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Study of Sex Estimation of the Sternum by Multi-Slice Computed Tomography and Digital X-ray in Libyan Population

Esmail M. A. Abdualhadi*, Nagah I. Hegazy, Ghadeer M. M. Abdelaal
Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine, Zagazig University, Egypt
***Corresponding Author:** Esmail Muftah Alhadar Abdualhadi, **Mobile:** (+20)12925916954,
Email: ismailabdualhadi@gmail.com

ABSTRACT

Background: Currently, sex identification based on sternum measurement is accomplished either by directly measuring dried sternums from cadavers or by indirectly measuring pictures obtained from chest radiography.

Objective: The aim of the current work was to obtain an accurate estimation of sex in the forensic identification process by sternal measurements using digital X-ray versus multi-slice CT (MSCT).

Subjects and methods: This cross-sectional comparative study included a total of 116 Libyan populations stated in Tripoli (58 males and 58 females) and conducted at Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine at Zagazig University, Egypt, Al Khums Teaching Hospital, Tripoli Medical Center, Zliten Medical Center and Center for Judicial Expertise and Research, Libya. The included subjects were divided into two groups: Group I: included 58 males. and Group II: included 58 females. Sternal measurements using digital X-rays and MSCT scan were done for both groups.

Results: ROC assessment showed that manubrium length (ML), mesosternum length (MSL) and sternal index (SI) were the most specific (specificity 54.4, 69, and 71.7% respectively) and the most sensitive (sensitivity 58.6, 69, and 62.1% respectively). Regarding the comparison of different measured parameters of the sternum measurement using MSCT scanning between male and female; the current study demonstrated a statistical significance decrease in ML, manubrium width (MW), MSL, sternebra 1 width (S1W), and sternebra 3 widths (S3W) among male compared to female (< 0.05). The means of ML, and MW were significantly higher among males, while the mean SI was significantly higher among females.

Conclusion: It could be concluded that MSCT scanning is superior to digital X-ray radiographs in sex identification and is a useful technique for imaging the sternum.

Keywords: Multi-Slice Computed Tomography, Sex Estimation, Digital X-ray, Sternum

INTRODUCTION

Identification is a crucial step in any forensic inquiry. Bones, if found, are a crucial part of the identifying process. Sex dimorphism refers to the many biological, psychological, and anatomical distinctions between males and females, including but not limited to differences in skeleton structure, hormone levels, and physiological processes. Only if enough of a skeleton is found and examined can a proper diagnosis be established from the pieces that have been found. In such situations, subtle distinctions become crucial [(1)].

In cases of challenging identification, such as dismemberment, mutilation, or explosion, determining a person's sex through an analysis of their bones using metric measures or radiographic imaging is a vital step [(2)]. The sternum and the fourth rib of humans may exhibit morphological and metric differences that indicate sexual dimorphism [(3)].

The sternum sits smack dab in the middle of the chest's front. From upper to lower, it is made up of the manubrium, the main body (mesosternum), and the xiphoid process. The manubrium articulates with the torso at the manubriosternal joint and features a jugular notch at its upper border. The top of the xiphoid process articulates with the bottom of the body [(4)].

Currently, sex identification based on sternum measurement is accomplished either by directly measuring dried sternums from cadavers or by indirectly measuring pictures obtained from chest radiography [(5)].

Damage to the cadaver necessitates maceration, which prevents the use of conventional osteometric techniques. Maceration of the retrieved remains is a challenging process because of the workload and time restrictions in the event of a terrible disaster. Bones aren't necessary if you use computed tomography or radiography, for example. In a forensic investigation, these radiographs allow for identification of partially decomposed bodies without maceration [(6)].

Validated data from a variety of populations around the world are necessary before radiological measurements performed on people of different races can be used in actual forensic medicine [(7)]. New methods of cross-sectional imaging have had a profound impact on forensic medicine. Virtual anthropology using 3D imaging methods like computed tomography (CT) provides a high-resolution, high-quality view of virtually any anatomical or pathologic structure [(8)].

Postmortem exams are increasingly employing the MSCT (multi-slice computed tomography) method. A virtual autopsy could be used in communities where performing one would be frowned upon or outright outlawed, allowing for good medical and legal practise to be carried out without compromising on morals [(7)].

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This study was aimed to obtain an accurate estimation of sex in the forensic identification process by sternal measurements using digital X-ray versus multi-slice CT.

SUBJECTS AND METHODS

This cross-sectional comparative study included a total of 116 Libyan populations stated in Tripoli (58 males and 58 females) and conducted at Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine at Zagazig University, Egypt, Al Khums Teaching Hospital, Tripoli Medical Center, Zliten Medical Center and Center for Judicial Expertise and Research, Libya. This study was conducted between July 2021 to December 2021.

Inclusion criteria:

- Age between eighteen and thirty years.
- Males and females.
- From Libya.

Exclusion criteria:

- Age < 18 or > 30 years.
- Previous history of sternal fractures or malunion.
- Atypical development of the sternum.
- Pathological fusions of the sternum and sternal surgical intervention.

The included subjects were divided into two groups; **Group 1** includes 58 males, and **Group 2** includes 58 females. Sternal measurements using digital X-rays and MSCT scan were done for both groups.

Apparatus:

I. Digital X-ray parameters:

Each subject had a digital X-ray taken of their chest from lateral view. To establish uniformity in imaging, the sternum was visualized in lateral view [9]. A routine thoracic digital X-ray protocol was followed:

- **Manubrium length (ML):** From the top of the manubrial border to where it meets the sternal body (at the sternoclavicular joint).
- **Mesosternum length** (**MSL**): how far sagittally the xiphisternal joint is located from the sternal angle.
- **Sternal index (SI)**: (manubrium length/mesosternum length) ×100.

II. CT scanning parameters:

In the Radiology Departments of Al Khums Teaching Hospital, Tripoli Medical Center, and Zliten Medical Center, all patients were scanned using 16 Multi Detector Computed Tomography (MD-CT) Scanner. Images from this high-quality equipment were formatted and improved to ensure accurate and repeatable measurements.

Morphometric Image Analysis

The gender was determined by measuring the circumference of the sternum (3-D MDCT imaging). Using the Mouse-Driven technique, measurements were taken with Dicom viewer software, which came preinstalled on the device.

All MDCT exams now follow the same set of rules. Within a single breath-hold, patients were scanned from the thoracic inlet to the lung bases. The beam pitch coefficient of the scans was 1.5, and they were obtained with a collimation of 16 mm 1 mm and a table feed of 6 mm per 0.8 seconds of scanner rotation. The following measurements were taken in accordance with **Bass's** [10] guidelines:

- **Manubrium** length **(ML):** how far the manubriosternal joint is from the jugular notch along the sagittal plane.
- **Manubrium width (MW):** a measure of breadth taken where a line extending from the center of an incisura costail on either side meets.
- **Mesosternum length (MSL):** how far sagittally the xiphisternal joint is located from the sternal angle.
- **Sternebra 1 width (S1W):** how far apart first sternum is on the left and right.
- **Sternebra 3 width (S3W):** the left and right third sternal distance.
- **Sternal index (SI):** (manubrium length/mesosternum length) × 100.

Using sagittal images, we calculated ML and MSL; using coronal images, we calculated S1W and S3W.

***Ethical Consideration*:**

This study was ethically approved by Zagazig University's Research Ethics Committee (ZU- IRB #7021/27-6-2020). Written informed consent of all the participants was obtained after being informed of the research's goals. The study protocol conformed to the Helsinki Declaration, the ethical norm of the World Medical Association for human testing.

Statistical analysis

IBM SPSS was used, namely version 27.0. The range of values, from minimum to maximum, as well as the central and quartile values, were employed to describe numerical information. The acquired results were deemed statistically significant at the 5% level. This study made use of a Chi-square test. P value < 0.05 was considered significant.

RESULTS

No statistically significant differences were found among groups as regard age. there was a statistically significant increase in all parameters among male compared to female except SI which showed statistically significant decrease among male compare to female **(Table 1).**

Table (1): Demographics, and comparing males and females among different measured parameters of the sternum by X-ray data of the studied groups:

Variable	**Group I (Male) (*n*=58)**	**Group II (Female) (*n*=58)**	***t***	**P**
Age: (years) *Mean ± SD* *Range*	24.31 ± 3.93 18-30	24.45 ± 3.57 18-30	0.20	0.48 NS
Variable	**Group I (Male) (n=58)**	**Group II (Female) (n=58)**	***t***	**P**
Manubrium length (ML): **Mean ± SD** **Range**	53.19±7.07 40-68	50.09±6.62 34-65	2.44	0.02*
Mesosternum length (MSL): **Mean ± SD** **Range**	84.03±16.32 50-110	74.97±16.94 31-95	2.94	0.004*
Sternal index (SI): **Mean ± SD** **Range**	53.71±6.60 41-65	56.60±5.81 44-72	2.51	0.01*

t: Independent t test

There was a statistically significant increase in all parameters among male compare to female except SI which showed statistical significant decrease among male compare to female **(Table 2).**

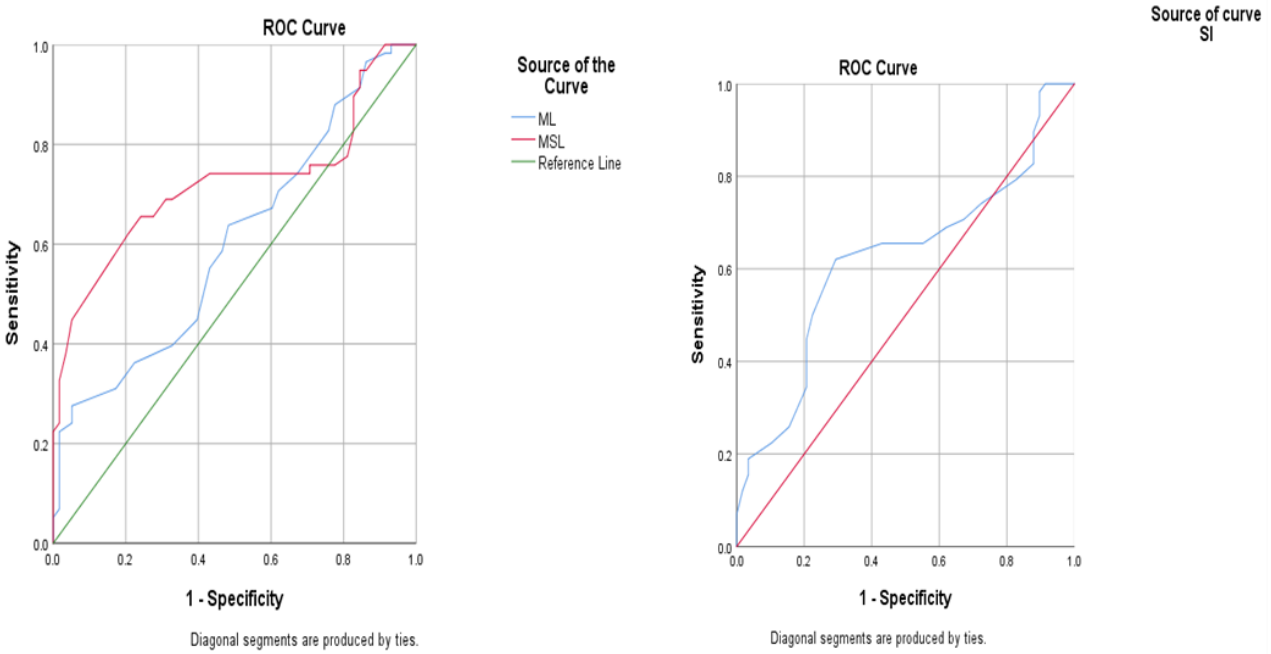
Table (2): comparing males and females among different measured parameters of sternum measured by CT:

Variable	**Group I (Male) (*n*=58)**	**Group II (Female) (*n*=58)**	***t***	**P**
Manubrium length (ML): *Mean ± SD* *Range*	50.81±6.6 40-65	43.16±9.27 24-59	**5.12**	**<0.001****
Manubrium width (MW): *Mean ± SD* *Range*	60.81±4.08 52-70	52.79±6.78 39-66	**7.71**	**<0.001****
Mesosternum length (MSL): *Mean ± SD* *Range*	83.38±13.4 52-107	63.28±16.75 28-92	**7.14**	**<0.001****
Sternebra 1 width (S1W): *Mean ± SD* *Range*	26.22±6.55 15-45	22.91±5.88 12-38	**2.87**	**0.005***
Sternebra 3 width (S3W): *Mean ± SD* *Range*	28.21±6.10 15-41	25.41±6.56 12-36	**2.38**	**0.02***
Sternal index (SI): *Mean ± SD* *Range*	58.41±6.56 45-69	63.21±6.10 50-76	**4.03**	**<0.001****

At a cut off, more than 51.5 mm, ML had a 61.2% success rate in identifying male sex, MSL had a 69.2% success rate, and SI had a 66.4% success rate in identifying male sex **(Table 3, Fig. 1).**

Table (3): Validity of sternal measurement by X-ray in sex determination:

Variable	Cut off	AUC (95% CI)	Sens.	Spec.	PPV	NPV	Accuracy	P
ML:	**>51.5**	**0.60 0.50-0.71**	58.6	54.4	**61.8**	**64.9**	61.2	**0.04***
MSL:	**>86.5**	**0.72 0.62-0.82**	69	69	**69**	**69**	69	**<0.001****
SI:	**<54.5**	**0.62 0.52-0.73**	62.1	71.7	**67.9**	**65.1**	66.4	**0.03***



(A) **(B)**

Figure (1 a,b): Roc-curves for validity of sternum parameter measured by X-ray in sex determination.

The accuracy of ML in determination of male sex at cut off more than 46.5 mm was 66.4%, of MW at cut off more than 57.5 mm was 75.9%, of MSL at cut off more than 76 mm was 75%, of S1W at cut off more than 23.5 mm was 63.8%, of S3W at cut-off more than 26.5 mm was 62.9% and of SI at cut off less than 60.5 mm was 69% **(Table 4, Fig. 2).**

Table (4): Validity of sternal parameters measured by CT in sex determination:

Variable	Cut off	AUC (95% CI)	Sens.	Spec.	PPV	NPV	Accuracy	P
ML:	**>46.5**	**0.73 0.63-0.83**	72.4	60.3	**64.6**	**68.6**	66.4	**<0.001 ****
MW:	**>57.5**	**0.84 0.77-0.91**	81	70.7	**73.4**	**78.8**	75.9	**<0.001 ****
MSL:	**>76**	**0.84 0.76-0.91**	79.3	70.7	**73**	**77.4**	75	**<0.001 ****
S1W:	**>23.5**	**0.66 0.56-0.76**	65.5	62.1	**63.3**	**64.3**	63.8	**0.003***
S3W:	**>26.5**	**0.62 0.52-0.72**	65.5	60.3	**62.3**	**63.6**	62.9	**0.03***
SI:	**<60.5**	**0.69 0.60-0.79**	67.2	70.7	**69.6**	**68.3**	69	**<0.001 ****

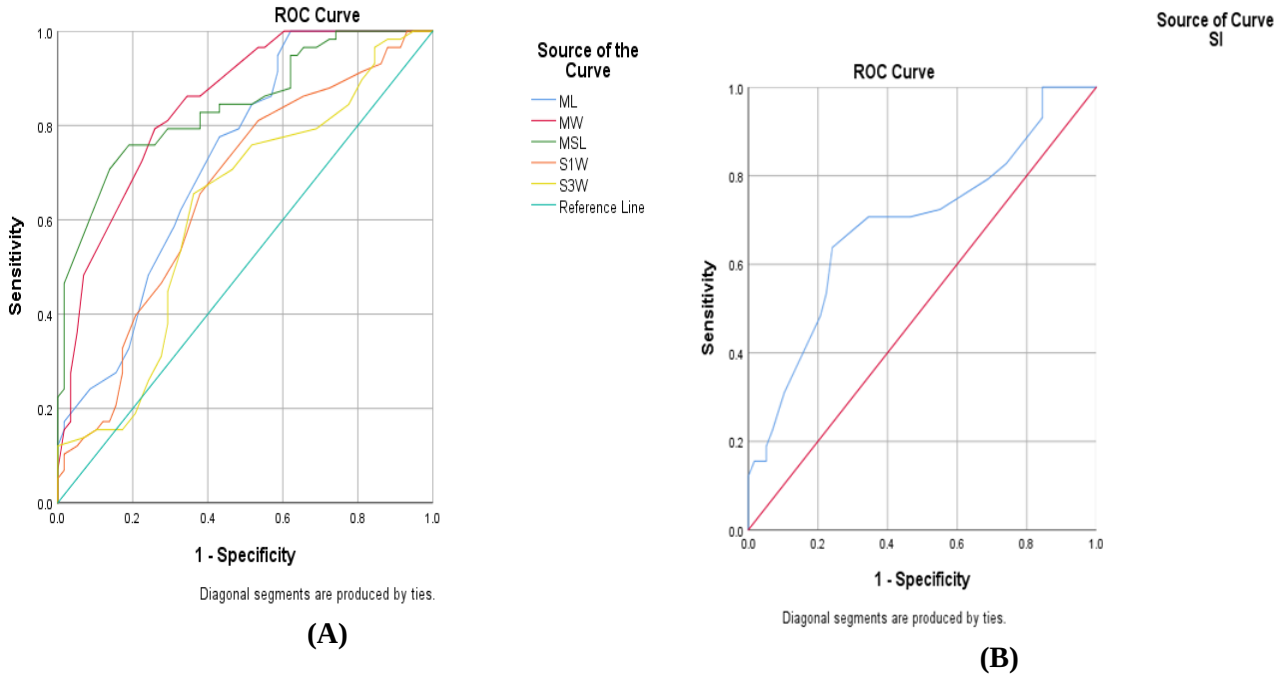


Figure (2 a,b): Roc-curves for validity of sternal parameters measured by CT in sex determination.

The results of the sternal parameter stepwise discriminant analysis are shown in the table: MSL and SI; cross-validated sex classification accuracy was 57.8 %. This formula can be used to predict sex: **Sex=** 2.68 **+ (0.05**×**MSL) + (-0.12**×**SI)**

There is a 57.8 percent chance that the sternum in question belongs to a male if the result is greater than or equal to 0.47, and a 41.8 percent chance that it belongs to a female if the result is less than or equal to 0.47 (Table 5).

Table (5): Stepwise discriminant analysis of sternal parameters by X ray to detect sex:

Variable	Canonical Discriminant Function Coefficients		Wilks' Lambda	Functions at Group Centroids	Sectioning point	Accuracy
	Un-standardized	Standardized				
MSL:	0.05	0.83	0.86	**Male = 0.40 Female= -0.40**	0.47	57.8%
SI:	-0.12	-0.75				
Constant	2.68	---				

The results of the sternal parameter stepwise discriminant analysis are shown in the table.: MW, MSL, and SI; cross-validated sex classification accuracy was 78.4 %. This formula can be used to predict sex: **Sex=** -6.9+ **(0.12**×**MW) + (0.04**×**MSL)+ (-0.5**×**SI)**

If the value is greater than or equal to -28.89, it indicates that the sternum belongs to a male, and if it is less than -28.89, it indicates that the sternum belongs to a female (with an accuracy of 78.4%) (Table 6).

Table (6): Stepwise discriminant analysis of sternal parameters by CT:

Variable	Canonical Discriminant Function Coefficients		Wilks' Lambda	Functions at Group Centroids	Sectioning point	Accuracy
	Un-standardized	Standardized				
MW:	0.12	0.67	0.51	**Male= 0.98**	0.18	78.4%
MSL:	0.04	0.59				
SI:	-0.05	-0.29		**Female= -0.98**		
Constant	-6.90	----				

DISCUSSION

Prior research on the sternum and numerous other skeletal parts has demonstrated that osteometric standards for estimating sex cannot be accurately extended to other dissimilar samples due to differences in body size, robustness, and the degree of sexual dimorphism exhibited by the skeleton between human groups. It is important to use bone collections that are typical throughout time periods for developing anthropological standards, such as those used to determine sexuality [11].

Various approaches have been developed by forensic anthropologists for identifying a person's gender using both metric and non-metric skeleton characteristics. Measurements (length and breadth) taken from an X-ray of the human sternum can reliably determine a person's sex. The digital X-ray sternum measurement in men and women has only been the subject of a small number of studies [12].

Regarding the comparison of different measured parameters of the sternum measurement using digital X-ray between males and females; the mean of ML in males (53.19 mm) was larger than that in females (50.09 mm), and the mean of MSL in males (84.3 mm) was larger than in females (74.97 mm). The results obtained in this study demonstrate that there was a statistically significant increase in ML and MSL among males compared to females ($P < 0.05$).

To calculate a person's sternal index (SI), take their manubrial length and multiply it by their mesosternal length. According to our data, the average SI for males was 53.71, while the average SI for females was 56.02. (56.60). Men saw a statistically significant (P 0.01) decline in comparison to women.

Consistent with the present findings, it was found that women have a greater SI [1].

In a study of **Osunwoke *et al.*** [13] according to morphometric studies of X-rays of the sternum, length and width measurements derived from X-rays of the human sternum can be used to reliably determine sex if a large enough range of variation is provided. Eighty-seven men and twenty-six women gave consent to have their sternums studied. Manubrium length in males was found to be 60.710.7mm, while in females it was 46.06.13mm. The average male mesosternum was 101.3±13.22 mm in length, whereas the average female mesosternum measured 77.9±7.07mm. The combined length of the manubrium and mesosternum for male and females was 164.6 ± 19.96mm and 123.3±11.8mm, respectively. They concluded that Important for medical science and forensics alike is the fact that the male and female sternums differ significantly.

In the current study, Validity of X-ray sternal measurement for sex identification was assessed using the ROC curve. The dividing line between sensitivity and specificity was calculated for each parameter. Based on this study's ROC analysis, ML, MSL, and SI were found to be the most sensitive (71.7%), specific (54.4%), and specific (54.4%) (sensitivity 58.6, 69, and 62.1 percent respectively). According to the accuracy of validity to discriminate between both genders, our results revealed that the accuracy of ML in the determination of male sex at a cut-off of > 51.5 mm, was 61.2%, the accuracy of MSL at a cut-off of > 86.5 mm was 69%, and the accuracy of SI at a cut-off of < 54.5 mm was 66.4%.

In accordance with our findings, a study by **Torwalt and Hoppa** [5] showed that X-rays of the chest can reliably determine a person's sex with a 95.8% success rate for males and a 90.3% success rate for females in the Canadian population.

Mukhopadhyay [14] revealed that the discriminant function was 100% accurate for both sexes, showing that it may be used to reliably differentiate males from females without the need for invasive techniques like the sternal index. The width of the supra sternal notch and the width of the sternum are two factors that can be successfully used even when only a portion of the bone is present, which is common when investigating a forensic case. Technically determining a person's sex based on their sternum can be incredibly useful.

Regarding the stepwise discriminant analysis of sternal parameters between both genders by X ray to detect sex, MSL and SI; cross-validated sex classification accuracy was 57.8 %. This formula can be used to predict sex: $Sex = 2.68 + (0.05 \times MSL) + (-0.12 \times SI)$. There is a 57.8 percent chance that the sternum in question belongs to a male if the result is greater than or equal to 0.47, and a 41.8 percent chance that it belongs to a female if the result is less than or equal to 0.47.

In the study done by **Abdel Aal *et al.*** [3] Based on a simple logistic regression equation, the sum of the manubrium and sternum lengths has the highest predictive value (92.2% accuracy) for identifying a person's sex among the criteria considered.

Regarding the comparison of different measured parameters of the sternum measurement using MSCT scanning between male and female; the current study demonstrated a statistical significance decrease in ML, MW, MSL, sternebra 1 width (S1W), and sternebra 3 widths (S3W) among male compared to female (< 0.05). The mean of ML in males (50.81 mm) was larger than that in females (43.16 mm), the mean of MW in males (60.81 mm) was larger than that in female (52.79 mm), and the mean of MSL in males (83.38 mm) was larger than in females (63.28 mm). On the other hand, sternal index (SI) showed statistical highly significant also decrease among male compared to female ($P < 0.001$). The mean of the SI in males (53.71 mm) was lower than that of females (56.60 mm).

These results agreed with the Egyptian study done by **Abdel Aal *et al.*** [3] who observed statistically significant variations between sexes in the parameters assessed by MSCT scanning of the sternum for Upper Egyptian groups; males showed higher variation.

A recent study of **Elsayed *et al.* [15]** performed on a hundred people (50 males and 50 females). Individuals in this group ranged in age from 25 to 45. The study found statistically significant differences between males and females in MW and ML, with respective P-values of (P 0.001) and (P 0.001). Males averaged a greater MW (66.4) and ML (47.4) than females did (54.3, and 42.3 respectively). There was also a statistically significant difference between males and females on the SI's mean values, with a p-value of less than 0. 001.. Males, on average, had a lower SI value (47.) than females, who averaged (55.1).

This research employed the ROC curve to assess the reliability of MSCT sternal measurement for gender identification. The optimum balance point between sensitivity and specificity was calculated for each parameter. ROC assessment showed that ML, MW, MSL, S1W, S3W and SI were the most specific (specificity 60.3, 70.7, 70.7, 62.1, 60.3 and 70.7% respectively) and the most sensitive (sensitivity 72.4, 81, 79.3, 65.5, 65.5 and 67.2% respectively). These findings were agreed with the results of the study of **Elsayed *et al.* [15],** and **Sweilum *et al.* [16]**.

In the present study, ROC analysis was revealed that sensitivity and specificity values for sex determination were higher in SL as a single measurement (as the sensitivity was 83% and specificity was 70.6%), but all measurements together were more sensitive and specific (88.6% and 84.3%).

Similarly, **Ekizoglu *et al.* [17]** Scores for sensitivity and specificity in sex discrimination were found to be highest in the SL assessment.

According to the accuracy of validity to discriminate between both genders, our results revealed that the accuracy of ML in the determination of male sex at a cut-off of > 46.5 mm, was 66.4%, the accuracy of MW at a cut-off of > 57.5 mm was 75.9%, the accuracy of MSL at a cut-off of > 76.5 mm was 75%, the accuracy of S1W at a cut-off of > 23.5 mm was 63.8%, the accuracy of S3W at a cut-off of > 26.5 mm was 62.9%, and the accuracy of SI at a cut-off of < 60.5 mm was 69 %. These findings were agreed with the results of **Macaluso and Lucena [18],** and **Elsayed *et al.* [15]**.

In contrast to the present study; **Gupta *et al.* [19]** reported that among the central Delhi population, the length of the manubrium (ML) is the most accurate indicator for sex detection. While **Changani *et al.* [2],** found that the sum of the SL and ML is the most accurate indicator of sex at the chest.

Regarding the stepwise discriminant analysis of sternal parameters by MSCT to detect sex, the current study shows that in the stepwise discriminant analysis of the sternal parameters 3of 6 measurements were selected: MW, MSL, and SI; cross-validated sex classification accuracy was 78.4 %. Prediction of sex was done by this equation: **Sex= -6.9+ (0.12×MW) + (0.04×MSL) + (-0.5×SI).** With an accuracy of 78.4 percent, a value more than or equal to -28.89 indicates that the sternum belongs to a male, while a result less than -28.89 indicates that the sternum belongs to a female.

In the study of **Elsayed *et al.* [15],** Predicting sex in the Sohag governorate sample population using the discriminant function equation and cross-checked classification accuracies yields an average accuracy of 88% for men and 92% for females (90 percent).

CONCLUSION

It could be concluded that the MSCT scanning is a very helpful tool for imaging the sternum and effective in sex identification more than Digital X-ray radiograph.

In the present study, all sternal measurements which was assessed were statistically significant higher in males except SI which was higher in females. The different sternal measurements are reliable predictors for sexual dimorphism. The virtual sternal angles used in the study are of value in sex prediction. Although there is possibility of sex prediction if the manubrium or the body alone was available, but the high percentage was obtained when the measurements were taken from the whole sternum.

The model equation for sex estimation in Libyan population sample from sternal dimensions can be used by medicolegal physicians in living and dead, whether complete skeleton or dismembered remains related to chest regions are brought for forensic examination and can be accepted by law agencies. These equations should be applied only to Capital cities in Libyans population.

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