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Original Article

A Study for the Determination of Sex by Multidetector Computed Tomography of Sternum using Discriminant Function and Logistic Regression

CrossMark

دراسة لتحديد الجنس عن طريق التصوير المقطعي المحوسب المتعدد الكاشف لعظم القص باستخدام وظيفة التمايز والانحدار اللوجستي

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Abstract

Post-mortem investigations of skeletal remains as well as radiographs from living individuals provide useful information for the discrimination of sex. Our study aimed to find out a mathematical model to differentiate gender based on greater degree of accuracy than the anthropological measures taken from the sternum obtained from cadaver dissection.

The study was performed on 108 adults who were brought for examination of chest due to various medical reasons. Their age ranged between 18 and 80 years.The cases were selected randomly after considering the inclusion and exclusion criteria. Sternal measurements were taken by studying CT (Computed Tomography) scans.

Of these cases, 73 were males and 35 were females. The discriminant function equation (Df) = 0.071 Manubrial Length +0.075 Manubrio-Sternal Length +0.036 Width at S1 +0.037 Width at S3 -11.367 (Constant). Overall 80.6% of the sample was correctly classified into their group.

This study revealed that measurements from CT scan of sternum can be used to differentiate between sex of individuals which adds to a great advantage in forensic anthropology.

المستخلص

توفر الفحوص التي تجري بعد الوفاة لبقايا الهيكل العظمي وكذلك التصوير الشعاعي للأفراد الأحياء معلومات مفيدة للتمييز بين الجنسين. وكان الهدف من هذه الدراسة معرفة نموذج رياضي لتمييز الجنس تعتمد بدرجة أكبر الدقة مقارنة بالقياسات الأنثروبولوجية المأخوذة من عظم القص الذي تم الحصول عليه من تشريح جثة.

أجريت الدراسة على ١٠٨ من البالغين الذين تم إحضارهم لفحص الصدر بسبب أسباب طبية مختلفة، وتراوحت أعمارهم بين ١٨ و٨٠ سنة. واختيرت الحالات عشوائياً بعد النظر في معايير الإدراج والاستبعاد. وقد أخذت قياسات من منطقة القص sternal من خلال دراسة التصوير المقطعي (CT) ومسح الصور وإعادة تهيئتها. وكان ٧٣ من هذه الحالات من الذكور و٣٥ من الإناث.

معادلة دالة التمايز هي: (Df) = 0.071 Manubrial Length +0.075 Manubrio-Sternal Length +0.036 Width at S1 +0.037 Width at S3 -11.367 (Constant). عموماً تم تصنيف ٨٠,٦ ٪ من العينة بشكل صحيح في مجموعتهم.

كشفت هذه الدراسة عن أن القياسات من الأشعة المقطعية لعظم القص يمكن استخدامها للتمييز بين جنس الأفراد ما يضيف إليها ميزة كبيرة في علم الأدلة الجنائية.

Keywords: *Forensic Science, Sternum, radiology, sex estimation, CT scan thorax, identificating.*

الكلمات المفتاحية: علوم الأدلة الجنائية، منطقة قص العظم، الأشعة، تقدير الجنس، الأشعة المقطعية لمسح الصدر، تحديد الهوية.

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1. Introduction

In forensic investigation, identification plays one of the most important parts. Bones when they are available are an important element of identification. There are number of differences between males and females among which skeletal differences along with hormonal and physiological differences are in total known as sexual dimorphism. When a skeleton is partially recovered, it is necessary that the diagnosis can be made from the available parts. In these cases, fine differences also assume importance [1].In various cases of dubious identity, where fragments of bones or only some of the bones are found; it becomes important to identify the individuals from these remnants. The sternum plays an important role being a flat bone which can survive a great degree of compression. Sex determination is well studied in forensic medicine. Determination of sex plays an important role in the process of identification for medico-legal cases [2].Post-mortem investigations of skeletal remains as well as radiographs from living individuals provide useful information for the discrimination of sex [3-9].Explosions, putrefaction, traumatic damage, and geographic factors may hinder investigations of the pelvis and skull bones. However, the integrity of the sternum is well preserved even in advanced skeletal destruction. Differences in ethnic groups are prominent as shown by studies as early as Hyrtl's and Ashleys [10].The sternum has drawn considerable attention in studies related to sexual dimorphism [11-14].

Previously studies on sternal lengths for sex determination was done on various populations like Spaniards [15], South African Blacks [16], Japanese [17], Egyptian [18]. Studies on sternal length for sex determination were done mostly on cadaveric dissections and recently some studies have utilized radiological measurements also. The accuracy of radiological measurements which have been done on different ethnic populations can only be utilized in practical forensic medicine when we have obtained validated data from different populations of the world. In this relevance, the authors have named in the present work to assess the reliability of HRCT of chest measurements of sternum and to build a mathematical model for accurately predicting sex of an individual from measurement of sternal parameters from multislice computed tomography.

2. Methodology

2.1 Study Subjects

Multidetector Computed Tomography (MDCT) images were taken from 108 subjects, of which 73 were male and 35 were female, between the age group of 18 and 80 years. The cases were randomly selected from the general population who came for HRCT Scan of thorax for various medical conditions and informed consent was obtained from them before participation in this study. Ethical clearance (No. CM/CNMC/2017) was taken from Ethics Committee of Calcutta National Medical College; no additional radiation exposure was given to study subjects. Patients showing congenital, pathological or traumatic lesions of the chest wall were excluded.

2.2 Methods

The CT scan was performed on 16 slice Alexion Machine (Toshiba, Japan)at the CT scan centre of Calcutta National Medical College campus. A routine thoracic CT protocol was followed. All scans were obtained with the following parameters: tube voltage 120 kV, effective mA 120 and slice thickness 1mm. All images were transferred to a commercially available workstation. On the workstation, multiplane reformatting (MPR) of images in the sagittal and coronal planes was obtained using commercially available software (RadiAnt DICOM Viewer).

Our study was conducted at the CT Scan Centre of Calcutta National Medical College from June, 2018 to August, 2018 on 108 subjects of age ranging from 18 years to 80 years.

The following measurements were taken for this study:

- Manubrium length (ML): the distance from the jugular notch to the sagittal midpoint of the manubriosternal joint (Figure-1).
- Mesosternum length (MSL): the distance from the sternal angle to the sagittal midpoint of the xiphisternal joint (Figure-1).
- Sternebra 1 width (S1W): the distance between the left and the right first sternebra (depressions between the articulation notches for the second and third costal cartilage) (Figure-2).
- Sternebra 3 width (S3W): the distance between the left and right third sternebra (depressions between the articulation notches for the fourth and fifth costal cartilage).
- Sternal index: (manubrium length/mesosternum length) x 100.

2.3 Statistical Analysis

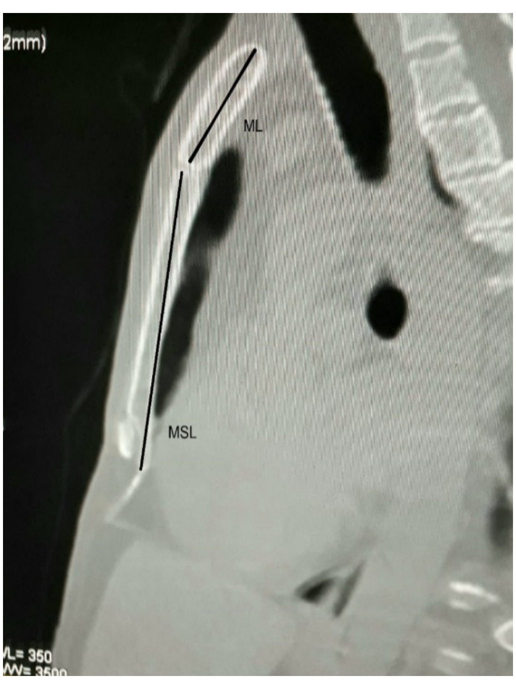

Figure 1- *Sagittal reformatted MDCT image shows the sagittaldimension of the manubrium. (ML) and the sagittal dimension ofthe mesosternum (MSL).*

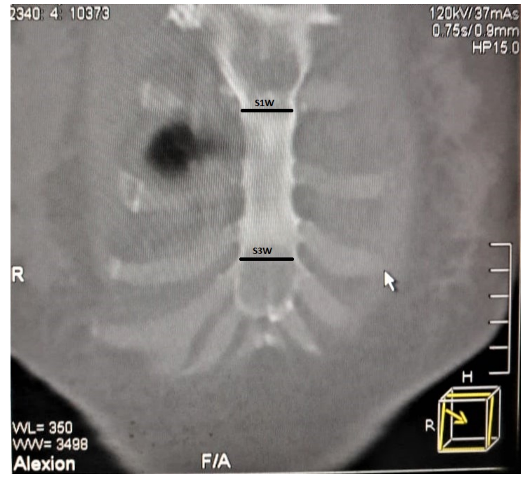

Figure 2- *Coronal reformatted MDCT image shows sternebra 1width (S1W) and sternebra 3 width (S3W)*

The results were statistically analyzed using Statistical Package for Social Sciences (SPSS, version 25). Results were expressed in the form of maximum & minimum values, mean, standard deviation, chi-square test, discriminant function and logistic regression analysis.

3. Results

Discriminant function was performed on the data entering all the variables together with sex as the grouping variable. The variables were entered together as the sample size was 108 of which 73 were males and 35 were females. The mean and standard deviation of the variables are seen in the chart in Table-1. ROC curve was first done on the variables to see the discriminating power of the variables. The Wilk's lambda for the model is 0.621 which signifies a good discriminating power of the model as shown in Table-2. The Eigen value for this model is 0.609. Relative contribution of each variable to the discriminant equation is shown in Table-2. The discriminant function equation is, Df=0.071 Manubrial Length +0.075 Manubrio-Sternal Length +0.036 Width at S1 +0.037 Width at S3 -11.367 (Constant) (Table-3).The cutoff point is 0.535 -1.117/2 = -0.291 as shown in Table-4. So above this value -0.291, the cases are male. Below this value -0.291, the cases are female. Overall 80.6% of the sample was correctly classified into their group by a model as shown in Table-4. At the individual group level, 80.0% of females and 80.8% of male were correctly classified. Cross-validated results showed 79.6% of the cases correctly classified by this model. After the results were used t get a discriminant equation, the formula was used on a separate sample of 20 cases to validate the results.

When age was correlated with the measured variables none of them showed any significant correlation as shown in Table-6. So, age could not be predicted with accuracy from this preliminary study. On doing logistic regression with the given variables we found that the Nagelkerke R Square was 0.551 (Table-5). The Hosmer and Lemeshow Test were also significant. The model was correctly able to predict sex overall in 82.4% cases, 87.7 in males and 71.4% in females (Table-6). This shows a good fit for this model (Table-7).

4. Discussion

Usually there is a considerable variability in the degree of sexual dimorphism even within closely related populations. This is due to genetic environmental and various socio-economic factors. It is therefore possible to produce images that are parallel, perpendicular or at an angle that suits the shape of the bone to obtain a one-to-one replicate image. Using the newest technology of MSCT makes it possible to form images that are very similar to the original of the bone shape that needs to be measured, in any axis and in a rapid manner [19]. The findings of the present study reemphasise the population variability in sternal dimensions (Table-8). When compared to the study by Ramadan et al [19]. Discriminant analysis of sternal parameter is a successful method of sex estimation studies as has been proved in previous studies[15] by Macaluso and Lacuna, on Spanish population and Western Australian sample done by Franklin et. al. [19], on comparison with Bongiovanni and Spradley, who found the frequency of 61% for males and 55.6% for females which is in variation from our study. Direct measurement analysis can usually be performed on skeletal remains. However sometimes it may not be possible, Therefore the clinical diagnostic importance of radiological methods like CT and MRI which have high resolution and in which 3D images can be obtained can be used for morphometric studies. In 2012 the Royal College of Radiologists reported a 25.5% increase in radiological images in comparison to 2004/05 with 86% increase in use of CT and 125% use in MRI [20]. Thus, an increase in number of radiological based studies can be used for forensic anthropologic studies due to increase in radiological data base. Population specific studies concluded that mean sterna measurements in South Africans [16] and Indians [14, 21-23] were lower than that of their European [24-28], US [7,29] and Canadian counterparts. Like studies in North and West Indian population reported larger female sternum measurement in North India and larger male sternum measurement in Western India [30,21-23]. Our study which has been done on an ethnically single population has shown difference between the west and north Indian population. We found that the accuracy of predicting sex in our study was 80.0% in males and 80.8% in females which Ramadan et. al. [19] was 73% and 80.6% respectively. When compared to male population, the female population generally have a smaller sternum, which is similar from the findings from previous studies like Japanese [17], Turks [19], Spaniards [15], South Africans [16], West Australians and also in other areas in India like Changani et al. [31], 2014. Our study has been conducted in the eastern Indian population. All variables in this study had significant sexual dimorphism.

At the individual group level, 80.0% of females and 80.8% of male were correctly classified. Cross-validated

Table 1- *Synopsis of statistical parameters of sternal measurements expressed in mm.*

Sex		Sternal Index	ML	MSL	S1W	S3W
Male	Mean	56.10	48.22	87.84	25.31	26.66
	N	73	73	73	73	73
	Std. Deviation	10.252	5.166	11.783	4.371	5.438
	Minimum	33	40	50	17	15
	Maximum	98	60	124	49	39
Female	Mean	63.11	44.15	71.22	23.51	25.12
	N	35	35	35	35	35
	Std. Deviation	9.333	5.253	11.177	5.915	9.969
	Minimum	49	22	27	15	16
	Maximum	86	54	89	40	76
Total	Mean	58.37	46.90	82.45	24.72	26.16
	N	108	108	108	108	108
	Std. Deviation	10.453	5.511	13.934	4.968	7.212
	Minimum	33	22	27	15	15
	Maximum	98	60	124	49	76

Table 2- *Synopsis of the Canonical Discriminant Function Coefficients showing the degree to which, the variables contribute to the equation.*

Variables	Coefficient
ML	0.071
MSL	0.075
S1W	0.036
S3W	0.037
(Constant)	-11.367
Unstandardized coefficients	

ML, Manubrium length; MSL, Mesosternum length; S1W, Sternebra 1 width; S3W, Sternebra 3 width

Table 3- *Synopsis of the Group Centroid which provides the cut off point for the differentiation of sex.*

Sex	Function coefficient
Male	0.535
Female	-1.117
Unstandardized canonical discriminant functions evaluated at group means	

Table 4- *Classification and cross validation results showing the cross validation and distribution of sex by this Discriminant Equation.*

		Sex	ML		Total
			Male	Female	
Original	Count	Male	59	14	73
		Female	7	28	35
	%	Male	80.8	19.2	100.0
		Female	20.0	80.0	100.0
Cross-validated[b]	Count	Male	58	15	73
		Female	7	28	35
	%	Male	79.5	20.5	100.0
		Female	20.0	80.0	100.0

Table 5- *Model Summary of logistic regression.*

Model Summary	
Cox & Snell R Square	Nagelkerke R Square
0.395	0.551

Table 6- *Classification Table for Logistic Regression.*

Observed		Predicted		
		Sex		Percentage Correct
		Male	Female	
Sex	Male	64	9	**87.7**
	Female	10	25	**71.4**
Overall Percentage		0.395		**82.4**

Table 7- *Logistic regression model predicting sex in Indian (Bengali) population.*

Model R	R Square	Adjusted d R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
				R Square Change	F Change	df1	df2	Sig. F Change	
0.615	0.379	0.354	0.378	0.379	15.688	4	103	0.000	2.350

results showed 79.6% of the cases correctly classified by this model. This is different from those in Japanese (90.5%) [17], Western Australians (84.5%), South Africans (86.9%), North Indians (84.8%). Collectively all the results indicate that sternum can be used as a good indicator of sex determination in most regional populations.

The female to male ratio in the current work was 1:2 which is different from that reported by Wadhavan et al, 2009 [32] and Darwish et al, 2017 [18] where the ratio was 1:1. In this regard, there is an inequality between division of both sexes. Puttabanthi et al, 2012 [33] stated that the lengths of manubrium and sternal widths act as a good discriminator of female sterna. Our study found similar findings and agreed with them. On the other hand, Osunwoke et al, 2010 [27] who conducted the study on southern Nigerian population stated that the length of the body of sternum was sexually dimorphic whereas the manubrial length was not sexually dimorphic.

Table 8- *Sternal variations between the study population and other populations*.

Study	Population	Manubrium length (mean)		Mesosternum length (mean)		Sternebra 1 width (mean)		Sternebra 3 width (mean)	
		Male	Female	Male	Female	Male	Female	Male	Female
Chowdhuri et al. (2019) Present Study	Eastern Indian (Bengali)	48.22	44.15	87.84	71.22	25.31	23.51	26.66	25.12
Macaluso et al (2014)	Spaniards	51.85	45.85	106.25	87.77	28.31	24.68	35.36	30.15
Macaluso et al (2010)	South African Black	48.51	43.85	98.74	81.43	24.95	21.83	31.77	27.30
Torimitsu et al (2015)	Japanese Cadavers	50.21	46.99	101.18	86.27	29.16	24.89	32.93	27.17
Darwish et al (2017)	Egyptian adults	46.40	37.60	103.00	86.70	28.70	25.10	35.10	29.30
Changani et al (2014)	Gujarat	-	-	-	-	27.80	23.76	32.25	27.50
Puttalbanthi et al (2010)	Unknown human skeletal remains	47.48	21.68	92.36	88.95	53.32	27.73	33.41	30.64
Ramadan et al (2010)	Turkish patients	53.90	50.30	100.70	85.10	28.70	25.20	34.90	30.70
Ekizoglu et al (2010)	Turkish patients	52.50	48.20	104.90	89.10	28.80	25.00	34.10	30.20

The calculated discriminant functions for a combination of three measurements, single measurement and indices, yielded an overall accuracy ranging from 63.3% to 90.6% [34] from different models that can be used to determine sex from these measurements performing logistic regression analysis.The accuracy of sex determination was 84.7% and 81.8% taking into account only sternal measurements with general accuracy rate being 82.9% [35].A series of new forensic standards for the estimation of sex in that population were outlined; cross-validated expected classification accuracies range between 77.2 and 84.5%amongst the Australian population [36].

This study conducted in an ethnic regional population has shown similarity in predictability to studies conducted in other populations like Japanese, South Africans, Western Australians, Spaniards, but has also shown a variation which is indigenous and regional in character which highlights the necessity of such a study in an ethnic population like Bengalis who have some ethnic characters which are independent from other Indian populations. Therefore, this study has shown that it can be used for determination of sex in Bengali population.

4. Conclusion

When fragmentary remains are found as is often in cases of disasters or mass graves, it is difficult to find whole bones, especially of transverse flat bones like sternum. So, it is difficult to calculate stature or estimate sex from such fragmentary remains. Since our study uses a tool like MDCT for measurement of the lengths of the parts of the sternum, it should be effective to a great degree in finding out such data as sex because of its accuracy of measurement and predictability through a mathematical model with lesser chances of error. Integration of all the anthropological data from regional populations can be utilize in development of data base, which can be utilized for various image-based techniques which can augment or may be in future replace traditional autopsy.

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