit depth were measured; which had sex estimation accuracy of 80-89%.[14] It has been observed that rib morphology varies across populations, therefore, there is a need for population-specific standards.[14-16]

Consequently, formulas developed for one population may not be directly transferable to another without modification. The present study is undertaken to investigate sexual dimorphism of the sternal end of the ribs in the Nepali population contributing to the population specific database.

METHODS

An analytical, cross-sectional study was conducted at the Department of Forensic Medicine, Kathmandu Medical College, Duwakot, Bhaktapur, Nepal after obtaining ethical approval from the Institutional Review Committee, Kathmandu Medical College (Reference No. 21032023/01). The study included a total of 90 autopsied cases of Nepali individuals with known age and sex. Cases with fractured, diseased, or deformed ribs were excluded. Non-probability (convenience) sampling was used to select all eligible cases available during the study period from May 2022 to April 2023.

During routine autopsy, the thoracic cavity was opened via a midline incision from the supra-sternal notch to the symphysis pubis, avoiding the umbilicus. Soft tissues overlying the ribs were reflected, and intercostal muscles were carefully dissected to expose the ribs. The costal cartilages were transected approximately 2 cm medial to the costochondral junction using a dissection knife, and the ribs were separated 5 cm lateral to the costochondral junction using rib shears to obtain a standardized rib segment from both sides. All ribs were cleaned of soft tissues and inspected for traumatic alterations and only ribs free from fragmentation or deformations are included in the study.

Superior-Inferior Height (SI) is the maximum vertical distance from most superior margin to the most inferior margin of the sternal end, along the long axis of the articular end. Anterior-Posterior Breadth (AP) is the maximum horizontal distance across the sternal end from the most anterior to the most posterior margin, perpendicular to the SI height. Morphometric measurements of the sternal ends of the ribs including SI and AP distance were recorded in millimeters using calibrated Vernier calipers as shown in figure 1 and figure 2 respectively. Each side is Measurements were independently taken by two researchers to minimize inter-observer bias. Any discrepancies between observers were resolved by re-measurement and averaging the two values to ensure accuracy and reproducibility. Each measurement was labelled as R or L for the side followed by a number representing the rib level followed by SI or AP of individual measurement.

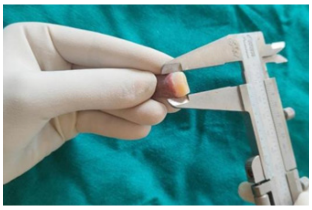

Figure 1. Measurement of supero-inferior height

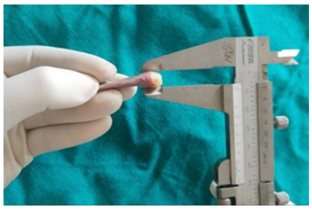

Figure 2. Measurement of antero-posterior length

All data were documented in a standard proforma and entered into an Excel sheet. Statistical analysis was done using IBM SPSS Statistics software v 26. Descriptive statistics, including mean and standard deviation (SD), were calculated for all measurements. The Independent t-tests was applied to examine differences between male and female measurements. The specific age brackets were adopted directly from the methodology established by Kocak et al. in their seminal study on sex determination from the sternal end of the rib.[17] On the basis of this study, sample was stratified into two age groups: a younger group (15-32 years) and an older group (33-74 years). This stratification was implemented to assess the potential influence of age-related morphological changes on the accuracy of sex estimation.

Discriminant function analysis was conducted to develop predictive models for sex estimation, and the accuracy of these models was evaluated using classification matrices. The structure matrix was generated to evaluate the contribution of each morphometric variable to the discriminant function, indicating which measurement most strongly differentiated males from females. Cross-validation was applied to evaluate the robustness and generalizability of the discriminant function. A p-value of < 0.05 was considered statistically significant.

RESULTS

The study sample consisted of 50 males and 40 females, aged 15 to 74 years. The overall mean age was 38.71 ± 14.87 as shown in table 1. The descriptive statistics for SI and AP of ribs 2-7 on both left (L) and right (R) sides in male group are given in table 2 and female group in table 3. These tables also shows that the mean values for SI measurements are noted consistently increasing from 2nd rib to 7th rib on both sides, as well as the mean values for AP measurements are noted rising trend from 2nd rib to 7th rib on both sides in both genders.

Table 1. Descriptive statistics of the age for the entire sample population (N=90)

Gender	Frequency	Mean (years) ± SD
Male	50	40.76 ± 13.77
Female	40	36.15 ± 15.94
Total	90	38.71 ± 14.87

Table 2. Descriptive statistics of the superior-inferior height (SI) and anterior-posterior length (AP) measurements for right (R) and left (L) side of corresponding rib level for male (N=50)

Rib	Minimum (mm)	Maximum (mm)	Mean (mm) ± SD
L2SI	8.54	16.26	12.38 ± 1.70
L3SI	9.31	17.08	13.80 ± 1.70
L4SI	9.30	17.90	14.87 ± 1.85
L5SI	9.22	17.79	14.59 ± 1.79
L6SI	9.31	19.50	15.31 ± 1.93
L7SI	10.90	20.00	15.84 ± 1.98
R2SI	8.67	16.22	12.72 ± 1.63
R3SI	8.95	18.22	13.97 ± 1.88
R4SI	10.10	17.60	14.79 ± 1.80
R5SI	9.01	19.00	14.53 ± 1.95
R6SI	10.35	19.38	15.37 ± 2.07
R7SI	10.89	19.90	15.97 ± 1.99
L2AP	4.09	10.44	6.79 ± 1.35
L3AP	4.10	11.38	7.08 ± 1.47
L4AP	4.70	12.00	7.47 ± 1.64
L5AP	4.36	11.00	7.38 ± 1.56
L6AP	4.98	13.40	7.98 ± 1.67
L7AP	5.22	11.72	8.00 ± 1.54
R2AP	4.00	11.00	7.26 ± 1.46
R3AP	4.52	11.00	7.32 ± 1.51
R4AP	5.01	12.26	7.93 ± 1.59
R5AP	5.30	11.10	7.52 ± 1.33
R6AP	5.67	13.50	8.03 ± 1.67
R7AP	5.27	12.06	8.17 ± 1.69

Table 3. Descriptive statistics of the superior-inferior height (SI) and anterior-posterior length (AP) measurements for right (R) and left (L) side of corresponding rib level for female (N=40)

Rib	Minimum (mm)	Maximum (mm)	Mean (mm) ± SD
L2SI	9.22	13.49	11.04 ± 1.04
L3SI	6.98	15.05	12.28 ± 1.64
L4SI	10.38	16.13	12.98 ± 1.37
L5SI	10.24	15.63	12.81 ± 1.41
L6SI	11.06	16.74	13.59 ± 1.68
L7SI	10.79	18.64	14.03 ± 1.80
R2SI	8.88	14.57	11.10 ± 1.48
R3SI	10.14	14.46	12.37 ± 1.24
R4SI	10.18	15.64	12.75 ± 1.45
R5SI	10.46	15.70	12.64 ± 1.44
R6SI	10.62	16.43	13.31 ± 1.45
R7SI	11.50	18.42	13.99 ± 1.76
L2AP	4.40	7.19	5.95 ± 1.01
L3AP	4.12	7.19	6.21 ± 0.90
L4AP	4.08	8.30	6.08 ± 1.23
L5AP	4.58	8.77	6.28 ± 0.95
L6AP	4.06	9.80	6.77 ± 1.38
L7AP	4.19	10.00	7.08 ± 1.16
R2AP	4.54	8.14	5.82 ± 0.88
R3AP	4.66	8.22	6.41 ± 1.06
R4AP	5.18	9.69	6.84 ± 1.09
R5AP	5.05	8.38	6.78 ± 0.94
R6AP	4.61	9.80	7.11 ± 1.26
R7AP	5.49	9.60	7.34 ± 0.92

Independent samples t-tests were performed to compare the SI heights and AP lengths of the ribs between males and females as shown in table 4. It demonstrated statistically significant differences ($p < 0.005$) between males and females across all SI heights and AP lengths of 2nd to 7th ribs on both sides. Mean differences were consistently positive, indicating larger rib dimensions in males. The 95% confidence intervals did not cross zero in any variable, confirming robust sexual dimorphism.

The structure matrix (Fig. 3) shows pooled within-groups correlations of rib measurements with the standardized canonical discriminant function. These correlations indicate the relative contribution of each measurement to group discrimination, with higher absolute values reflecting stronger discriminatory power. Among all variables, R4SI exhibited the highest discriminating power ($r = 0.570$), followed by R2AP ($r = 0.538$) and L4SI ($r = 0.527$). Additional SI variables—including R6SI, L5SI, R5SI, and R7SI also clustered with high correlation values (> 0.48), indicating that vertical rib height contributed more prominently to sex differentiation than AP dimensions, which showed

Table 4. Independent samples test for superior-inferior height (SI) and anterior-posterior (AP) length measurements for right (R) and left (L) side of corresponding rib level (N=90)

Rib	Mean difference	95% Confidence Interval		p-value
		Lower	Upper	
L2SI	1.34	0.73	1.95	0.000
L3SI	1.52	0.81	2.23	0.000
L4SI	1.88	1.18	2.58	0.000
L5SI	1.77	1.08	2.46	0.000
L6SI	1.72	0.95	2.49	0.000
L7SI	1.81	1.00	2.61	0.000
R2SI	1.62	0.95	2.28	0.000
R3SI	1.59	0.91	2.28	0.000
R4SI	2.04	1.34	2.74	0.000
R5SI	1.89	1.15	2.63	0.000
R6SI	2.06	1.29	2.83	0.000
R7SI	1.98	1.17	2.78	0.000
L2AP	0.83	0.32	1.34	0.002
L3AP	0.86	0.34	1.39	0.002
L4AP	1.39	0.76	2.01	0.000
L5AP	1.09	0.53	1.65	0.000
L6AP	1.20	0.55	1.86	0.000
L7AP	0.92	0.33	1.50	0.002
R2AP	1.44	0.91	1.96	0.000
R3AP	0.91	0.34	1.47	0.002
R4AP	1.09	0.51	1.67	0.000
R5AP	0.74	0.24	1.23	0.004
R6AP	1.17	0.56	1.77	0.000
R7AP	1.20	0.68	1.73	0.000

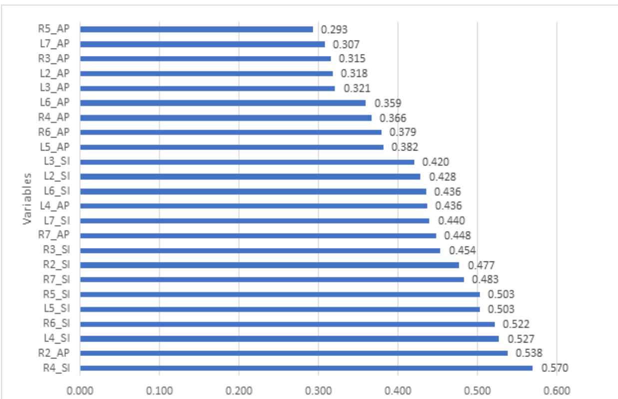

Figure 3. Structure Matrix: Correlations of variables with Canonical Discriminant Function

moderate correlations overall. Lower-ranked variables ($r < 0.35$) contributed minimally to group separation. Overall, SI measurements of mid-thoracic ribs emerged as the strongest predictors in the discriminant model.

Discriminant Function analysis of the data was performed and a predictive equation was constructed. Discriminant equation formulae for each level of ribs were also formulated as shown in the table 5. The centroid values for male and female are also given in the table, where the females were classified with negative values, whereas males classified with positive values. The Eigen value, Canonical correlation, Wilk's Lambda, Chi-square and p-value for

Table 5. Predictive Equations using Eigen value, Canonical correlation, Wilk's Lambda and Chi-square value. (N=90)

Rib	Discriminant equation	Centroid		Eigen value	Canonical Correlation	Wilk's Lambda	Chi-square	p-value
		Male	Female					
L2SI	(SI x 0.68) - 8.12	0.41	-0.51	0.21	0.42	0.82	17.11	0.000
L3SI	(SI x 0.59) - 7.82	0.40	-0.50	0.20	0.41	0.82	16.54	0.000
L4SI	(SI x 0.60) - 8.47	0.50	-0.63	0.32	0.49	0.75	24.79	0.000
L5SI	(SI x 0.61) - 8.43	0.48	-0.60	0.29	0.47	0.77	22.82	0.000
L6SI	(SI x 0.54) - 7.93	0.41	-0.52	0.22	0.42	0.81	17.64	0.000
L7SI	(SI x 0.52) - 7.88	0.42	-0.52	0.22	0.43	0.81	17.96	0.000
R2SI	(SI x 0.63) - 7.63	0.45	-0.57	0.26	0.46	0.78	20.80	0.000
R3SI	(SI x 0.61) - 8.13	0.43	-0.54	0.24	0.44	0.80	18.99	0.000
R4SI	(SI x 0.60) - 8.37	0.54	-0.68	0.38	0.52	0.72	28.33	0.000
R5SI	(SI x 0.57) - 7.84	0.48	-0.60	0.29	0.47	0.77	22.80	0.000
R6SI	(SI x 0.54) - 7.90	0.50	-0.62	0.32	0.49	0.75	24.34	0.000
R7SI	(SI x 0.52) - 7.94	0.46	-0.57	0.27	0.46	0.78	21.21	0.000
L2AP	(AP x 0.82)- 5.29	0.30	-0.38	0.11	0.32	0.89	9.82	0.002
L3AP	(AP x 0.79)- 5.33	0.30	-0.38	0.12	0.32	0.89	9.99	0.002
L4AP	(AP x 0.67) - 4.63	0.41	-0.52	0.22	0.42	0.81	17.70	0.000
L5AP	(AP x 0.75) - 5.18	0.36	-0.45	0.17	0.38	0.85	13.85	0.000
L6AP	(AP x 0.64)- 4.79	0.34	-4.31	0.15	0.36	0.86	12.39	0.000
L7AP	(AP x 0.72) - 5.47	0.29	-0.36	0.11	0.31	0.90	9.22	0.002
R2AP	(AP x 0.80) - 5.33	0.51	-0.64	0.34	0.50	0.74	25.64	0.000
R3AP	(AP x 0.74) - 5.17	0.30	-0.37	0.11	0.32	0.89	9.68	0.002
R4AP	(AP x 0.72) - 5.38	0.35	-0.43	0.15	0.36	0.86	12.83	0.000
R5AP	(AP x 0.85) - 6.11	0.28	-0.35	0.10	0.30	0.86	8.42	0.004
R6AP	(AP x 0.69) - 5.40	0.36	-0.45	0.16	0.38	0.85	13.65	0.000
R7AP	(AP x 0.80) - 6.41	0.43	-0.53	0.23	0.43	0.80	18.57	0.000

SI- supero-inferior height in mm; AP – antero-posterior length in mm.

each equation were also analyzed. The summary of the results is given table 5.

Predictive equations derived from all variables yielded statistically significant results ($p < 0.05$). The discriminant equation using the R4SI has the highest canonical correlation (0.526), highest Eigen Value of 0.382, with lowest Wilk's Lambda of 0.723 and Chi-square of 28.335 followed by the R2AP has the highest canonical correlation (0.504), highest Eigen Value of 0.341, with lowest Wilk's Lambda of 0.746 and Chi-square of 25.645. Thus, the most effective parameter for sex determination was found to be the supero-inferior height of the right fourth rib, followed by the antero-posterior length of the right second rib.

Table 6. Classification result using Discriminant Function analysis and their cross validation. (N=90)

Methods	Gender	Predicted Group Membership[a,b]		Total
		Male frequency (%)	Female frequency (%)	
Original	Male	41 (82)	9 (18)	50
	Female	5 (12.5)	35 (87.5)	40
Cross-validated	Male	34 (68)	16 (32)	50
	Female	7 (17.5)	33 (82.5)	40

[a]96.9% of original grouped cases correctly classified.
[b]71.9% of cross-validated grouped cases correctly classified.

Table 6 shows that 96.9% of the original grouped cases were classified correctly. A cross validation was done only for those cases in the analysis. 71.9% of the cross-validated grouped cases were correctly classified with sensitivity of 68% and specificity of 82.5%.

The percentage accuracy of sex prediction using age-stratified groups is presented in table 7. In both younger and older groups, R4SI was the most reliable parameter. In the older group, R4SI achieved accuracies of 94.6% for males, 95.2% for females, and 94.8% overall. In the younger group, it achieved 92.3% for males and 100% accuracy for females, and 96.9% overall.

Table 7. Percentage accuracy of sex prediction according to age. (N=90)

Age group (years)	Frequency (N)	Male (%)	Female (%)	Discriminant function analysis	
				Original Group	Cross-validated Group
Younger (15-32)	32	12/13 (92.3%)	19/19 (100%)	96.9%	71.9%
Older (33-74)	58	35/37 (94.6%)	20/21 (95.2%)	94.8%	75.9%

DISCUSSIONS

Genetic, environmental, and climatic factors influence population phenotypes, and rib dimensions are both age and population dependent.[14-16] The higher mean values observed in males indicate greater rib robustness, consistent with the general trend of larger skeletal dimensions in males due to greater muscle mass and thoracic volume.[17-19] Among the measured parameters, the SI height contributed most significantly to sex discrimination, suggesting that vertical rib height at the sternal end is a reliable indicator of sexual dimorphism.

Our present study showed R4SI as the most effective parameter for sex determination across both younger and older groups with overall accuracies up to 96.9% and 94.8% respectively which is consistent with the findings reported by Kocak et al. in his study where the accuracies were 88.6% and 86.5% in younger and older groups respectively.[17] Furthermore, in the present study, R2AP was observed to be the next most reliable parameter, particularly in the younger group.

Cologlu et al. examined the sternal end of the right fourth rib in Turkish population (including 150 males and 144 females) following the methodology of Iscan, which reported classification accuracies ranging from 81.0% to 92.6%, with an overall accuracy of 88.0%.[14,20] Similarly, Munoz et al. analyzed 504 left fourth ribs (444 males and 60 females) from autopsies at Instituto de Ciencias Forenses (INCIFO) in Mexico and demonstrated that both SI height and AP breadth was statistically dimorphic.[21] In line with these studies, the present analysis of Nepali samples also identified the SI height of the right fourth rib as the most reliable parameter for sex estimation, achieving accuracies comparable to those reported in Turkish and Mexican populations.[20,21] These findings further reinforce the rib's value as a population-specific discriminator in forensic anthropology. Previous research on the Nepali population, while providing foundational data, has not incorporated sexual dimorphism as assessed through rib morphology. For instance, one study by Karki et al. details sex estimation based on sternal analysis, and another study by Shrestha et al. establishes age estimation using left 4th rib morphometry; however, the specific application of rib characteristics for determining sex remains unexamined.[11,16]

The present findings align with the general understanding that sexual dimorphism in ribs becomes more pronounced with increasing age. the overall classification accuracy in cross validated group was slightly higher in the older group than in the younger group. This supports the notion that morphological differences between male and female ribs become more distinct as skeletal maturation progresses.[22] Notably, the high classification accuracy observed for females in the younger group suggests that certain rib dimensions, particularly R4SI and R2AP, may begin to reflect subtle patterns of sexual differentiation even before complete skeletal maturity is attained. These results are consistent with previous studies that have reported the gradual development of rib dimorphism during late adolescence and its stabilization in adulthood.[20-25] These findings indicate that the vertical dimension of the sternal end retains strong sexual dimorphism throughout adulthood, whereas the antero-posterior dimension may be more age-sensitive.

Despite yielding good classification rates, studies focusing solely on the fourth rib share a key limitation. The fourth rib is morphologically similar to other ribs and difficult to identify when not in articulation. Moreover, during recovery, it is common for only a few ribs to be present, making it challenging to determine their precise anatomical position. To overcome these limitations, the present study analyzed multiple ribs that enhances the reliability and applicability of the findings by accounting for natural anatomical variation along the rib cage.[26] This approach captures morphological differences between different ribs, leading to more robust and accurate discriminant functions. It also increases the practical applicability of the method in forensic and archaeological settings, where complete rib recovery is uncommon.[1] Furthermore, comparing classification accuracy across different ribs helps identify those with higher sexual dimorphism, thereby improving the diagnostic and predictive potential of rib-based sex estimation.[27,28]

The development of our discriminant function models may have been constrained by several factors. The morphometric data were derived from fresh (wet) ribs, a potential source of measurement bias as their dimensions may not be directly equivalent to dry bone.[29,30] Furthermore, confounding variables such as age, population differences, and/or undetected bone pathology that could impact the generalizability and accuracy of the sex estimation formulae. These considerations highlight the importance of accounting for biological and postmortem factors when developing population-specific discriminant function models.

CONCLUSION

The present study demonstrates that rib morphometry, particularly the supero-inferior height of the right fourth rib and the antero-posterior length of the right second rib, provides a reliable basis for sex estimation. These findings confirm that specific rib measurements can serve as robust indicators of sexual dimorphism, supporting their practical application in forensic and anthropological contexts, even when only partial rib elements are available.

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