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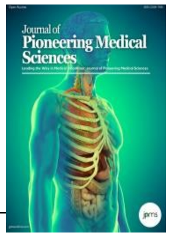

Research Article

Sex Determination and Length and Stature Estimation from The Sternum Bone

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Abstract: **Background:** Determining the sex is the first and most important step in determining biological and anthropological characteristics and is an essential element in starting a medical research work. In cases where we are dealing with unidentified skeletons of individuals, to determine gender and characteristics such as age, height, and identity, forensic medicine has intervened and plays a significant role in determining the mentioned characteristics. **Materials:** This study was performed on 61 three-dimensional CT scan images of the sternum, which included 38 males (62%) and 23 females (38%)..**Methods**: All soft tissues fats and bones except the sternum have been removed. According to the following explanations, 9 parameters of sternal bone were measured using an electronic caliper, and then the data was statistically analyzed. To evaluate the difference between the means, statistical tests were performed on the obtained metric data and significant parameters were examined according to the following study. **Results:** The findings in this study showed that the length of the mesosternum has the highest correlation with the total length of the sternum (R = .951**), followed by the size of the sternum surface strongly correlated with the length of the sternum. (R =.892**). **Conclusion:** According to the present study, we can determine the sex through the sternum bone and also determine the length of the sternum by various parameters taken in the sternum bone by other parameters. In other words, we can determine the sex through the sternum bone when we have no bone except the sternum in forensic medicine.

Keywords: sex Determination, sternum, anthropology

INTRODUCTION

Determining the sex is the first and most important step in determining biological and anthropological characteristics. It is an essential element in starting medical research work in cases where we are dealing with unidentified skeletons of individuals, to determine gender and characteristics such as age, height, and identity, forensic medicine has intervened and plays a significant role in determining the mentioned characteristics [1-9].

Sometimes, Forensic medicine and cognitive archeology encounter bodies that have several parts lost or unusable due to environmental conditions or corruption [9]. Therefore, to determine the sex, the parts of the body skeleton that are more durable and resistant are selected and examined [6]. The parts of the pelvis, skull, and femur are included [4,7,9,]. Of course, other bones are checked as well, including the calcaneus, the tibia, and the occipital. The mandible bones have also become more common since the 1970s because researchers found that these bones are also due to their high resistance to Environmental erosion, predictability, an increase in hormonal secretions during puberty, and no changes after puberty, which are reliable and useful for determining sex [2, 4, 5]. Other research has shown that other bones in the body, such as the sternum, are also involved for several reasons, including its resilience and role in human stature, the important relationship between sternal bone length and height in humane and ease of imaging can be used as a reliable bone to determine sex [1, 2, 5 – 12]. Various studies have been conducted on several groups of Asian populations, including Japan, India, China, and Thailand. It was found that the sternum bone can be used as a reliable bone to determine the sex of their population. Another research has also shown that different parts of the sternum, including the length and width of the mesosternum, and the total length of the bone, can be used as a reference bone for sex determination [2, 9,12]. In related research, we may encounter cases where another bone is not available for examination and determination of gender. Therefore, we can use the sternal bone as a source of high reliability and accuracy to determine the sex of individuals. According to studies conducted in Iran, only one study has been investigated, which has studied the difference between the sternum in both sexes using dry bone, and CT scan images of the sternum have not been examined. Also, no research has been done on the modeling and achieving sternum length through other parameters (the combined length of manubrium and body, width of manubrium, etc.) [12-14]. The purpose of this study is to review and determine the gender of individuals from an anthropological point of view using the sternum bone and modeling the size of bone length using other parameters in the population of central Iran because sometimes we encounter cases where another bone is not available to examine and determine the sex. Also, according to the comparison of DNA profiling costs, the method used in this research has more advantages. In this study, it is also possible to determine the stature and height of individuals, which is impossible in the DNA method Profiling. It should be noted that CT scans of different parts of the chest can also take accurate images of the sternum with a twofold increase in advantages of this bone compared to other parts of the body.

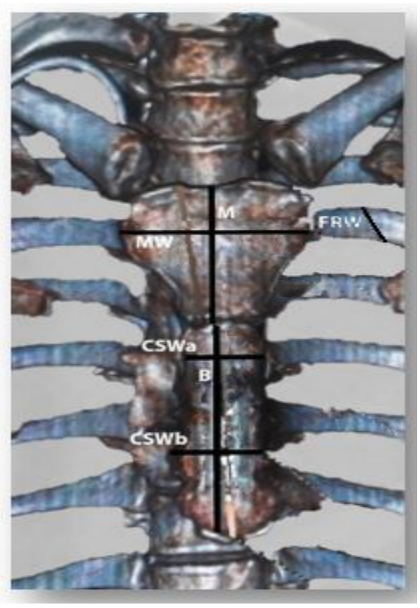
MATERIALS AND METHODS:

This original research study was conducted in 2024 in Iran, Markazi province, Arak University of Medical Sciences, and in the radiology center of Ayatollah Khansari Teaching Hospital.This study was performed on 61 three-dimensional CT scan images of the sternum, which included 38 males (62%) and 23 females (38%); CT scan images were measured according to standard osteometric techniques. For this purpose, CT scan images available in the radiology center of the hospital were used in digital format. The existing images were used by Syngo fast view software with a multi-level reconstruction method with maximum design intensity; So that all tissues, fats, and other bones except the sternum were removed. Also, by changing the intensity and applying appropriate filters, the bone was made in three-dimensional volume to be able to rotate and measure dimensions and angles.

The software output image is something like a dry bone image that can be viewed in 3D and measured using an electronic caliper, and any of its dimensions and angles can be measured. It should be noted that the scanning protocol and converting it to three-dimensional images are considered the same in all images used. Next, a table was designed and the opposite parameters were examined in three-dimensional and digital images of the bone.In total, the sternum bones were measured according to standard measurement techniques; finally, for data analysis, SPSS 23 software and logistic regression were used. Sizes that can be used to estimate the stature and height of people. The sizes examined in the taken skeletons are:

Manubrium length (M): is the longest distance from the highest point of the Manubrium to the lowest point of the Manubrium, which includes the proximal point of the Manubrium to Manubrium-mesosternal junction (Figure 1). Sternal body length (mesosternum) (B): is the longest distance between the manubriosternal junction and the mesoxiphoid (Figure 1)

Total sternum length (TL): the sum of the length of the manubrium and the length of the sternum body (M + B).



Manubrium width (MW): the width of the manubrium at the linear surface that passes through the midpoint (Figure 1). Corpus sterni width/ Body width(a): (CSWa/ BWa): The width of the sternal body at the linear plane passing between the middle of the incisura Costalis 2 and 3 from right to left (Figure 1).

Corpus sterni width/ Body width (b): (CSWb/ BWb): The width of the sternum body at the linear plane passing between the middle of the incisura Costalis 4 and 5 from right to left (Figure 1).Left fourth rib width (FRW): The distance between the top and bottom edges of the rib on the left, which is towards the costalis cavity (sternal end) (Figure 1).

Sternum index (SI): the division of the length of the manubrium by the mesodermal multiplied by 100. Or [(ML / BL) ×100] sternum surface area (SSA): is the product of [(Manubrium length + Body length) × (Manubrium width + Body width a + Body width b) ÷ 3] or [(ML + BL) × (MW + BWa + BWb)/3]

Figure 1 shows an anterior image of the thorax with a longitudinal axis of the sternum, containing various parameters measured namely M(ML), B(BL), MW, CSWA (BWa), CSWb (BWb), FRW (R4W).

RESULTS:

According to the present study, the mean sternum length (without the xiphoid process) in the Iranian population is 140.6±14.8 mm, with the shortest sternum length being 112.7 mm and the longest sternum bone being 174.6 mm. According to Table 1, the mean, minimum, and maximum parameters of manubrium length, sternum body length, sternal body width, total sternum bone length, sternal index, sternal surface, and fourth rib width are specified.
(The units for all measurements are mm)

Table 1: Manubrium length (ML), sternal trunk length (BL), sternal body width (CSWa)which is the width of the sternum at the linear plane passing through the middle of Incisura Costalis 2 and 3 from right and left, sternal body width (CSWb) which is the width of the sternum at the linear plane passing through the middle of the incisura costalis 4 and 5 from right to left., total sternum length (CL), sternal index (SI), sternum surface area (SSA), fourth rib widthLeft (FRW)

Table 1: List of Individuals with Gender and Age Details

	N	Minimum	Maximum	Mean	Std. DeviationSD (±)
M/ML (length of the manubrium)	61	37.2	61.0	45.03	±4.66
B/BL (length of the sternal body)	61	72.1	132.5	95.56	±13.09
CSWa	61	19.0	40.0	27.15	±4.50
CSWb	61	22.2	53.8	36.74	±6.38
Combined length of the manubrium and body (CL/TL)	61	112.70	193.50	153.1	±40.4
SI (sternal index)	61	31.77	63.09	47.83	±7.13
Manubrium width (MW)	61	54.1	61.8	57.95	±3.85
sternum surface area (SSA)	61	3537.41	9108.75	5829.28	1206.61
FRW (fourth rib width)	61	13.22	23.98	19.119	2.92

According to Table 2, four different models for gender prediction have been used.

Table 2: The proposed models for sex prediction

Model No1	includes parameters: M, B, MW, CSWa, CSWb.
Model No.2	contains the FRW parameter
Model No.3	includes parameters: CL, FRW.
Model No.4	includes parameters: FRW, SSA.

According to Table 3, the logistic regression model (Multiple Binary Logistic Regression) has been used to influence the independent variables M, B, MW, CSWa, CSWb on gender determination. Gender in this model is the dependent variable, And the possibility of being a male compared to being a female has been examined. (Male: 1, Female: 0)

According to Table 3, the only significant and measurable variables are M, B, and MW ($P < 0.05$). Therefore, the role of each of these parameters to predict gender is as follows:
M: with a unit increase in M, the chance of being male increases by 63.8%.
B: With a unit increase in B, the chance of being male increases by 36.0%.
MW: With a unit increase in MW, the chance of being male increases by 69.7%.

Table 3: Logistic regression results of variables

		B	S.E.	Wald	df	Sig.	Exp(B)	95%C.I.for EXP(B)	
								Lower	Upper
Step1a	**M**	.494	.210	5.53	1	.019	1.638	1.08	2.47
	B	.307	.111	7.62	1	.006	1.360	1.09	1.691
	MW	.529	.230	5.26	1	.022	1.697	1.08	2.66
	CSWa	-.082	.248	.10	1	.743	.922	.566	1.50
	CSWb	-.144	.164	.77	1	.380	.866	.628	1.19
	Constant	-73.15	24.30	9.06	1	.003	.000		

According to Table 4, the Binary Logistic Regression model has been used to influence the independent variable FRW on gender determination.According to Table 4, Therefore, a unit increase in the FRW value increases the chance of being a male by 68.5%.

Table 4: Logistic regression results of the variable FRW (fourth rib width on the left).

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step1a	**FRW (fourth rib width)**	.988	.256	14.86	1	<0.001	2.685	1.62	4.43
	Constant	-17.87	4.73	14.22	1	<0.001	.000		

According to Table 5, the Binary Logistic Regression model has been used to influence the independent variable CL, FRW on gender determination.According to Table 5, therefore, a unit increase in the CL value increases the chance of being a male by 43.1% and a unit increase in the FRW value increases the chance of being a male by 65.2%.

Table 5: Logistic regression results of the variable CL (total sternum length), FRW (fourth rib width on the left), SE (standard error)

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1a	**CL**	.358	.140	6.59	1	.010	1.431	1.08	1.88
	FRW	.975	.392	6.18	1	.013	2.652	1.22	5.72
	Constant	-66.91	23.41	8.17	1	.004	.000		

According to Table 6, the Binary Logistic Regression model has been used to influence the independent variable FRW, SSA on gender determination.

According to Table 6, therefore, a unit increase in the FRW value increases the chance of being a male by 47.8% and a unit increase in the SSA value increases the chance of being a male by 0.004%.

Table 6: Logistic regression results of the variable FRW (fourth rib width on the left), SSA (sternum surface area)

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1a	**FRW**	.908	.318	8.15	1	.004	2.478	1.32	4.62
	SSA	.004	.001	6.26	1	.012	1.004	1.00	1.00
	Constant	-36.15	11.72	9.50	1	.002	.000		

According to Table 7, in general, the prediction accuracy of Model 1 to determine genderis91.8%., Model No.2 ,90.2%, Model No. 3 ,96.7٪ , Model No. 4,93.4%.The accuracy of prediction of each model by gender is also specified. The best model for predicting gender is a model that includes CL and FRW parameters (Model No. 3); because this model has the highest accuracy of prediction for females and males and also the highest accuracy in general. Accuracy rate ٪96.8% and (R^2= 0.910)

Table 7: shows the prediction accuracy of each model in females, males, and in general, as well as the coefficient of determination (R^2) and compares the accuracy of each model (R^2: Nagelkerke R Square)

Model	R^2	Accuracy of sex determination in females (%)	Accuracy of sex determination in male (%)	Accuracy of sex determination in total (%)
1	.877	87.0	94.7	91.8
2	.664	82.6	94.7	90.2
3	.910	95.7	97.4	96.7
4	.885	91.3	94.7	93.4

According to Table 5, the results of logistic regression for model 3 can be seen.According to this table, the logistic regression equation for model 3 is as follows:

Li=-66.9+0.358(CL)+0.975 (FRW). In this equation (Li) is a linear function of CL, FRW.

In this study, the measure of B (mesosternum) has the highest correlation with the total length of the sternum (R = 0.951**), In addition, the SSA measure has the highest correlation with the total sternum length after mesosternum (R = 0.892**). In this study, the mean length of the manubrium has a moderate relationship with the total length of the sternum (R = 0.503**).In this study, the mean width of the manubrium has a positive strong correlation with the total length of the sternum (R = 0.627**)In the present study, CSWa and CSWb had a moderate relationship with total sternal length (R =0.492**) and (R =0.524**).

DISCUSSION:

The present study was performed on 61 CT scan images of the sternum. In this study, the length of the sternum bone and 7 other parameters as well as the width of the fourth rib were measured. The relationship between these parameters and the full length of the sternum was investigated. The results of this study showed that generally, the mean total sternum length in the population of Iran and females and males(70.29mm) is less than that in Turkey(73.25mm), and the population in Turkey has larger dimensions compared to the Iranian population [19].

In the study population in Turkey, the size of the mesosternum is smaller than in Iranian [19]. Geography, diet, and race may be the reasons for this difference in skeletal growth. Therefore, using a logistic regression model to estimate the total length of the sternum and predict sex in the Iranian population is useful. According to the results, the average length of the manubrium in this study is less than the study population in Turkey [19]. In the study done in Turkey, this measure is more than in females but in males, this measure is less [19]. In forensic medicine, the manubrium plays a key role in determining the length of the sternum and, in some cases, in designing the prosthesis for this bone; because this part of the bone has more bone strength and density than other parts of the sternum and is, therefore, more accessible. Because the sizes of all parameters in males and females are different, it is not possible to use the sizes of one sex to predict the other sex. This study showed that in males, such as females, Manubrium length (M), CSWa, SI, and FRW were not related to sternum length. In the present study, many parameters have a positive relationship with the length of the sternum, and if there is a part of the sternum and the fourth rib, the total length of the sternum and gender can be determined. It is also possible to predict the stature of the person based on the length of the sternum. To determine the ratio of human height and stature with sternum length, more studies on different populations and races are needed to achieve more accurate information to achieve these goals (predicting the height and stature of individuals based on sternum length and sternum length determination by using its other parameters).

Limitations

This study, while comprehensive in its analysis of sternum-based sex determination, has certain limitations. First, the sample size, consisting of 61 individuals from a central Iranian population, may not fully represent the broader population's variability, limiting the generalizability of the findings to other regions or ethnic groups. Additionally, while the study exclusively focused on the sternum and fourth rib, it did not account for potential variations arising from other skeletal elements, which might affect the accuracy of sex determination when used in combination. Another limitation is the reliance on three-dimensional CT scans, which, although accurate, may not always be available in forensic settings, potentially limiting the practical application of these models in resource-constrained environments. Moreover, the study did not explore the effects of factors such as age, nutritional status, or pathological conditions on sternum dimensions, which could influence measurements and affect model reliability. Finally, while the models demonstrated high accuracy, they require validation in larger and more diverse populations to ensure broader applicability in forensic anthropology.

CONCLUSION:

This study demonstrates the potential of using sternum measurements as a reliable tool for sex determination and total sternum length estimation in forensic anthropology, particularly when other skeletal remains are unavailable. By developing accurate logistic regression models, with Model 3 showing the highest predictive power (96.7%), the findings emphasize the significance of the combined sternum length and fourth rib width as key parameters in distinguishing sex. The study not only highlights the utility of the sternum in forensic cases but also addresses a critical gap in population-specific data, particularly for the Iranian demographic. Given its practicality, cost-effectiveness, and non-invasive nature, this method offers a viable alternative to DNA analysis, enhancing the accuracy and efficiency of forensic investigations. While further research is needed to refine these models and expand their applicability across diverse populations, this study lays a strong foundation for advancing sex determination techniques in anthropology and forensic medicine.

Declarations

Ethics approval and consent to participate: This manuscript was approved by the Arak University ethics committee. (Ethical Code: IR.ARAKMU.REC.1400.343).

Consent for publication: All authors have consent for publication

Availability of data and material: All data generated or analyzed during this study are included in this article. Further inquiries can be directed to the corresponding author.

Conflict of interests: none

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