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Original Article

Usage length of sternum components and sternal angle through images obtained by computerized tomography image reconstruction in gender determination

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Abstract

Aim: This study investigates the total sternum length and the lengths of each part of the sternum using computed tomography (CT) images oriented orthogonally to reveal whether there are any significant gender differences with respect to these values.

Material and Methods: Thin-section thorax CT images from 60 subjects (30F, 30M) between 20 and 40 years of age were used, oriented to the orthogonal plane using an image-processing program.The sternal angle (SA), manubrium length (ML), corpus length (CL), xiphoid processlength (XPL), total sternum length (TSL), manubrium-corpus length proportion (sternal index; SI), and the proportion of the three parts separate from the TSL were compared by gender.

Results: The values of the ML (M: 5.36 cm, F: 4.76 cm), CL (M: 10.11 cm, F: 8.75 cm), and TSL (M: 19.18 cm, F: 16.28 cm) were longer in males ($p \leq 0.05$) than in females. No statistically significant difference was determined in the ratios of the XPL, SI, and sternum parts to the TSL ($p > 0.05$). The mean values of the SA in males and females were 161.4° and 160.51°, respectively ($p > 0.05$). In an ROC analysis, the most significant measurement for gender determination was found to be the CL, and the linear discriminant analysis yielded a correct determination rate of 86% for males and 93% for females.

Conclusions: Although metric measurements of the sternum could provide high accuracy rates in gender determination, to increase reliability, image analyses should be conducted in the orthogonal plane to remove errors that could be caused by the differences in orientation.

Keywords: Sternum; Sternal Angle; Sternal Index; Gender Determination; Computed Tomography; Image Analysis; And Anthropometry.

INTRODUCTION

Gender determination, crucial for forensic investigations and archaeological studies, is performed using several procedures, including osteometry, odontometric data, and DNA analysis (1). However, in many cases, DNA analysis is unavailable due to high cost, inaccessibility, various difficulties in DNA extraction, and the requirement of highly trained personnel (2). On the other hand, anthropometric studies of skeletal differences may yield essential information for gender identification procedures. Yet, osteometry is an effective method, preferred with respect to its simple and repeatable processing, low cost, and high accuracy rates (3,4).

The manubrium and body parts of the sternum form the sternal angle, the angle of Louis, first defined by the French surgeon and physiologist Antoine Louis (5). As to the current literature reports, there have been very limited metric studies dealing with the usage of the sternum for gender determination (6-8). These studies have carried out gender-dependent parametric measurements of the sternum, but none has dealt with the measurements on images with corrected orientation. The angle and length measurements of the sternum are affected profoundly by the orientation of the images, and current studies have suggested no method that eliminates this problem.

The multidetector CT (MDCT) used in this study is an imaging method capable of viewing all the tissues, particularly the bone tissue with sharp boundaries (9). This research was conducted on evaluating the

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correlation between gender and the metric parameters of the sternum through MDCT images, which were oriented toward the orthogonal plane, to provide a tool for gender determination. The results compared with the literature reports accumulated using different methods and populations.

MATERIAL and METHODS

Image Population

The study was approved by the Ethical Committee for Non-Interventional Clinical Investigations of the Karabuk University with the decision number of 6/19. Randomly selected thoracic CT images of 60 patients between the ages of 20 and 40 (30F, 30M) from the Western Black Sea region of Turkey admitted to the hospital with various indications were included in the study. The average age of male subjects was 31.23 and that of the females was 34.2. Individuals with any kind of thoracic pathology background including trauma or surgical history were excluded.

MDCT Protocol

Images were obtained using a 16-row MDCT scanner (Aquilion 16; Toshiba Medical Sys-tems, Otawara, Japan). A routine thoracic CT protocol, with a cross-sectional thickness of 5 mm, was applied in the supine position. Tube voltage, gantry rotation, and pitch values were 120 kV, 0.75 s, and 1.0 mm, respectively. Multiplanar reconstruction was made using 2 mm slice thickness.

Image Analysis

All images were transferred to the DICOM medical image viewer software (Horos v2.2.0). Sagittal, transverse, and coronal multiplanar reformate images were obtained using 3D Curved-MPR in the axial plane with the standard bone dose. The coronal image series were corrected through uniplanar leveling, while the axial image series were adjusted by aligning the spine and the sternum. The sagittal image series, on the other hand, were fixed through aligning the sternal angle (SA) and the lower edge of the T4 vertebra. All the image sequences were oriented toward the orthogonal plane (Figure 1).

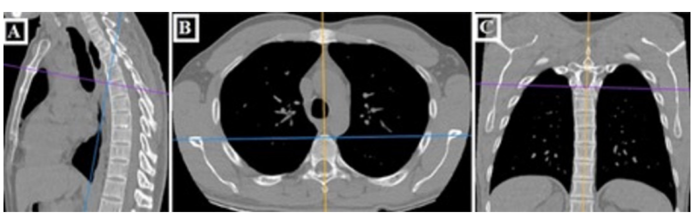

Figure 1. Sagittal (A), axial (B), and coronal (C) images in orthogonal plane

Images of median plane within the three-dimensional image series were used for the measurement procedure. The SA measurement was obtained by using the intersection of two lines joining the midpoints of the manubrium and corpus (Figure 2A). The manubrium length (ML), corpus length (CL), xiphoid process length (XPL), and total sternum lengths (TSL) were measured using the built in length measurement tool in the software (Figure 2B). The proportion of the length of each part of the sternum to the TSL was calculated using the ML/CL (Sternal Index, SI) formula. All measurements were obtained through three repetitions conducted by an experienced radiologist and were averaged. The measurement process was repeated by the same researcher 2 months later.

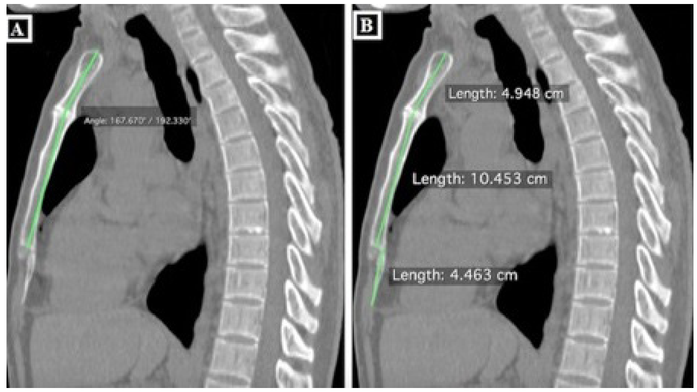

Figure 2. SA measurements conducted in midsagittal CT image (A), sternal length measurements conducted in midsagittal CT image (B)

Statistical Analysis

The validity of the data to normal distribution was tested through the Shapiro–Wilk test. Median, minimum, and maximum values were used as descriptors since the data displayed no normal distribution. The Mann–Whitney U test was used in paired comparisons. The value of $p\leq0.05$ was considered statistically significant. IBM SPSS Statistics 22.0 software was used for statistical analyses.

ROC curve analyses were conducted to evaluate the performances of former rules, to generate specific rules to discriminate between male and female subjects. An ROC curve analysis was used to determine the cutoff values the length of the manubrium, the body, the total sternum for gender, and from the area under the curve. Statistical significance was defined as $p\leq0.05$. Discriminant analysis was performed with statistical software (Minitab17, Minitab Inc., State College, PA, USA). An ROC curve analysis was conducted using the "Optimal Cut points" library by Lopez-Raton et. al., for R software (10,11).

RESULTS

In males, median values for the ML, CL, XPL, and TSL were determined as 5.36 cm, 10.11 cm, 3.52 cm, and 19.18 cm, respectively (Table 1). The proportion among the measurements of the sternum length was found in percentages, as 53.67% for the SI, 27.95% for the ML/TSL, 52.71% for the CL/TSL, and 18.35% for the XPL/TSL (Table 2). The median SA value of males was 161.4°.

In females, median values for the ML, CL, XPL and TSL were determined as 2.92 cm, 8.75 cm, 3.52 cm, and 16.28 cm, respectively (Table 1). The proportion among the measurements of the sternum length was found in percentages, as 56.40% for the SI, 29.23% for the ML/TSL, 53.74% for the CL/TSL, and 17.93% for the XPL/TSL (Table 2). The median SA value of females was 160.51°.

A statistically significant difference was determined for the ML, CL, and TSL values between males and females (p≤0.05) (Table 1).

Table 1. Sternum lengths, according to gender

Parameters (cm)	Male (Min-Max)	Female (Min-Max)	p
ML	5.36 (4.32-6.27)	4.76 (4.21-5.67)	.000
CL	10.11 (8.41-13.16)	8.75 (6.84-10.99)	.000
XPL	3.52 (1.45-6.03)	2.92 (1.52-5.02)	.099
TSL	19.18 (16.40-24.97)	16.28 (13.16-20.22)	.000

There was no statistically significant difference in the XPL, SA, and SI values, and in the ratios of sternum parts to the total sternum lengths (p>0.05) (Table 2).

Table 2. Percentage ratios of sternum lengths, according to gender

Parameters	Male (Min-Max) %	Female (Min-Max) %	p
SI (ML/CL)	53.67 (39-73)	56.40 (43-75)	.124
ML/TSL	27.95 (21-37)	29.23 (24-34)	.204
CL/TSL	52.71 (46-60)	53.74 (44-59)	.668
XPL/TSL	18.35 (9-27)	17.93 (11-28)	.871

In the ROC analysis, the cutoff values of the ML, CL, and XPL were determined as 5.23, 9.17, and 2.99 cm, respectively. The cutoff values for the TSL and SA were measured as 18.2 and 161.22, respectively. The sensitivity, specificity, and predictive values of the results are displayed in Table 3.

Table 3. ROC analysis results of the sternum

Parameters	Cut-off	Sensitivity %	Specificity %	Overall Accuracy %
ML	5.23	70	90	84
CL	9.17	86	90	89
XPL	2.99	80	50	62
TSL	18.2	80	83	88
SA	161.22	53	63	51

In the linear discriminant analysis conducted by using ML, CL, XPL, and SA predictors, the gender determination rate was found to be 86% for males and 93% for females (Figure 3).

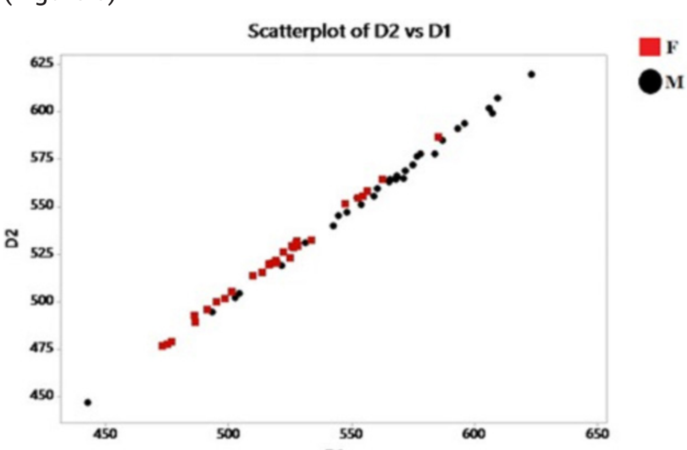

Figure 3. Graph of male and female gender distribution, according to the discriminant analysis

DISCUSSION

Studies have amply documented the usage of the bones of the pelvis, skull, extremities, and teeth for gender estimation and determination by employing various osteometric methods (12). Certain researches have also suggested that the sternum can be used in gender determination in case of the lack of commonly used bones mentioned above (10,11,13-15). However, these studies, in general, have used the morphometric analysis of the sternum by measuring certain parameters obtained from its dry form. According to current knowledge, studies focusing on sternum variations with MDCT and gender correlation are limited.

MDCT technology facilitates generating images that are close to the original bone shape and enables rapid measurements in any axis (16). Likewise, this study, carried out using MDCT images, has found that the ML, CL, and TSL values are significantly higher in malesas compared to females, indicating that these parameters can be utilized for gender determination with high accuracy rates.

In general, the results of this study have a consensus with regard to these values, as compared to those of previous research, concluding that the yare more reliable for gender determination. Hence, detailed literature reports have supported this conclusion. Bongiovanni and Spradley (12) indicated that the TSL was the most reliable determinant with 81.5% accuracy, while Ekizoğlu et al. (14) found the CL value as the most reliable determinant with an accuracy of 88%. Again, another study differentiated female and male specimens with accuracies of 87% and 92%, respectively, by applying a multivariate linear discriminant analysis technique to the sternum length measurements (17). Ramadan et al. (16) also achieved an accuracy rate of 89.3% in females and 88.2% in males, using different combinations in gender determination. The current study proved that the CL value was the most reliable determinant in gender determination, with a sensitivity of 86%, a specificity of 90%, and an accuracy of 89%. The discriminant analysis, conducted via the length of the three parts of the sternum and the SA determinants, differentiated female specimens with an accuracy of 93% and males with 86%.

The first study on the sexual dimorphism of the sternum by Krause appeared in the literature in the 18th century (12). Later, Wenzel (18) compared the proportions (SI) of the ML and CL lengths between males and females. Dwight and Hyrtl (19) found that the CL value was twice as large as or larger than that of the ML in males, and the ML was greater than half the length of the ML in females, which is known as the Hyrtl's law in literature. Strauch (20), Patermoller (21), and Bogusat (22) reported that these results could not be used in individual measures due to the significant overlap between the values of the genders, despite their results that confirmed Hyrtl's law. Another report using postmortem specimens from the Indian population indicated that the SI was unreliable in gender determination, but the CL could be beneficial (17). The findings of our study have shown that the SI values obtained from the CT images of 60 patients from the Western Black Sea region of Turkey are bigger than 0.5 in both males and females, displaying no significant difference between genders. After all, the results presented here in are clearly contrary to Hyrtl's law.

This study facilitates a comparison between the data acquired herein and those of the researches conducted on various populations including India, Europe, Canada, East Africa, and the US displayed in Table 4 (12,17, 23,24). Hence, studies focusing on the subject emphasize the necessity of gender determination standards for different populations. Genetic, environmental, and climatic differences could cause variations on the phenotype of a population. Therefore, morphometric standards for a population cannot be applied universally (12).

Based on the literature reports, it can easily be seen that the lowest measurements for the male sternum were reported in India and East Africa, and the highest values were measured in Canada. The results of our study indicated an average sternum length value, as compared to the literature reports accumulated so far in the world. Similarly, Ramadan et al. (16) conducted a study through MDCT images and found that the ML, CL, and SI values were 53.9 mm, 100.7 mm, and 54.1%, respectively, for males and 50.3 mm, 85.1 mm, and 59.8%, respectively, for females within the Turkish population.Yet, Ekizoğlu et al. (14), in their study conducted through a similar method, found that the ML, CL, and SI values were 52.5 mm, 104.9 mm, and 50.7%, respectively, in males and 48.2 mm, 89.1 mm, and 54.7%, respectively, in females. The findings of the two studies conducted on the different regions of Turkey possess strong similarities in comparison with the data from the studies done in Turkey and around the world.

It is also essential to mention that, even though morphometric analyses can be done effectively using MDCT images in life tissue,certain measurement errors might occur during image analysis due to orientation. To our knowledge, the measurement techniques are not explicitly clear in the literature. This study performed a different measurement technique where all the images were oriented to the orthogonal plane, and the measurements were done repeatedly to eliminate these errors. Thus, the data acquired herein has been validated to avoid measurement errors.

The data related to the gender determination of the SA is very limited in literature and is usually obtained from cadaveric studies. Kirum et al. (25) have used cadaveric sternums in their study and reported that there is no significant difference in the SA value between the genders (male 163.4°, female 165.0°). Similarly, the SA values obtained in the present study (men 161.4°, women 160.5°) have shown no statistically significant difference between men and women, indicating certain conflicts on the use of this data in terms of gender estimation and determination. In the study by Kirum et al. (25), the SA value was found to be bigger in females, whereas our study determined the opposite, indicating the SA value in men was slightly larger. The difference was not statistically significant, though. Other studies on populations of Kenya (26) and Croatia (27) have also reported SA values. Interestingly, the SA values found in our study have shown close similarities to the Kenyan population (Table 5). Consequently, the SA values examined in the present study were not found to be useful in terms of gender determination for the Western Black Sea region of Turkey.

Table 4. Comparison of the ML, CL and TSL and SI Measurements, to Literature

	ML (mm)		CL (mm)		TSL (mm)		SI (%)	
	Female	Male	Female	Male	Female	Male	Female	Male
Dahiphale et al. (17) (Hindistan)	43.78	48.45	70.19	94.42	113.8	142.1	63.01	46.20
Teige (23) (Europe)	43.90	47.70	88.50	103.40	133.70	153.40	54.30	46.20
Torwalt and Hoppa (24) (Canada)	48.79	54.43	93.55	109.41	142.34	163.84	-	-
Ashley (14) (East Africa)	44.20	45.90	82.90	96.50	127.10	142.60	-	-
Bongiovanni and Spradley (12) (United States)	48.24	51.84	89.38	104.80	136.75	154.97	53.68	48.41
Present study	47.6	53.6	87.5	101.1	162.8*	191.8*	56.40	53.67

*XPL is included in TSL.

Table 5. Population differences in the SA

Author	Population	Sample Size	Sampling Method	Mean SA (°)
El-Busaidy et al. (26) (2014)	Kenyans	80	Cadaveric specimens	M = 161.7 F = 159.9
Selthofer et al. (27) (2006)	Croatians	90	Cadaveric specimens	M = 166.4 F = 165.3
Kirum et al. (25) (2017)	Ugandans	85	Cadaveric specimens	M = 163.4 F = 165.0
Present study (2017)	Turks	60	MDCT	M = 161.4 F = 160.5

CONCLUSION

Overall, morphometric analyses with MDCT images could be done efficiently in living cases. However, several measurement errors might occur during image analysis due to orientation. To our knowledge, the measurement techniques are not explicit in the literature. In the present study, all images were oriented to the orthogonal plane and were repeatedly measured to eliminate these errors. This study provides a morphometric analysis of sternum lengths for different genders within a small sample size obtained from the Western Black Sea region of Turkey. It is possible to determine the gender of an individual through the metric measurements of the sternum, due to the identified high accuracy rates. It is recommended that similar studies be applied to wider populations in different population groups. This study could contribute to the data of the works of anthropologists, forensic specialists, and clinicians.

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