Estimation of sex from the sternal end of the left fourth rib in the Nepalese population

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SUMMARY

Forensic anthropological examinations are important in establishing the identity of an individual by developing a biological profile. This study aims to establish population-specific standards for estimation of sex from the sternal ends of ribs in a Nepalese population. A quantitative, observational study examining the left fourth ribs of 387 Nepalese deceased (106 females, 281 males) was conducted between November 2021 and March 2023. The variables examined included maximum superior-inferior height, maximum anterior-posterior breadth and pit depth. These variables were tested in order to develop models for prediction of sex. All variables were found to have non-normal distribution, and non-parametric tests were used.

The study found statistically significant differences in all morphometric measurements of the left fourth rib between the sexes using Mann Whitney U test ($p<0.001$). However, binary logistic regression analysis as well as discriminant function analysis showed only maximum superior-inferior height of the left fourth rib to have good accuracy. Prediction models developed for estimation of sex from maximum superior-inferior height of left fourth rib using binary logistic regression and discriminant function analyses showed good accuracy (84.2% and 81.7% respectively).

Key words: Forensic anthropology – Sternal ends of ribs – Sex estimation – Nepalese population – Forensic anthropology database

INTRODUCTION

Forensic anthropology examines unidentified human remains to develop a biological profile of the individual, comprising of the ethnicity, sex, age and stature. This is necessary for civil, legal and statistical purposes, in situations such as mass disaster, migration and conflicts (Acharya et al., 2017). Four primary methods have been validated for establishment of identity – DNA profiling, dactylography, forensic odontological examination and comparison of medical and surgical records. These primary identifiers require the availability of antemortem information about the missing person for comparison with the findings of unidentified human remains. These methods require infrastructure and expertise that is lacking in developing countries.

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Sex is an important component of the biological profile used to generate a hypothesis of identity (Spradley, 2016). Sex can be estimated using osteological, radiological and somatological examinations. The inherent genetic and environmental differences between populations require population-specific research for the establishment of prior probabilities (İşcan and Steyn, 2013).

The forensic anthropological examination of mutilated, decomposed or skeletonised human remains examines the sexual dimorphism in skeletal elements secondary to the effects of sex hormones that affect bone mass, bone growth and epiphyseal fusion (Raisz and Kream, 1981). The estimation of sex follows two main methods, morphological and morphometric. The morphological examinations are subjective and require expertise to accurately analyse the dimorphic characteristics. The morphometric examinations are more objective, but generally do not consider the geometric variations (İşcan and Steyn, 2013). Recent studies have found that "cognitive bias can occur even in metric sex-estimation conclusions" (Hartley et al., 2022). Over the years, sex estimation techniques have examined the pelvis and cranium (Acsádi and Nemeskéri, 1970), long bones of the lower limbs (Steyn and İşcan, 1997), long bones of the upper limbs (İşcan et al., 1998), vertebrae (MacLaughlin and Oldale, 1992), clavicles (McCormick et al., 1991), sternum (Hunnargi et al., 2008), as well as bones of the hand and foot (Smith, 1997; Case and Ross, 2007). Similarly, in Nepal, estimation of sex has been attempted from examination of the foramen magnum (Maharjan et al., 2018) and sternum (Karki et al., 2020).

Therefore, the main objective of the present study is to develop standards for conducting sex estimation from the sternal ends of left fourth rib in a contemporary Nepalese population. All these parameters are population specific, owing to the genetic and environmental variations between populations (Krishan and Kanchan, 2013). Additionally, intra-population nonconformities have also been reported due to temporal variations between populations (Saini et al., 2014).

MATERIALS AND METHODS

A quantitative, non-probability (convenience) sampling, observation study was conducted at the Department of Forensic Medicine, Maharajgunj Medical Campus, Institute of Medicine, Kathmandu, Nepal from November 2021 till March 2023. All adults (over 18 years) undergoing autopsy, without any trauma or deformity of the ribs, were included in the study. The family members were counselled about the study, its implications, importance and their option not to be included or to withdraw from the study at any time.

This study is a component of the research conducted (by RS) during the Ph.D. in Anthropology titled "Forensic anthropological examination of the sternal ends of ribs in a Nepalese population." The ethical clearance was obtained from Institutional Ethics Committee, Panjab University, Chandigarh, India (vide EC-D-2103-44 dated 06 April 2021), Institutional Review Committee, Institute of Medicine, Kathmandu, Nepal (vide 114 (6-11) E2 – 078/079 dated 10 September 2021) and National Health Research Council, Nepal (vide 1080 dated 17 November 2021).

The sample size (N=384) was calculated using Cochran's method (1977). Additionally, to account for the destruction of ribs during the maceration process, additional samples were collected. The left fourth ribs were collected from 412 deceased individuals and processed. A total of 387 samples (106 females and 281 males) were found to be suitable, and were analysed for the present study.

Sample collection

The dependent variable examined was the sex of individuals. The ribs were collected during the dissection of the thoracic cavity, as per regular autopsy protocol. The skin, subcutaneous tissue and muscles were reflected and dissected following a midline incision from the supra-sternal notch to the symphysis pubis. Similarly, intercostal muscles between the ribs were dissected and removed by gross dissection. Finally, the ribs were cut using rib shears, 5 cm lateral to the costochondral junction, while the costal cartilages were cut using a scalpel, 2 cm medial to the costochondral junction. Where the costal cartilages had calcified, the cartilages were cut using rib shears.

The left fourth ribs are frequently analysed in forensic anthropological examination. Therefore, this study reports the examination and analysis of left fourth ribs, to standardise and facilitate comparison with previous studies. Once collected, the ribs were stored in water, to allow for loosening and separation of soft tissue and cartilage. The ribs were boiled for 15-30 minutes to clear any adherent debris. Finally, the ribs were dried in an open, shaded area for 24 hours. The ribs confirmed to be free from damage of the articular surface of the sternal end of ribs were used for measurement of morphometric variables.

Parameters of left fourth rib taken for the study

The independent morphometric variables used in the study included maximum superior-inferior height, maximum anterior-posterior breadth and pit depth.

Pit depth of the sternal ends of left fourth ribs (L4PD)

The pit depth was measured using a depth micrometer (to the nearest 0.02 mm), perpendicular to the base of the pit, "where the distance between the base of the pit and the adjacent anterior or posterior wall is the greatest" (İşcan et al., 1984a). The depth should not be measured at the superior and inferior ends of the ribs, where bony projections may be present (Fig. 1).

Maximum superior-inferior height of the sternal ends of left fourth ribs (L4SI)

The maximum superior-inferior height of the sternal ends of left fourth rib was measured as the "maximum distance between the most superior and inferior points at the end of the rib" (İşcan et al., 1985) using a sliding (Vernier) calliper (to the nearest 0.02 mm) (Fig. 2).

Maximum anterior-posterior breadth of the sternal ends of left fourth ribs (L4AP)

The maximum anterior-posterior breadth of the sternal end of left fourth ribs measured the maximum distance "between the most anterior and posterior points" at the end of the rib (İşcan et al., 1985) using a sliding (Vernier) calliper (to the nearest 0.02 mm) (Fig. 3).

Manual, computer and statistical analyses

The data collected were analysed using Statistical Package for Social Sciences (SPSS, Version 21, Armonk, NY: IBM Corp.). The data was examined for normality of distribution data and then analysed to develop models for estimation of sex. Mann Whitney U test was used for statistical analysis.

Fig. 1.- Measurement of pit depth of sternal end of left fourth rib.

Fig. 2.- Measurement of maximum superior-inferior height of sternal end of left fourth rib.

Fig. 3.- Measurement of maximum anterior-posterior breadth of sternal end of left fourth rib.

RESULTS

The left fourth ribs of 387 individuals were analysed for the present study. The samples comprised of 106 females (27.4%) and 281 males (72.6%). L4SI was found to have a mean of 13.61 mm with a standard deviation of 1.65 mm. L4AP was found to have a mean of 6.94 mm with a standard deviation of 0.90 mm. L4PD was found to have a mean of 6.13 mm with a standard deviation of 3.15 mm (Table 1).

The variables were tested for normality of distribution, using visual evaluation, kurtosis, skewness as well as Kolmogorov-Smirnov test and Shapiro-Wilk test (Table 2). The variables were found to have non-normal distribution and were therefore analysed using non-parametric tests.

Following the test for normality, the independent morphometric variables were tested using Mann Whitney U test (Table 3). All three variables (L4SI, L4AP and L4PD) were found to have statistically significant difference ($p<0.001$) between the sexes.

Table 1. Descriptive statistics of morphometric measurement of left fourth rib.

	N	Minimum	Maximum	Mean	Std. Deviation
Maximum Superior-Inferior Height	387	9.32	17.48	13.61	1.65
Maximum Antero-Posterior Breadth	387	4.72	9.84	6.94	0.90
Pit Depth	387	.02	14.98	6.13	3.15

Table 2. Test for normality of morphometric measurement of left fourth rib.

	Sample size (n)	95% Confidence Interval		Skewness (SE-0.124)	Kurtosis (SE-0.247)	KS (df – 387)		Shapiro-Wilk (df – 387)	
		Lower	Upper	Statistic	Statistic	statistic	Sig.	statistic	Sig.
L4SI (mm)	387	13.44	13.77	-0.343	-0.383	0.090	<0.001	0.982	<0.001
L4AP (mm)	387	6.84	7.03	0.322	0.043	0.063	0.001	0.990	0.010
L4PD (mm)	387	5.82	6.45	0.717	-0.126	0.112	<0.001	0.950	<0.001

Table 3. Mann Whitney U test for differences between the morphometric measurements of left fourth ribs between males and females.

	Sex	N	Mean Rank	Sum of Ranks	Mann-Whitney U	Asymp. Sig.
L4SI	Female	106	84.45	8952.00	3281.000	<0.001
	Male	281	235.32	66126.00		
L4AP	Female	106	127.90	13557.00	7886.00	<0.001
	Male	281	218.94	61521.00		
L4PD	Female	106	162.67	17242.50	11571.50	<0.001
	Male	281	205.82	57835.50		

Binary Logistic Regression Analysis

The binary logistic regression model for estimating sex from L4SI was found to be statistically significant (χ^2 (1, N=387) = 181.824, p < .001). The model explained 54.3% (Nagelkerke R2) of the variance in sex, correctly classifying 66.0% of female samples and 91.1% of male samples. The overall accuracy of the model for estimating sex from maximum superior-inferior height of left fourth rib using binary logistic regression analysis was found to be 84.2%.

Similarly, the binary logistic regression model for estimating sex from L4AP was also found to be statistically significant (χ^2 (1, N=387) = 56.571, p < .001). However, the model explained only 19.7% (Nagelkerke R2) of the variance in sex, correctly classifying only 24.5% of female samples and 94.0% of male samples. The overall accuracy of the model for estimating sex from maximum anterior-posterior breadth of the left fourth rib using binary logistic regression analysis was found to be 74.9%.

Finally, the binary logistic regression model for estimating sex from L4PD was also statistically significant (χ^2 (1, N=387) = 12.883, p < .001). However, the model explained only 4.7% (Nagelkerke R2) of the variance in sex, classifying all samples as males.

The model summaries are provided in Table 4, while the classification results are provided in Table 6.

Discriminant Function Analysis

The discriminant function analysis for estimating sex from L4SI was found to be statistically significant (χ^2 (1, N=387) = 195.389, p < .001). The model explained 63.1% of the variance in sex, correctly classifying 82.1% of female samples and 80.4% of male samples. The overall accuracy of the model for estimating sex from maximum superior-inferior height of left fourth rib using discriminant function analysis was found to be 81.7%.

Table 4. Binary logistic regression equation for estimation of sex from morphometric measurements of the sternal ends of left fourth ribs.

	B	S.E.	df	Sig.	Exp(B)	Chi-square	Nagelkerke R Square
L4SI	1.309	0.137	1	<0.001	3.703	181.824	0.543
Constant	-16.157	1.761	1	<0.001	0.000		
L4AP	1.113	0.168	1	<0.001	3.044	56.571	0.197
Constant	-6.542	1.116	1	<0.001	0.001		
L4PD	0.140	0.041	1	0.001	1.150	12.883	.047
Constant	0.160	0.254	1	0.530	1.173		

Table 5. Discriminant function coefficients for estimation of sex from morphometric measurements of the sternal ends of left fourth ribs.

	B	Canonical Correlation	Chi-square	df	df2	Sig
L4SI	0.781	0.631	195.389	1	385	<0.001
(Constant)	-10.629					
L4AP	1.187	0.361	53.669	1	385	<0.001
Constant	-8.229					
L4PD	0.322	0.177	12.208	1	385	<0.001
Constant	-1.978					

Table 6. Classification tables for estimation of sex from morphometric measurements of the sternal ends of left fourth ribs.

		L4SI		L4AP		L4PD	
		Females	**Males**	**Females**	**Males**	**Females**	**Males**
Binary Logistic Regression	**Females**	70 (66.0%)	36	26 (24.5%)	80	0 (0.0%)	106
	Males	25	256 (91.1%)	17	264 (94.0%)	0	281 (100%)
	Overall	**84.2%**		**74.9%**		**72.6%**	
Discriminant Function Analysis	**Females**	87 (82.1%)	19	72 (67.9%)	34	68 (64.2%)	38
	Males	55	226 (80.4%)	100	181 (64.4%)	153	128 (45.6%)
	Overall	**81.7%**		**65.4%**		**50.6%**	

Similarly, the discriminant function analysis for estimating sex from L4AP was also found to be statistically significant (χ^2 (1, N=387) = 53.669, p < .001). The model explained only 36.1% of the variance in sex, correctly classifying 67.9% of female samples and 64.4% of male samples. The overall accuracy of the model for estimating sex from maximum anterior-posterior breadth of left fourth rib using discriminant function analysis was found to be 65.4%.

Finally, the discriminant function analysis for estimating sex from L4PD was also statistically significant (χ^2 (1, N=387) = 12.208, p < .001). However, the model explained only 3.2% of the variance in sex, correctly classifying 64.2% of female samples and 45.6% of male samples. The overall accuracy of the model for estimating sex from maximum anterior-posterior breadth of left fourth rib using discriminant function analysis was found to be 50.6%.

The model summaries are provided in Table 5, while the classification results are provided in Table 6.

DISCUSSION

This study aims to develop standards for estimation of sex from the sternal end of left fourth rib.

Table 7. Comparison of previous studies for estimation of sex from sternal ends of left fourth ribs with the present study.

1.	**İşcan, 1985**	SI, AP, PD	230 (144 males, 86 females)	America	80.4% – 89.1%
2.	**Çölolu et al., 1998**	SI, AP	294 (150 males, 144 females)	Turkey	81.0% – 92.6%
3.	**Koçak et al., 2003**	SI, AP	251 (173 males, 78 females)	Turkey	85.1% - 91.7%
4.	**Wiredu et al., 1999**	SI, AP	346 (221 males, 125 females)	Ghana	73.8% - 80.7%
5.	**Macaluso Jr et al., 2012**	SI, AP	117 (60 males, 57 females)	Spain	76.7% - 86.7%
6.	**Chand et al., 2015**	SI, AP	266 (200 males, 66 females)	India	82.5% - 86.8%
7.	**Khatri, 2015**	SI, AP, PD	100 (67 males, 33 females)	India	60% - 94%
8.	**Muñoz et al., 2018**	SI, AP	504 (444 males, 60 females)	Mexico	73.3% - 87.5%
9.	**Current Study**	SI, AP, PD	387 (281 males, 106 females)	Nepal	66.0% - 92.1%

The multiplicity of the ribs as well as the relatively smaller size of the sternal ends of ribs decrease the chances of alterations and therefore, are extremely valuable in the forensic anthropological examination of exhumed human remains.

During the development of age estimation models for the sternal ends of ribs (İşcan et al., 1984a; 1985; 1984b), the authors noticed that the changes in the ribs were sexually dimorphic. Based on this, İşcan (1985) examined right fourth ribs and recorded three measurements - maximum superior-inferior height, maximum anterior-posterior breadth, and maximum pit depth at the costochondral junction, using a coordinate calliper.

Similar studies have been conducted in Turkey (Çölolu et al., 1998; Koçak et al., 2003), Ghana (Wiredu et al., 1999), Spain (Macaluso Jr et al., 2012), India (Chand et al., 2015; Khatri, 2015) and Mexico (Muñoz et al., 2018) for estimation of sex from these rib measurements. The accuracy ranged from 60-94% in these studies (Table 7). All these studies show that osteometric measurements of the ribs are reliable for estimation of sex. All authors provide reasonable accuracy using pit depth and maximum anterior-posterior breadth, with good estimates being developed using maximum superior-inferior height. This is in contrast to our findings that show that maximum superior-inferior height provides good accuracy, while pit depth and maximum anterior-posterior breadth provides poor accuracy for estimation of sex.

The discriminant function analysis, as well as binary logistic regression of maximum superior-inferior height of the left fourth rib, provide good accuracy. Maximum anterior-posterior breadth and pit depth of left fourth rib showed poor correlation and accuracy for estimating sex using both binary logistic regression analyses, as well as discriminant function analysis.

CONCLUSION

The sternal end of the left fourth rib is a valuable tool for forensic anthropological investigations to establish identity. The ribs are useful for sex estimation, especially when the hip bone and cranium are not available. The sternal end of left fourth ribs have good accuracy for estimation of sex, using both binary logistic regression (84.2%) and discriminant function (81.7%) analyses.

This study demonstrates the importance of developing population-specific models to accurately predict the primary indicators of biological profile. The results of this study can thus be of great assistance in the management of the dead following disasters and other events of mass fatality.

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