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ORIGINAL ARTICLE

Estimation of stature and sex from sternal lengths: an autopsy study

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Abstract The aim of this study was to derive regression equations for estimating stature and further to estimate sex from four measured sternal lengths. This study included intact sterna from 65 males and 30 females, aged between 25 and 40 years, obtained during medico-legal autopsies. Stature and four sternal lengths, length of the manubrium (LM), length of the body (LB), length of the manubrium and body (LMB) and total sternal length, of each cadaver were measured. Stature and all measured sternal lengths were greater in males compared to females ($p < 0.001$). All sternal lengths were positively correlated with stature in sexes. LMB had the highest correlation coefficient in both males and females (correlation coefficient: 0.721 and 0.740, respectively). In both sexes, linear regression analysis for stature estimation revealed equations with the highest R^2 values when derived from LMB ($R^2 = 0.521$ for males and $R^2 = 0.547$ for females). On the other hand, only the multiple linear regression equation derived from the combination of the LB and LMB had the higher R^2 value ($R^2 = 0.640$) for stature estimation in females. Receiver-operating curve analysis for all measurements was statistically significant ($p < 0.05$ for all). These findings suggested that measured sternal lengths can be used for estimation of sex. However, LB and LMB measurements were found to be the most reliable sternal lengths for estimating sex with an accuracy rate of 90 %. Our results revealed that the sternum is a useful tool for estimating stature and sex when other skeletal bones are not available.

Keywords Stature estimation · Sternum · Sex estimation · Identification · Physical anthropology

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Introduction

In forensic medicine and scientific disciplines, which involve bioarchaeological, anthropological investigation and the identification of skeletal remains, and the method to be employed for this purpose are always important. For this objective, long bones are most frequently used for estimating stature. However, the partial or total destruction of long bones due to fracture, damage or disease reduces the amount of information that can be gained from these bones and reduces the possibility of successful identification.

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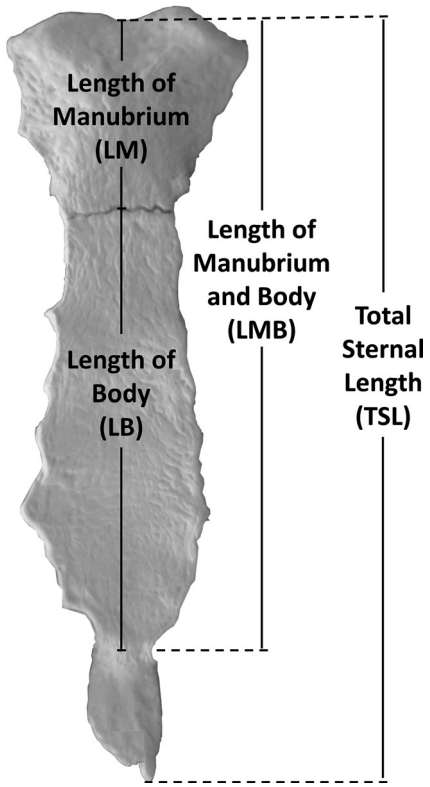


Fig. 1 Schematization of the sternal lengths measured in this study (Singh et al. 2011)

Therefore, stature estimation needs to be carried out from other bones as well. The skull (Krishan 2008; Sahni et al. 2010), vertebral column (Tibbetts 1981; Nagesh and Kumar 2006), bones of the hands and feet (Holland 1995; Agnihotri et al. 2007, 2008), sacrum (Duyar et al. 2005), scapula (Olivier and Pineau 1957; Shulin and Fangwu 1983; Campobasso et al. 1998) and sternum (Menezes et al. 2009; Singh et al. 2011) have been noted to be used for this purpose in the literature.

Stature has a definite and proportional biological relationship with body parts and each bone of the body (Ebeye Oladunni 2013). In the literature, genetic factors (Trotter and Gleser 1952; Kondo and Eto 1975), ethnic origin (Kondo and Eto 1975; Telkka 1950; Meadows and Jantz 1995; Ruff 2002), environmental factors (Silventoinen et al. 2000), socioeconomic status (Silva et al. 2012) and diet (Larson 1997; Pelin and Duyar 2003) have been reported to have effects on stature. In turn, the above-mentioned factors affect the developmental period of individuals who belong to a particular sex or population. Therefore, regression equations for different bones need to be developed for different geographical zones of the world to estimate stature; such examples are reported in the literature (Menezes et al. 2009; Singh et al. 2011).

The cadaveric stature that has been estimated from corpses is different from the living stature. The contributing factors are rigor mortis changes, age-dependent changes and positional differences (Cline et al. 1989; Trotter and Gleser 1952; Singh et al. 2011).

Dwight (1890) was the first to publish a study on the relation of the length of the sternum to age, sex and stature. The sternum is located in the middle of the anterior wall of the thorax in anatomical position. It consists of the manubrium, body (mesosternum) and xiphoid process, respectively, from superior to inferior. The manubrium includes the jugular notch at its superior border, articulates with the body and forms the manubriosternal joint. The inferior end of the body articulates with the superior end of the xiphoid process (Fig. 1) (Selthofer et al. 2006; Gatzoulis 2008). The sternum protects the lungs, heart and large blood vessels from physical injuries (Drake et al. 2009). Additionally, compared to other chest wall bones, the sternum, especially the manubrium, is likely to remain intact after possible mortal physical injuries (Huelke and Melvin 1979; Cox 2012).

In our present study, we aimed to investigate whether a correlation exists between stature and four measured sternal lengths to develop regression equations for stature estimation from the sternal lengths. Further, we aimed to find metric values for differentiating between male and female sterna.

Materials and methods

Population data

The total of 95 cadavers included 65 (33.7 ± 5.1 years) males and 30 (32.3 ± 5.8 years) females, originating from Denizli, Turkey. The cadavers were obtained during medico-legal autopsies performed at Pamukkale University School of Medicine, Department of Forensic Medicine. Ethics committee approval was received.

Corpses that were compressed, burned or had physical anomalies affecting stature measurement were excluded from the study. Sterna with acquired or congenital deformities were excluded as well.

It has been stated that the bone-lengthening process stops between 16 and 25 years because of epiphyseal closure, so cadavers under the age of 25 years were excluded (Krogman and Iscan 1986; Scanlon 2007).

The xiphoid process unites with the body of the sternum at around 40 years of age; therefore, cadavers over 40 years old were also excluded (Aggrawal 2003). Consequently, all studied sterna belonged to cadavers aged between 25 and 40 years. Besides, cadavers with a xiphoid process partially or completely united to the body of the sternum were also excluded without considering age.

The ages of the cadavers were assigned according to inquest documents recorded by the police and confirmed by the legal heirs before medico-legal autopsies. Unidentified cadavers were not included since the age of these cadavers could not be exactly determined.

Methodology

The metric system was used for morphometric measurements. Stature was measured in centimeters (cm), and all the other measurements (sternal lengths) were measured in millimeters (mm). All measurements were taken by same observer.

Measurement of cadaveric stature (S)

Cadavers were placed in supine position on the autopsy table. Then, the stature of each cadaver was measured from the cranial vertex to the base of the heel using a steel measuring tape as described by Nagesh and Kumar (2006; Singh et al. 2011).

Sternal measurements

After skin and soft tissue dissection, sterna were removed by making incisions in the sternoclavicular joints and junction of costal cartilages of all seven ribs. Then, all sterna were cleaned, washed and dried (Singh et al. 2011). The following measurements were taken from the anterior surface of the each sternum in the midsagittal plane using a digital vernier caliper (Singh et al. 2011). After measurements, sterna were placed in the thorax because of ethical constraints.

Length of manubrium sterni (LM)

The LM was measured as the distance from the jugular notch to the junction of the manubrium and body of the sternum in accordance with the technique as prescribed (Ashley 1956; Singh et al. 2011) (Fig. 1).

Length of body (LB)

LB was measured as the distance from the junction of the manubrium and sternal body to the junction of the sternal body and xiphoid process on the anterior surface of the sternum (Singh et al. 2011) (Fig. 1).

Length of manubrium and body (LMB)

LMB was measured as the distance from the jugular notch to the junction of the sternal body and xiphoid process on the anterior surface of the sternum and in the midsagittal plane in accordance with the technique described by Ashley (1956; Menezes et al. 2009, 2011; Singh et al. 2011) (Fig. 1).

Total sternal length (TSL)

TSL was measured as the total distance from the jugular notch to the distal end of the xiphoid process as mentioned above on the anterior surface of the sternum in the midsagittal plane (Singh et al. 2011) (Fig. 1). The xiphisternal joint is a symphysis and transformed to a synostosis by the 40th year (Gatzoulis 2008). As mentioned above, we measured the TSL in the sterna with the not ossified (partially or completely) xiphisternal joint. After measuring the TSL, the xiphoid process was removed by dissection, and then the other sternal measurements were taken (Singh et al. 2011).

Statistical analysis

Descriptive statistical parameters were calculated using the Statistical Package for Social Sciences, SPSS 11.0.1. The correlation coefficients were calculated to assess relations between different sternal lengths and stature. The comparison of sternal lengths in sexes was analyzed with Student's t test, and a p value of <0.05 was considered significant.

Both simple and multiple linear regression analyses were applied for the different sternal lengths to derive regression equations for estimation of the stature of the study population.

The hypothetical regression equation is represented as stature $(S) = \alpha + \beta X$, where α is the regression constant term, β stands for the regression coefficient of the independent variable (i.e., any sternal length), and X is the length of that particular sternal length.

The R^2 coefficient of determination was calculated to assess the significance of regression. The higher the value of R^2, the better the fit was and the more useful the regression equation was for prediction.

A receiver-operator characteristic (ROC) curve analysis was performed in order to identify the optimal cutoff point of sternal lengths (at which sensitivity and specificity are maximal) for the prediction of sex. The area under the ROC (AUROC) value was calculated as a measure of the accuracy of classification.

Results

Statistical descriptive results

For all cases, the mean stature was 169.04 ± 8.8 cm. The mean stature of the male cadavers was 173.2 ± 6.3 cm and that of females was 160.2 ± 6.7 cm. The descriptive

Table 1 Various statistical descriptive results of sternal lengths along with the correlation coefficient with stature in total, males and females

Measurements	Total ($n = 95$)		Males ($n = 65$; %68)		Females ($n = 30$; %32)		p^{+}
	Mean ± SD	Correlation coefficient	Mean ± SD	Correlation coefficient	Mean ± SD	Correlation coefficient	
Cadaveric stature (S; cm)	169.04 ± 8.8	1.00	173.1 ± 6.3	1.00	160.2 ± 6.7	1.00	<0.001
Length of manubrium (LM; mm)	51.5 ± 6.3	0.656*	53.0 ± 6.2	0.594*	48.3 ± 5.4	0.670*	<0.001
Length of body (LB; mm)	110.8 ± 12.9	0.746*	117.1 ± 8.6	0.560*	97.1 ± 9.5	0.372**	<0.001
Length of manubrium and body (LMB; mm)	160.2 ± 15.7	0.850*	167.3 ± 12.2	0.721*	144.9 ± 11.0	0.740*	<0.001
Total sternal length (TSL; mm)	200.0 ± 22.9	0.806*	209.6 ± 18.9	0.673*	179.2 ± 16.0	0.662*	<0.001

* Significant at the 0.001 level

** Significant at the 0.05 level

$^{+}$ p values are given for the t test

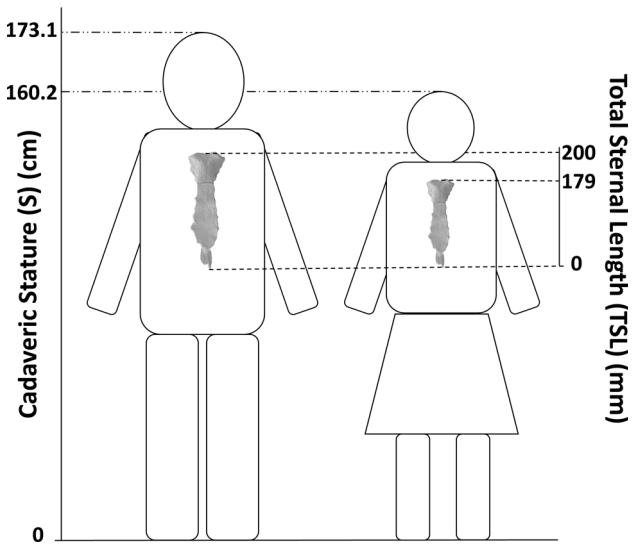


Fig. 2 The mean values of stature and total sternal lengths of 65 males and 30 females

results of sternal length measurements are given in Table 1 for the whole sample, male and female cases, respectively.

All measurements (stature and sternal lengths) were significantly higher ($p < 0.001$) in males compared to females (Table 1; Fig. 2).

Correlation analysis

Of the 95 cadavers, overall analysis revealed a significant and positive correlation between stature and all measured sternal lengths ($p < 0.001$ for all). In accordance with these findings, in males there was a significant and positive correlation between stature and all measured sternal lengths ($p < 0.001$ for all) and also that of females ($p < 0.05$ for the correlation between S and LB; $p < 0.001$ for all others). LMB had the highest correlation coefficients in both males and females (Table 1).

Regression analysis

Linear regression analysis

In Table 2, simple linear regression equations and coefficient of determination (R^2) values were given to estimate stature for each of the measured sternal lengths. Overall analysis showed that, in both sexes, the equations derived from LMB had the highest R^2 value. Thus, these equations had the highest accuracy when compared to the equations derived from each of the other measured sternal lengths (Table 2).

Multiple regression analysis

In males, the multiple linear regression analysis revealed that stature can be calculated with the highest coefficient of determination from the LMB value alone ($R^2 = 0.521$) (Table 2).

However, the multiple linear regression analysis revealed an equation with a higher R^2 value in females. The R^2 value was 0.541 when only LMB was used (Table 2), and it increased to 0.640 when the LB and LMB combination was used for stature estimation. The obtained equation for females was $S = 95.489 + 0.670 \times \text{LMB} - 0.334 \times \text{LB}$ ($R^2 = 0.640$).

Sex effect

The mean of all sternal lengths as well as stature was found to be significantly greater in males than females ($p < 0.001$ for all comparisons) (Table 1).

All areas under the ROC curves for all measurements were significantly different from 0.05 (Table 3; Fig. 3). This means all measurements can be used for determintion of sex.

Table 2 Linear regression equations (LRE) for cadaveric stature (S) estimation from sternal measurements in males and females

Variables	Males ($n = 65$)			Females ($n = 30$)		
	LRE ($S = \alpha + \beta X$)	SEE	R^2	LRE ($S = \alpha + \beta X$)	SEE	R^2
X_1: length of manubrium	$S = 141.192 + 0.602\ (X_1)$	0.103	0.353	$S = 120.276 + 0.827\ (X_1)$	0.173	0.448
X_2: length of body	$S = 125.320 + 0.408\ (X_2)$	0.076	0.314	$S = 134.845 + 0.261\ (X_2)$	0.123	0.138
X_3: length of manubrium and body	$S = 111.198 + 0.370\ (X_3)$	0.045	0.521	$S = 95.139 + 0.449\ (X_3)$	0.077	0.547
X_4: total sternal length	$S = 126.388 + 0.223\ (X_4)$	0.031	0.453	$S = 110.713 + 0.276\ (X_4)$	0.059	0.438

SEE standard error of estimate

Table 3 Statistics derived from receiver-operating characteristic (ROC) curve analysis of sternal lengths

Variables	AUROC	SEE (AUROC)	p	Cutoff value	Sensitivity (%)	Specificity (%)
Length of manubrium	0.710	0.054	0.001	50.70	67.7	66.7
Length of body	0.924	0.036	<0.001	103.82	93.8	86.7
Length of manubrium and body	0.911	0.035	<0.001	152.52	92.3	86.7
Total sternal length	0.891	0.036	<0.001	189.51	89.2	80

AUROC area under the ROC curve, *SEE* standard error of estimate

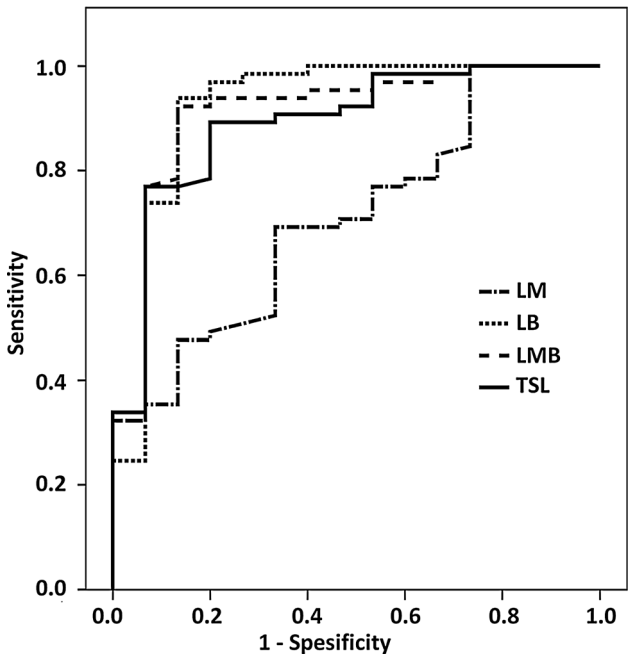


Fig. 3 Receiver-operating characteristic (ROC) curves for sternal lengths in sex

Suggested optimal cutoff values, their sensitivities, specificities and classification accuracy measurements are given in Table 3.

The suggested optimal cutoff value for LM is 50.7 mm with 67.7 % sensitivity and 66.7 % specificity. The suggested optimal cutoff value for LB is 103.82 mm with 93.8 % sensitivity and 86.7 % specificity. The suggested optimal cutoff value for LMB is 152.52 mm with 92.3 % sensitivity and 86.7 % specificity. The suggested optimal cutoff value for TSL is 189.51 mm with 89.2 % sensitivity and 80 % specificity (Table 3; Fig. 3).

According to the AUROC values, LB and LMB measurements were found to be the most effective parameters for estimating sex with overall accuracy values of 92.4 and 91.1 %, respectively (Table 3).

According to Hyrtl's law, the manubrium (M) – body (B) index [(M/B) × 100)] exceeds 50 in females and is <50 in males (Jit et al. 1980). We calculated this index to be 45.26 in males and 49.74 in females.

Discussion

This study is the first in which the relations between sternal lengths, or biometry in general, and stature and sex have been investigated using data obtained from a specific region—Denizli, Turkey.

The overall evaluation of the literature supports that sternal lengths may be useful for estimating stature and sex when long or other bones are not available (Menezes et al. 2009, 2011; Singh et al. 2011). Although, recently, Marinho et al. (2012) reported the estimation of stature from sternal lengths to be unreliable, our results revealed that the sternum can be used for identification.

Descriptive results

In the literature, it is common to come across studies in which vertebrae lengths, hand or middle finger lengths, and coronal suture lengths are used for obtaining linear

regression equations for stature estimation (Peng and Zhu 1983; Rao et al. 1989; Introna et al. 1993; Jason and Taylor 1995; Nagesh and Kumar 2006; Rastogi et al. 2008, 2009; Rao et al. 2009). Although there are many studies from Turkey evaluating the relation of the humerus, radius, ulna, femur, tibia and fibula lengths to stature, the sternum and other bones may need to be used for identification when the bones mentioned above cannot be accessed (Iris 1998; Karacam 1998; Gunay 1995; Batuk 1997; Sam 1994; Celbis and Agritmis 2006). To the best of our knowledge, there is no study investigating the relation of sternal lengths to stature and sex in Turkey. The present study is important for filling in this gap.

In order to protect the lungs, heart and large blood vessels from physical trauma, the sternum has a firm structure and often remains intact in the postmortem period (Drake et al. 2009).

There are studies in the literature in which identification is carried out using American, Australian, African and Indian sternal lengths (Lee 1980; Menezes et al. 2009, 2011; Macaluso 2010; Singh et al. 2011; Franklin et al. 2012).

In our study, the mean stature of male cadavers (173.2 ± 6.3) was higher than in females (160.2 ± 6.7). Studies from other populations confirm these findings (Ahmed 2013; Menezes et al. 2009, 2011; Singh et al. 2011). This finding may be based on the fact that males reach puberty at a later age than females; therefore, growth in body height continues for a longer period of time in males (Lee 1980; Abdel-Malek et al. 1990). Similar to stature, all sternal lengths of males were also longer than those of females. There are studies in the literature that show sternal lengths to be longer in males than in females (Stewart and McCormick 1983; Hunnargi et al. 2008; Ramadan et al. 2010; Singh et al. 2011).

Changes resulting from rigor mortis and extension due to lying down should also be kept in mind as factors that affect the estimated stature of cadavers (Singh et al. 2011).

Correlation analysis

Positive correlations were obtained between postmortem stature and each of the LM, LB, LMB, TSL values in all individuals in this study.

Similar to the results of Singh et al. (2011), we found a correlation between stature and each of LM, LB, LMB and TSL values in males. Menezes et al. (2009) also revealed a strong correlation (coefficient of correlation = 0.638) between stature and sternum length (LMB) in males. However, Menezes et al. (2009) did not give data of any sternal lengths other than the LMB.

Correlations between stature and LM, LB, LMB and TSL measures were found in females. These findings are in agreement with those found in the study of Singh et al. (2011). In another study, Menezes et al. (2011) revealed a strong correlation (correlation coefficient = 0.639) between stature and sternum length (LMB) in females.

Similar to the study of Menezes et al. (2009) in which the correlation between LMB and stature was evaluated in males, Menezes et al. (2011) did not evaluate any sternal lengths except LMB.

Regression analysis

Linear regression analysis

Our study revealed the highest coefficient of determination value when the LMB was used in the estimation of stature compared to other measured sternal lengths in both males and females (Table 2). This finding is congruent with previous studies (Singh et al. 2011; Menezes et al. 2011). Singh et al. (2011) showed that stature could be estimated from sternal lengths (LM, LB, LMB, TSL) in males and females.

In our study, the coefficient of determination value (R^2) of linear regression equations obtained in relation to each of the LM, LB, LMB and TSL values in the estimation of stature in both males and females was found to be higher than R^2 values found in the study by Singh et al. (2011).

In this study, the coefficient of determination value that has been obtained from the linear regression analysis between the stature and LMB value was found to be 0.521 in males. Menezes et al. (2009) obtained a regression equation for the estimation of stature from sternum length (LMB) in males; the coefficient of determination value has not been reported in that study.

In females, the coefficient of determination value that has been obtained from the linear regression analysis between stature and the LMB value was found to be 0.547. Menezes et al. (2011) obtained a linear regression equation for the estimation of stature from sternum length in females and reported the coefficient of the determination value to be 0.408. The R^2 value obtained in that study was lower than the value obtained in our study. While the higher R^2 value implies that the equation is more useful, this may also be accounted for by the fact that the calculated coefficient of the determination value may be affected by the sample size included in the study.

Multiple linear regression analysis

In both males and females, when only the LMB values were used the R^2 value was found to be higher than 0.52.

In males, the obtained equations using the combination of any sternal lengths did not have a higher coefficient of determination value compared to those obtained from the

linear regression equations. In other words, the coefficient of determination value, i.e., R^2, did not increase with the subsequent addition of different sternal lengths.

On the other hand, in females, only the multiple linear regression equation derived from the combination of the LB and LMB had a higher R^2 value ($R^2 = 0.64$) for stature estimation. The combination of LB and LMB was found to be highly significant for stature estimation in females (see Tables 2, 3).

Singh et al. (2011) showed that the coefficient of determination value increased with the subsequent addition of variables (LM, LB, TSL and LMB) in both sexes.

However, our suggested equations obtained from linear and multiple regression analysis for stature estimation have higher R^2 values in both males and females.

Sex effect

Sexual dimorphism has been previously reported between males and females in respect to sternal lengths (Jit et al. 1980).

In our study, all measurements were found to be higher in males than in females (Table 1). LMB measurements carried out on X-ray images by Stewart and McCormick (1983) were found to be shorter in females than in males.

According to ROC analysis, our results revealed that LB and LMB values had the highest accuracies when used for estimating sex. Also, LB has higher accuracy than LMB.

In addition, our results for males are consistent with the "manubrium-body index," which has been called Hyrtl's law. However, those for females are inconsistent. Contradictory to our results, Ramadan et al. (2010) have stated that Hyrtl's law is not applicable to Turkish males. Our findings revealed that the use of LB and LMB values provides more reliable knowledge for sex estimation rather than calculating the manubrium-body index.

Conclusions

Identification of skeletal remains is very important for many disciplines. The present study indicates that stature and sex can be predicted from sternal lengths.

In our study, males had greater stature and sternal measurements compared to females, thus corroborating previous studies. All sternal lengths, especially LMB, were found to be well correlated with stature in both sexes. For males and females, we had linear regression equations derived from each of the sternal lengths, with high R^2 values. In addition, we only had a multiple linear regression equation for females, with a higher R^2 value compared to that obtained from linear regression analysis, when only derived from the combination of LB and LMB.

Our findings suggested that each of the sternal measurements can be used for estimation of sex. Moreover, LB and LMB had the highest accuracies for estimating sex.

Further, we conclude that, compared to other studies, the results of our study suggest that sternal lengths may be more reliable estimators of stature and sex.

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Conflict of interest None declared.

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