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Estimation of sex based on metrics of the sternum in a contemporary Jordanian population

A computed tomographic study

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Abstract

There is a paucity of osteometric standards for sex estimation from unknown skeletal remains in Jordan and the sexual dimorphism of the sternum has not yet been investigated. The aim of this study was to evaluate the sexual dimorphism in sternal measurements using 3D multidetector computed tomography (MDCT), and to assess their reliability for sex estimation in a Jordanian population. A total of 600 MDCT scans (300 males and 300 females) were used and a total of 8 sternal measurements were studied (manubrium length, sternal body length, combined length of manubrium and body, corpus sterni width at 1st and 3rd sternebrae, sternal index and area). Sexual dimorphism was evaluated by means of discriminant function analyses. Significant sexual dimorphism was found mainly in middle-aged and older adults. Including all subjects, multivariate, and stepwise functions gave an overall accuracy of 83.0% and 84.0%, respectively. Additionally, multivariate and stepwise analyses were conducted separately for each age group. The accuracy of sex estimation in multivariate analysis (all variables) varied from 63.2% in the young, and 83.7% in the middle adults to 84.9% for older adults. In stepwise analysis, the highest accuracy rates were provided by only sternal area in young adults (81.6%), and sternal area combined with sternal body length in middle-aged and older adults (84.2% and 85.3%, respectively). The best sex discriminator using univariate analysis (single variable) was sternal area followed by sternal body length (84.0% and 80.8% respectively). Notably, univariate analyses for most variables gave relatively higher classification accuracies in females but were poor at predicting males in the sample (sex bias ranged between −6.4% and −20%). Our data suggest that dimorphism in the human sternum increases with advancing age and separate discriminant functions are needed for each age group in Jordanians. In addition, multivariate and stepwise analyses using sternum gave higher classification accuracies with comparatively lower sex biases compared to univariate analyses.

Abbreviations: B = Sternal body length, CL = combined length, CSW_{S1} = Corpus sterni width at 1st sternebra, CSW_{S3} = Corpus sterni width at 3rd sternebra, ML = Manubrium length, MW = Manubrium width, SA = Sternal area, SI = Sternal index.

Keywords: computed tomography, discriminant function, Jordanians, sexual dimorphism, sternum

1. Introduction

Postmortem sex identification has been extensively described in forensic literature since the late 1960s.[1] It can be done by one of three methods: morphologic, osteometric and DNA analysis.[2,3] This task proves much more challenging when the remains are incomplete, which may occur in the setting of various incidents such as mass disasters, fires, explosions, crashes and physical violence. The most accurate method of sex estimation is DNA

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analysis; however, in certain circumstances it cannot be used. Due to its complexity, DNA may not be always extracted and it necessitates the presence of qualified personnel while also proving to be quite expensive.[4] Conversely, the osteometric method uses skeletal remains to accurately determine sex and create a biological profile. It has demonstrated to be less costly and complex, easily reproducible, and does not require special expertise; thereby, is considered a fundamental part of medico-legal investigation.[5] The pelvis and the skull have been primarily used by forensic anthropologists to estimate sex as they are considered highly accurate, with the pelvis being the most accurate.[6] However, depending solely on these two areas may hinder the sex estimation process as they are prone to trauma or may not be present.[7–9] Notably, the pelvis was described as fragile and susceptible to damage while the skull is less accurate than postcranial bones.[10,11] As a result, other bony elements need to be investigated as potential estimators of sex.

The sternum has been frequently examined in different population-based studies as a potential sex estimator using either traditional or virtual tools.[7,8,12–15] It has revealed a recovery rate of >59% in skeletal remains housed in the Forensic Anthropology Data Bank.[7] In addition, early studies of sex estimation using the sternum have led to the formulation of Hyrtl's law which states that the manubrium of the female sternum exceeds half the length of the body, while the body in the male sternum is, at least, twice as long as the manubrium.[16] This aids in the reinforcement of the presence of sexual dimorphism in the sternum. Jordanians are considered a population of mixed ancestry due to the mass immigration of refugees from the neighboring countries. The lack of traditional repositories of skeletal remains in Jordan necessitates the use of alternative identification methods. There is a paucity of osteometric data for sex estimation from unknown skeletal remains in Jordan. Therefore; our current research project aims to establish population-specific osteometric standards from different bones and/or bony elements to optimize the accuracy of identification and to contribute to current forensic standards for this underrepresented population. The specific objective of this study was to assess the sexual dimorphism in sternum using 3D MDCT, and its reliability to predict sex in a sample of Jordanian population by means of discriminant function analyses.

2. Materials and methods

Six-hundred chest CT scans (300 males (20–82 years) and 300 females (21–80 years) were obtained from the Radiology Department at Jordan University Hospital. The sample was comprised of native Jordanian individuals of known age and sex. Any pathological condition, deformity or trauma in the sterna that led to ambiguous anatomy resulted in the exclusion of the corresponding CT scan. In addition, this study included only CTs in which all sternebrae of the sternum body were fused.

This retrospective study was performed in line with the principles of the Declaration of Helsinki and approved by the Institutional Review Board at the Jordan University Hospital. The requirement for informed consent was waived as the study analyzed only archival CT scans (entirely retrospective) and involved no risk to the subjects. PACS workstation (Fujifilm's PACS Synapse workstation 3.2.1, Stamford) was used to record five linear measurements (in mm) (Fig. 1). Measurements were taken following the definitions of McCormick et al and Jit et al (Table 1).[17,18] The images were acquired with a 64-detector-row CT scanner. Scans were obtained with 140 kV voltages, 230 mA current, 1 mm slice thickness, 0.5 s/cycle scan speed and 1.2 scan pitch. Multi-detector 3D images were reconstructed using multiplanar reconstruction (MPR) and 3D-rendering algorithms.

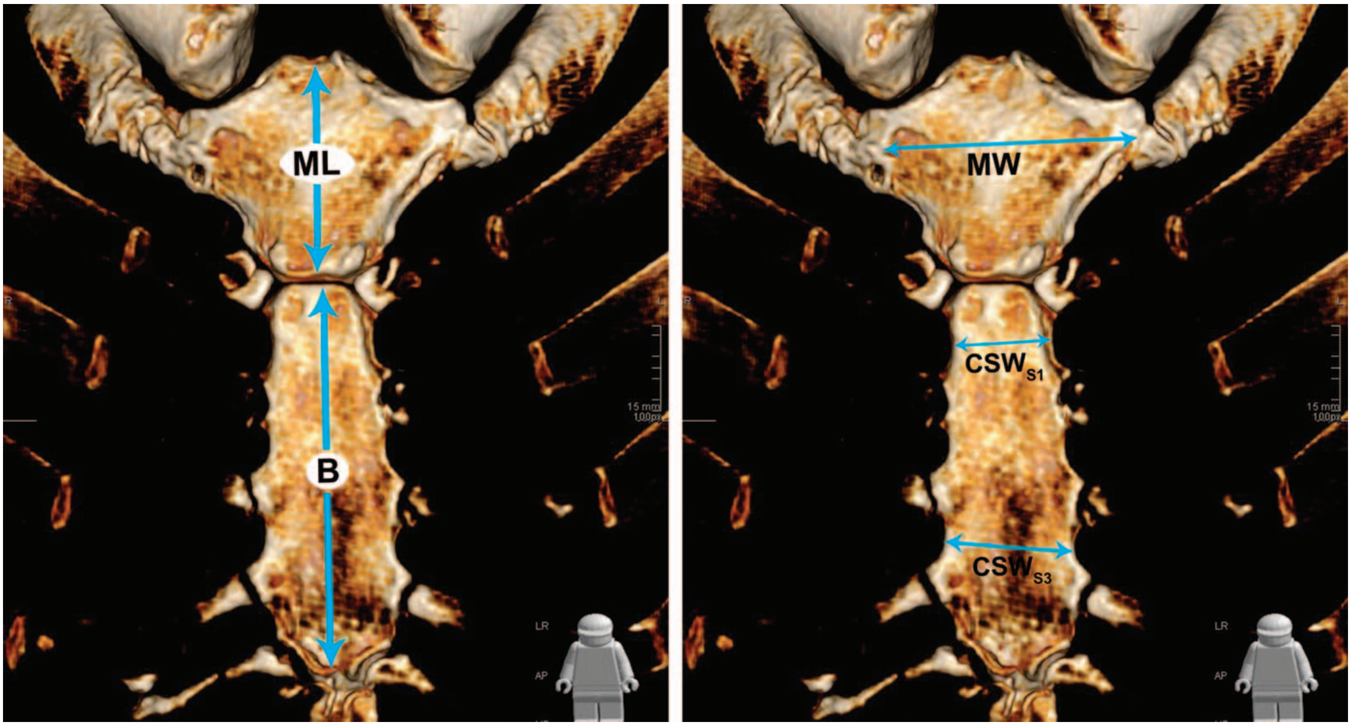

Figure 1. Reconstructed three-dimensional computed tomography of a sternum showing the measurements used in the present study.

Table 1

Definition of the measurements used in the present study.

Measurement	Description
Manubrium length (ML)	Distance taken from the midpoint of the concavity of jugular notch to the midpoint of the manubriosternal junction
Sternal body length (B)	Distance taken from the midpoint of the manubriosternal junction to the midpoint of the xiphisternal junction
Combined length (CL)	Sum of the manubrium and body lengths
Manubrium width (MW)	Distance taken between the midpoints of the facets for the first costal cartilages on each side
Corpus sterni width at 1st sternebra (CSW_{S1})	Distance taken between the midpoints of the facets for the second and third costal cartilages on each side
Corpus sterni width at 3rd sternebra (CSW_{S3})	Distance taken between the midpoints of the facets for the fourth and fifth costal cartilages on each side
Sternal area (SA)	Calculated using the formula: $(ML+B) X (MW+CSWS_1+CSW_{S3})/3$
Sternal index (SI)	Calculated using the formula: (ML/ B) X 100

The measurements were acquired by two radiology experts. Age and sex were blinded during the conduction of the osteometric measurements. The combined length of manubrium and sternal body, sternal area and index were calculated as defined in Table 1. To explore the effect of age on sexual dimorphism, the subjects were divided into three age groups: young adults within the range of 20 to 35 years (138 subjects, 67 males and 71 females, mean age 29.4 years); middle-aged adults within the range of 36 to 55 years (202 subjects, 96 males and 106 females, mean age 48.4 years); and older adults within the range of 56 to 80 years (260 subjects, 137 males and 123 females, mean age 68.3 years).

2.1. Statistical analysis

The data was entered into a spreadsheet and analyzed using the IBM SPSS Statistics for Windows, version 22 (IBM Corp, Armonk, NY). Descriptive statistics obtained included the mean and standard deviation for each variable in all subjects and in each age group. Sexual dimorphism and comparisons between different age groups were based on one-way ANOVA. The normal distribution was tested using the Shapiro–Wilk test. A P-value $\leq .05$ was considered significant. Inter-observer variability was analyzed using the kappa statistic. Using a sample of 50 CT images, inter-observer variability was excellent for all measurements, $r>0.90$ ($P<.05$).

Multivariate, stepwise and univariate discriminant function analyses were performed and sectioning points were calculated. The equality of the variance and covariance matrices between males and females was confirmed by Box's M test. The sectioning point was obtained by taking the average of the two centroids. The classification results for each analysis (multivariate, stepwise and univariate) were cross-validated using "leave one out classification" method. The sex bias was calculated as the percent difference between the correct classification accuracies in males and females (% of males correctly classified – % of females correctly classified).

3. Results

3.1. Sexual dimorphism of sternal variables

The mean and standard deviation for each sternal variable according to sex in all subjects and in different age groups were shown in Table 2. Considering all ages combined, all variables were found to be significantly larger in males, except for the sternal index ($P<.05$). When the analyses were performed separately for each age group, all variables contributed significantly to sexual dimorphism in different age groups ($P<.05$) except for manubrium length in young and middle-aged adults, corpus sterni width at 1st sternebra and 3rd sternebra and sternal index in the young adults ($P>.05$). In all subjects, the most dimorphic variables were sternal area, sternal body length, combined length of manubrium and body, and manubrium width. In young adults, the most dimorphic variable was sternal area, while sternal area, sternal body length, and combined length of manubrium and body were the most dimorphic variables in middle-aged and older adults (Table 2). All sternal variables increased with increasing age (except for sternal index), but this increase was not significantly different between the three age groups in both males and females ($P>.05$).

3.2. Multivariate discriminant function analysis

The multivariate analyses (all sternal variables were entered simultaneously) were developed and sectioning points were obtained for all subjects, young, middle-aged and older adults (Table 3). In all subjects, sex was determined correctly in 83.0% of the scans with a sex bias of 1.2% (83.6% were males and 82.4% were females).

The highest overall correct classification rate was obtained from the older adults with an overall accuracy rate of 84.9% with a sex bias of −2.4% (83.8% were males and 86.2% were females). In middle adults, sex was determined correctly in 83.7% of the scans with a sex bias of 1.5% (84.5% were males and 83.0% were females). On the other hand, low classification accuracies were obtained from all sternal variables in young adults; sex was determined correctly in only 63.2% of the scans with a high sex bias of −7.9% (58.8% were males and 66.7% were females) (Table 3).

3.3. Stepwise discriminant function analysis

Sternal area, sternal body length, manubrium width, and corpus sterni width at 1st sternebra were selected as best discriminators of sex in all subjects using the forward stepwise discriminant function analysis (Table 4). The 4 variables selected in the stepwise analysis increased slightly the accuracy of sex estimation; sex was determined correctly in 84.0% of the scans with a sex bias of −2.4% (82.8% were males and 85.2% were females).

In young adults, only sternal area was selected as the best discriminator of sex with an overall accuracy rate of 81.6% and a sex bias of 1.4% (82.4% were males and 81.0% were females), while sternal area and sternal body length were selected as best discriminators of sex in both middle-aged and older adults with

Table 2

Means, Standard deviations and "*P*" values of sternal measurements according to sex and age in Jordanian population.

Sternal measurement	Age group	Male (SD)	Female (SD)	*F*	*P*
Manubrium length	All	49.7 (10.7)	47.1 (8.7)	8.9	.003[a]
	18–35 years	48.6 (11.5)	46.5 (9.6)	0.4	.551
	36–55 years	49.4 (11.0)	46.8 (9.3)	3.3	.072
	≥56 years	50.0 (10.5)	47.4 (8.1)	5.0	.026[a]
	F	0.206	0.189		
	P	0.814	0.828		
Sternal body length	All	101.4 (11.0)	84.5 (9.9)	326.6	<.001[a]
	18–35 years	99.9 (15.7)	82.9 (10.9)	15.5	<.001[a]
	36–55 years	101.2 (9.8)	83.7 (9.6)	165.2	<.001[a]
	≥56 years	101.8 (11.2)	85.5 (9.7)	151.7	<.001[a]
	F	0.270	1.290		
	P	0.764	0.277		
Combined length	All	151.2 (16.9)	131.6 (13.6)	201.1	<.001[a]
	18–35 years	148.4 (18.2)	129.4 (15.9)	11.8	.001[a]
	36–55 years	150.6 (17.4)	130.5 (14.1)	82.3	<.001[a]
	≥56 years	151.9 (16.6)	132.9 (12.7)	104.2	<.001[a]
	F	0.386	1.217		
	P	0.680	0.298		
Manubrium width	All	64.4 (9.8)	54.8 (10.9)	106.5	<.001[a]
	18–35 years	62.5 (8.9)	53.1 (11.4)	7.6	.009[a]
	36–55 years	62.9 (8.3)	54.6 (11.4)	35.3	<.001[a]
	≥56 years	65.7 (10.7)	55.3 (10.5)	61.6	<.001[a]
	F	2.518	0.371		
	P	0.083	0.691		
Corpus sterni width at 1st sternebra	All	28.5 (5.0)	24.9 (4.1)	74.3	<.001[a]
	18–35 years	27.9 (4.5)	24.7 (4.3)	3.8	.051
	36–55 years	28.5 (4.9)	24.8 (4.1)	32.9	<.001[a]
	≥56 years	28.7 (5.2)	25.1 (4.3)	36.2	<.001[a]
	F	0.354	0.164		
	P	0.702	0.850		
Corpus sterni width at 3rd sternebra	All	34.7 (6.7)	30.4 (5.4)	63.5	<.001[a]
	18–35 years	34.3 (8.5)	29.8 (6.0)	3.7	.064
	36–55 years	34.6 (6.5)	30.1 (5.3)	28.8	<.001[a]
	≥56 years	34.9 (6.7)	30.7 (5.4)	30.3	<.001[a]
	F	0.094	0.463		
	P	0.911	0.630		
Sternal area	All	6416.4 (937.1)	4829.1 (799.7)	414.9	<.001[a]
	18–35 years	6137.3 (1040.7)	4661.3 (1064.9)	18.4	<.001[a]
	36–55 years	6307 (868.7)	4761.9 (813.4)	171.4	<.001[a]
	≥56 years	6528.9 (960.9)	4915.7 (730.5)	227.6	<.001[a]
	F	2.415	1.565		
	P	0.091	0.211		
Sternal index	All	49.3 (11.1)	56.4 (12.3)	45.7	<.001[a]
	18–35 years	50.0 (16.4)	56.7 (12.7)	1.9	.166
	36–55 years	48.8 (9.9)	56.6 (12.8)	22.9	<.001[a]
	≥56 years	49.5 (11.2)	56.2 (12.0)	21.4	<.001[a]
	F	0.155	0.029		
	P	0.856	0.971		

[a] Significant at ≤0.05, *one-way ANOVA.

overall accuracies of 84.2% and 85.3% (sex bias 0.5% and −3.2%), respectively (Table 4).

3.4. Univariate discriminant function analysis

Additionally, each sternal variable was subjected to univariate discriminant analysis to determine the importance of each sternal variable in discriminating between sexes. The single discriminant functions were developed and sectioning points were obtained (Table 5). The best sex discriminator using the univariate analysis was sternal area followed by sternal body length. Overall accuracy rates of 84.0% and 80.8% were obtained, respectively (Table 6). Notably, the univariate analyses of most variables (manubrium length, combined length of manubrium and body, manubrium width, corpus sterni width at 1st and 3rd sternebrae, and sternal area) gave relatively higher classification accuracies in females but were poor at predicting males in the sample (sex bias ranged between −6.4% and −20%).

4. Discussion

Over the past decades, an increased need has been developed for new and reliable methods of forensic identification to identify victims of natural disasters, wars, terrorist attacks, bomb blasts,

Table 3

Multivariate direct discriminant function analysis of sternal measurements: Canonical discriminant function coefficients, sectioning points, and classification results in Jordanian population.

Sternal measurements	Unstandardized coefficients	Standardized coefficients	Structure matrix	Centroids	Sectioning point	Predicted group membership: Male	Predicted group membership: Female	Correct classification	Sex bias
All subjects									
Manubrium length	0.053	0.515	0.134	F: −0.997	0.000	83.6%	82.4%	83.0%	1.2%
Sternal body length	0.092	0.965	0.810	M: 0.997					
Manubrium width	0.072	0.753	0.463						
Corpus sterni width at 1st sternebra	0.095	0.441	0.387						
Corpus sterni width at 3rd sternebra	0.044	0.269	0.357						
Sternal area	−0.001	−0.540	0.914						
Sternal index	−0.008	−.089	−.303						
Constant	−15.541								
Wilks' Lambda: 0.500, Eigen value: 0.998, Canonical correlation: 0.707, *P* value: <.001*									
Young adults (20–35 years)									
Manubrium length	0.039	0.414	0.111	F: −0.790	0.093	58.8%	66.7%	63.2%	−7.9%
Sternal body length	0.278	3.686	0.726	M: 0.976					
Manubrium width	0.208	2.166	0.509						
Corpus sterni width at 1st sternebra	0.309	1.362	0.376						
Corpus sterni width at 3rd sternebra	0.182	1.312	0.354						
Sternal area	−0.004	−4.246	0.793						
Sternal index	0.115	1.664	−0.261						
Constant	−37.572								
Wilks' Lambda: 0.551, Eigen value: 0.813, Canonical correlation: 0.670, *P* value: .007*									
Middle-aged adults (36–55 years)									
Manubrium length	−0.018	−.186	0.119	F: −1.021	0.048	84.5%	83.0%	83.7%	1.5%
Sternal body length	0.159	1.540	0.845	M: 1.116					
Manubrium width	0.082	0.816	0.390						
Corpus sterni width at 1st sternebra	0.108	0.487	0.377						
Corpus sterni width at 3rd sternebra	0.055	0.323	0.353						
Sternal area	−0.001	−0.805	0.861						
Sternal index	0.056	0.645	−0.315						
Constant	−20.859								
Wilks' Lambda: 0.465, Eigen value: 1.151, Canonical correlation: 0.732, *P* value: <.001*									
Older adults (≥56 years)									
Manubrium length	0.119	1.128	0.138	F: −1.060	−0.051	83.8%	86.2%	84.9%	−2.4%
Sternal body length	0.044	0.463	0.759	M: 0.959					
Manubrium width	0.072	0.764	0.484						
Corpus sterni width at 1st sternebra	0.076	0.361	0.371						
Corpus sterni width at 3rd sternebra	0.044	0.269	0.339						
Sternal area	0.000	−0.350	0.930						
Sternal index	−0.068	−0.787	−0.258						
Constant	−11.831								
Wilks' Lambda: 0.494, Eigen value: 1.025, Canonical correlation: 0.711, *P* value: <.001*									

* Significant at ≤0.05.

mass murders etc. In these circumstances, any skeletal remain or a single preserved bone piece becomes fundamental for identification in the forensic context.[19–21] Many studies demonstrated high accuracy between measurements taken from a dry element and measurements taken from the 3D-CT image of the same dry element or the virtual bone surfaces reconstructed from CT scans of living individuals.[22–25] For example, the mean difference between the actual measurements and the measurements on the 3D CT images of the skull was only 0.9 mm.[26] Additionally, no significant difference was found between MDCT measurements using juvenile clavicles and those taken by direct osteometric methods,[22] confirming the consistency of measurements obtained from computed tomography and thus validating its use in osteometric studies.

This study and others are being carried out in order to establish a forensic anthropology databank on sex estimation of skeletonized remains in Jordan. In line with our results, previous studies performed in different populations reported significant differences in sternal measurements between sexes.[7–9,15,27] However, sternal differences between sexes were explored in different age groups in our study to explore the effect of age on sexual dimorphism of sternum. Sexual dimorphism was found mainly in the middle-aged and older adults. Manubrium length was significantly dimorphic in older adults only. Additionally, no significant differences in corpus sterni width at 1st sternebra, 3rd sternebra and sternal index were found in young adults, suggesting that dimorphism in the human sternum increases with advancing age. This can be attributed in part to the

Table 4

Stepwise discriminant function analysis of sternal measurements: Canonical discriminant function coefficients, sectioning points & classification results in Jordanian population.

Sternal measurements	Unstandardized coefficients	Standardized coefficients	Structure matrix	Centroids	Sectioning point	Predicted group membership: Male	Predicted group membership: Female	Correct classification	Sex bias
All subjects									
Sternal area	0.000	0.355	0.920	F: −0.991	0.000	82.8%	85.2%	84.0%	−2.4%
Sternal body length	0.057	0.597	0.816	M: 0.991					
Manubrium width	0.023	0.236	0.466						
Corpus sterni width at 1st sternebra	0.043	0.198	0.389						
Constant	−10.090								
Wilks' Lambda: 0.504, Eigen value: 0.986, Canonical correlation: 0.705, *P* value: <.001*									
Young adults (20–35 years)									
Sternal area	0.001	1.000	1.000	F: −0.626	0.074	82.4%	81.0%	81.6%	1.4%
Constant	−5.048			M: 0.774					
Wilks' Lambda: 0.662, Eigen value: 0.512, Canonical correlation: 0.582, *P* value: <.001*									
Middle-aged adults (36–55 years)									
Sternal area	0.001	0.632	0.883	F: −0.996	0.046	84.5%	84.0%	84.2%	0.5%
Sternal body length	0.079	0.768	0.867	M: 1.088					
CL	−0.23	−0.366	0.612						
Constant	−8.178								
Wilks' Lambda: 0.478, Eigen value: 1.094, Canonical correlation: 0.723, *P* value: <.001*									
Older adults (≥ 56 years)									
Sternal area	0.001	0.764	0.962	F: −1.025	−0.049	83.8%	87.0%	85.3%	−3.2%
Sternal body length	0.032	0.338	0.785	M: 0.927					
Constant	−8.112								
Wilks' Lambda: 0.511, Eigen value: 0.957, Canonical correlation: 0.699, *P* value: <.001*									

* Significant at ≤0.05.

variations in the ossification patterns and the fusion of manubrio-mesosternal and mesosterno-xiphisternal junctions. Previous studies showed that most of the ossification begins after the teenage years and progresses with aging.[28–30] In an autopsy study of South Indian population, none of the sterna aged below 30 years showed fusion of mesosterno-xiphisternal junction and nonfusion of mesosterno-xiphisternal junction was reported till the age of 48 years in males and 46 years in females.[31] Additionally, the fusion times of the sternal body's four sternebrae are found to be highly variable and different times of fusion were reported in different populations.[32,33] A study of the fusion phases of sterna from a Black South African population demonstrated that the majority of sterna remain unfused throughout adult life, with complete fusion observed

Table 5

Univariate direct discriminant function analysis: Canonical discriminant function coefficients and sectioning points in Jordanian population.

Sternal measurements	Unstandardized coefficients	Constant	Wilks' lambda	Eigen value	Canonical correlation	Centroids	*P*
Manubrium length	0.102	−4.939	0.982	0.018	0.132	F: −0.133 M: 0.133	.003*
Sternal body length	0.096	−8.881	0.604	0.656	0.629	F: −0.808 M:0.808	<.001*
Combined length	0.065	−9.180	0.712	0.404	0.536	F: −0.634 M:0.634	<.001*
Manubrium width	0.096	−5.738	0.824	0.214	0.420	F: −0.462 M: 0.462	<.001*
Corpus sterni width at 1ststernebra	0.216	−5.786	0.870	0.149	0.360	F: −0.386 M: 0.386	<.001*
Corpus sterni width at 3rdsternebra	0.164	−5.346	0.887	0.128	0.336	F: −0.356 M: 0.356	<.001*
Sternal area	0.001	−6.455	0.545	0.883	0.674	F: −0.911 M: 0.911	<.001*
Sternal index	0.085	−4.504	0.916	0.092	0.290	F: 0.302 M: −0.302	<.001*

Standardized coefficient = 1.000, Structure matrix = 1.000, Sectioning point: 0.
* Significant at ≤0.05.

Table 6

Classification results of sternal measurements in Jordanian population by univariate discriminant function analysis.

Sternal measurements	Univariate analysis: Predicted group membership: Male (%)	Female (%)	Correct classification (%)	Sex bias (%)
Manubrium length	44.8	64.8	54.8	−20.0
Sternal body length	81.6	80.0	80.8	1.6
Combined length	68.4	80.0	74.2	−11.6
Manubrium width	62.8	72.0	67.4	−9.2
Corpus sterni width at 1st sternebra	54.8	70.4	62.6	−15.6
Corpus sterni width at 3rd sternebra	56.8	70.0	63.4	−13.2
Sternal area	80.8	87.2	84.0	−6.4
Sternal index	69.2	62.4	65.8	6.8

both in young and old individuals.[34] However, in our study, no significant differences were found in sternal variables between the three age groups in both sexes. This finding is in line with the previous studies.[15,35] In a study of Spanish population, a sample of dry sterna was separated into three age groups; adults (21–40 years), mature (41–60 years), and senile (>60 years) and no statistical differences were found between age groups.[15] Additionally, a study of a Turkish population using MSCTs divided the sample arbitrary into four age groups (21–40 years, 41–60 years, 61–80 years, and ≥81 years) and the effect of age group on all measurements was found to be statistically insignificant.[35] Therefore, in these two former studies, the different age groups were grouped together in their discriminant function analyses.[15,35]

Similar to the dimorphic pattern obtained in this study, the four most dimorphic sternal variables in South African and Western Australian populations were sternal area, the combined length of the manubrium and body, sternal body length and manubrium width.[12,36] It can be noted from the single variable analyses of previous international studies (Tables 7 and 8) that SA, CL, B, and MW gave comparatively higher overall classification accuracies ranging between 70.1% and 95.0%. On the other hand, the four variables (ML, CSW_{S1}, CSW_{S3}, and SI) yielded relatively lower sex determination accuracies compared to other sternal variables. Previous studies used also direct multivariate/stepwise analyses with different combinations methods for measurement data (Table 9). Using the five linear sternal measurement (ML, B, MW, CSW_{S1}, and CSW_{S3}), the highest accuracy rate was reported in a study conducted on an Egyptian sample with an overall accuracy of 96.7%.[27] Considering all sternal variables in our discriminant analysis, the highest classification accuracy was obtained from the older adults with an overall accuracy rate of 84.9% (sex bias −2.4%), followed by the middle-aged adults with an overall accuracy rate of 83.7% (sex bias 1.5%). On the other hand, lower classification accuracies (overall 63.2%) with a high sex bias (−7.9%) were obtained from the young adults. In a forensic context, variables with high sex biases have limited forensic applicability and cannot certainly be used as sex estimators.[12] Sternal area was the most dimorphic variable in the young adults and it was selected by the stepwise analysis as the best discriminator of sex. These data suggest that young ages have comparatively lower level of dimorphism in sternum and the highest accuracy of sex estimation in young sterna can be obtained by using sternal area only. Additionally, the data of this study confirms that the sternum has comparatively higher levels of dimorphism in subjects aged more than 35 years. The univariate analysis was performed to figure out the contribution of each variable individually in sex estimation and to test which single variable is the most or least reliable in sex estimation. The classification accuracies obtained from the univariate analysis of each sternal variable are comparable with those reported from different

Table 7

Comparison of the accuracy (%) of the linear sternal measurements in sex estimation in previous international studies using univariate analysis.

Study Sample	ML (%)			B (%)			CL (%)			MW (%)			CSW_{S1} (%)			CSW_{S3} (%)		
	♂	♀	*All*	♂	♀	*All*	♂	♀	*All*	♂	♀	*All*	♂	♀	*All*	♂	♀	*All*
Japanese[8]‡	62.0	63.0	62.5	79.0	89.0	84.0	81.0	90.0	85.5	77.0	88.0	82.5	70.0	76.0	73.0	70.0	79.0	74.5
South African Blacks[36]*	65.0	73.5	68.4	82.9	84.3	83.5	79.7	88.0	83.0	77.2	81.9	79.1	61.8	78.3	68.4	65.0	75.9	69.4
Spanish[38]*	72.3	72.5	72.4	75.4	84.3	79.3	80.0	82.4	81.0	84.6	86.3	85.3	73.8	72.5	73.3	69.2	72.5	70.7
Saudi[37]†	68.0	73.0	70.5	85.0	85.0	85.0	86.0	93.0	89.5	77.0	76.0	76.5	72.0	73.0	72.5	61.0	72.0	66.5
Croatian[13]†	64.4	72.7	68.0	83.6	81.8	82.8	84.9	83.6	84.4	78.1	80.0	78.9	72.6	74.5	73.4	65.8	69.1	67.2
Spanish[15]*	69.7	83.3	76.2	88.4	85.3	87.0	93.1	84.6	89.1	–	–	–	70.4	81.0	75.0	69.4	72.7	70.7
Americans Blacks &Whites[7]*	61.0	68.0	64.5	80.0	77.0	78.5	77.0	86.0	81.5	–	–	–	61.0	71.0	66.0	58.0	68.0	63.0
South Indian[14]*	76.1	64.0	70.9	76.1	62.0	70.1	80.6	66.0	74.4	–	–	–	74.6	66.1	70.9	74.6	58.0	67.5
Chinese[39]†	59.4	74.1	65.9	77.6	79.5	78.4	80.4	84.8	82.4	66.4	75.9	70.6	–	–	–	–	–	–
Turkish[9]†	67.6	71.3	–	80.9	80.2	–	–	–	–	–	–	–	68.0	76.7	–	57.3	70.8	–
Western Australian[12]†	–	–	–		–	83.4	–	–	83.4	–	–	77.5	–	–	72.2	–	–	–

B = Sternal Body Length, CL = Combined Length, CSW_{S1} = Corpus Sterni Width 1st Sternebra, CSW_{S3} = Corpus Sterni Width 3rd Sternebra, ML = Manubrium Length, MW = Manubrium Width.
* Dry sterna.
† MDCT/MSCT.
‡ Postmortem MDCT, **** Digital radiographs.

Table 8

Comparison of the accuracy (%) of the sternal index and area in sex estimation in previous international studies using univariate analysis.

		SI (%)			SA (%)		
Study sample	**Data**	♂	♀	*All*	♂	♀	*All*
Japanese[8]	Postmortem MDCT	67.0	59.0	63.0	88.0	93.0	90.5
South African Blacks[36]	Dry sterna	74.8	60.2	68.9	83.7	91.6	86.9
Spanish[38]	Digital radiographs	60.0	56.9	58.6	86.2	92.2	88.8
Spanish[15]	Dry sterna	75.9	69.2	72.7	–	–	–
Saudi[37]	MDCT	66.0	59.0	62.5	86.0	90.0	88.0
Croatian[13]	MSCT	69.9	54.5	63.3	84.9	94.5	89.1
Turkish[9]	MDCT	64.3	56.4	–	–	–	–
Turkish[35]	MSCT	–	–	–	83.8	79.0	81.8
Egyptian[27]*	MSCT	–	–	–	–	–	95.0

SA = Sternal area, SI = Sternal Index.
* Multiple regression analysis was used in this study.

populations (Tables 7 and 8). However, lower classification accuracies were obtained in our study using the univariate analyses compared to multivariate or stepwise analyses. The highest classification accuracy obtained from a single variable analysis was from sternal area with an overall accuracy rate of 84.0%.

According to Hyrtl's law, sternal index would be <50 in males and >50 in females. However, several studies reported sternal index as an unreliable parameter because of the significant overlap between sexes and the associated large sex bias (Table 8).[7,9,13,15,37] In line with the later studies, sternal index

Table 9

Comparison of the accuracy of sternal measurements in sex estimation in previous international studies using Multivariate stepwise analysis.

		Accuracy (%)			
Study sample	**Data**	♂	♀	*All*	***Variables used***
Japanese[8]	Postmortem CT	78.0	87.0	82.5	ML, MW
		86.0	87.0	86.5	B, CSW_{S1}
		87.0	91.0	89.0	ML, B, MW, CSW_{S1}
South African Blacks[36]	Dry sterna	88.0	85.4	86.4	ML, B
		81.3	79.5	80.6	ML, MW
		82.9	86.7	84.5	B, CSW_{S1}
Spanish[15]	Dry sterna	92.3	88.2	90.7	CL, SBMW
		94.7	87.0	91.8	B, SBMW
		86.2	87.0	86.5	ML, T, CSW_{S1}
Americans Blacks &Whites[7]	Dry sterna	79.8	85.7	82.8	ML, B, CSW_{S1}
		80.0	88.2	84.1	ML, B, CL, CSW_{S1}, CSW_{S3}, SI
South Indian[14]	Dry sterna	80.6	64.0	73.5	ML, B
		77.6	66.0	72.6	CSW_{S1}, CSW_{S3}
		79.1	74.0	76.9	ML, B, CSW_{S1}, CSW_{S3}
		80.6	76.0	78.6	CL, CSW_{S1}, CSW_{S3}
		82.1	76.0	79.5	CL, CSW_{S1}
Chinese[39]	MDCT	80.4	83.0	81.6	SI, CL, MW
		72.7	80.4	76.1	MW, MI
Saudi[37]	MDCT	87.0	94.0	90.5	ML, B, MW, CSW_{S1}
		89.5	85.0	94.0	ML, B, MW, CSW_{S1}, CSW_{S3}
		80.0	80.0	80.0	ML, MW
		88.0	89.0	88.5	MW, CSW_{S1}, CSW_{S3}
Croatian[13]	MSCT	89.0	92.7	90.6	MW, B, CSW_{S1}
Turkish[9]	MDCT	83.8	86.1	–	ML, B, CSW_{S1}, CSW_{S3}
		80.5	81.7	–	ML, B
		83.8	83.7	–	ML CSW_{S1}, CSW_{S3}
Turkish[35]*	MSCT	87.8	80.4	84.7	ML, B, MW, CSW_{S1}, CSW_{S3}
Western Australian[12]	MSCT	–	–	84.5	CL, CSW_{S1}
		–	–	84.5	MW, CSW_{S1}
		–	–	84.0	CL, MW
Egyptian[27]*	MSCT	–	–	96.7	ML, B, MW, $CSWS_1$, CSW_{S3}

B = Sternal Body Length, CL = Combined Length, CSW_{S1} = Corpus Sterni Width 1st Sternebra, CSW_{S3} = Corpus Sterni Width 3rd Sternebra, MI = Manubrium index calculated as MW/ML × 100, ML = Manubrium Length, MW = Manubrium Width, SBMW = the maximum width of the sternal body after measuring all sternebrae, T = Sternal body thickness.
* Multiple regression analysis was used in this study.

yielded a comparatively lower overall accuracy of 65.8% and a sex bias of 6.8%.

In conclusion, the overall accuracy of sex estimation using sternum in Jordanians varied from 63.2% in young adults, and 83.7% in middle-aged adults to 84.9% for older adults. Sternal variables have limited forensic applicability in young adults and the sternal area is the most accurate single variable for estimating sex in young ages. However, in subjects aged more than 35 years, the equations derived from the discriminant function analysis are reliable and can be used by forensic investigators as sex estimators in Jordanians.

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Author contributions

All authors drafted the work, approved the version to be published; and agreed to be accountable for all aspects of the work. **Heba Kalbouneh:** Conceptualization, Formal analysis; Supervision; Writing - original draft. **Nidaa Mubarak**: Investigation; Methodology. **Salah Daradkeh**: Project administration; Visualization. **Omar Ashour:** Data curation and investigation. **Ahmad Muneer Alkhatib:** Data curation and investigation. **Lojayn Suboh:** Data curation. **Amani Nofal:** Data curation. **Waleed Mahafzah:** Investigation; Methodology. **Mohammad Alsalem:** Validation; Writing - review & editing.

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References

[1] du Jardin P, Ponsaille J, Alunni-Perret V, Quatrehomme G. A comparison between neural network and other metric methods to determine sex from the upper femur in a modern French population. Forensic Sci Int 2009;192:127e121-126.
[2] Primorac D, Schanfield M, Marjanovic D. Primorac D, Schanfield M. Forensic DNA analysis and statistics. Forensic DNA Applications: An Interdisciplinary Perspective 1st ed.2014;CRC Press, 55–82.
[3] Krishan K, Chatterjee PM, Kanchan T, Kaur S, Baryah N, Singh RK. A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. Forensic Sci Int 2016;261:165e161-168.
[4] Iwamura ES, Soares-Vieira JA, Munoz DR. Human identification and analysis of DNA in bones. Rev Hosp Clin Fac Med Sao Paulo 2004;59:383–8.
[5] Darmawan MF, Yusuf SM, Kadir MR, Haron H. Comparison on three classification techniques for sex estimation from the bone length of Asian children below 19 years old: an analysis using different group of ages. Forensic Sci Int 2015;247:130e131-111.
[6] Gonzalez PN, Bernal V, Perez SI. Geometric morphometric approach to sex estimation of human pelvis. Forensic Sci Int 2009;189:68–74.
[7] Bongiovanni R, Spradley MK. Estimating sex of the human skeleton based on metrics of the sternum. Forensic Sci Int 2012;219:290e291-297.
[8] Torimitsu S, Makino Y, Saitoh H, et al. Estimation of sex in Japanese cadavers based on sternal measurements using multidetector computed tomography. Leg Med (Tokyo) 2015;17:226–31.
[9] Ekizoglu O, Hocaoglu E, Inci E, et al. Sex estimation from sternal measurements using multidetector computed tomography. Medicine (Baltimore) 2014;93:e240.
[10] Walker PL. Greater sciatic notch morphology: sex, age, and population differences. Am J Phys Anthropol 2005;127:385–91.
[11] Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci 2011;56:289–96.
[12] Franklin D, Flavel A, Kuliukas A, et al. Estimation of sex from sternal measurements in a Western Australian population. Forensic Sci Int 2012;217:230e231-235.
[13] Bedalov A, Basic Z, Marelja I, et al. Sex estimation of the sternum by automatic image processing of multi-slice computed tomography images in a Croatian population sample: a retrospective study. Croat Med J 2019;60:237–45.
[14] Chandrakanth HV, Kanchan T, Krishan K. Osteometric analysis for sexing of modern sternum—an autopsy study from South India. Leg Med (Tokyo) 2014;16:350–6.
[15] Garcia-Parra P, Perez Fernandez A, Djorojevic M, Botella M, Aleman I. Sexual dimorphism of human sternum in a contemporary Spanish population. Forensic Sci Int 2014;244:313e311-319.
[16] Dwight T. The Sternum as an index of sex and age. J Anat Physiol 1881;15(Pt 3):327–30.
[17] McCormick WF, Stewart JH, Langford LA. Sex determination from chest plate roentgenograms. Am J Phys Anthropol 1985;68:173–95.
[18] Jit I, Jhingan V, Kulkarni M. Sexing the human sternum. Am J Phys Anthropol 1980;53:217–24.
[19] Sidler M, Jackowski C, Dirnhofer R, Vock P, Thali M. Use of multislice computed tomography in disaster victim identification–advantages and limitations. Forensic Sci Int 2007;169:118–28.
[20] Brough AL, Morgan B, Rutty GN. Postmortem computed tomography (PMCT) and disaster victim identification. Radiol Med 2015;120: 866–73.
[21] Blau S, Robertson S, Johnstone M. Disaster victim identification: new applications for postmortem computed tomography. J Forensic Sci 2008;53:956–61.
[22] Brough AL, Bennett J, Morgan B, Black S, Rutty GN. Anthropological measurement of the juvenile clavicle using multi-detector computed tomography–affirming reliability. J Forensic Sci 2013;58:946–51.
[23] Stull KE, Tise ML, Ali Z, Fowler DR. Accuracy and reliability of measurements obtained from computed tomography 3D volume rendered images. Forensic Sci Int 2014;238:133–40.
[24] Corron L, Marchal F, Condemi S, Chaumoître K, Adalian P. Evaluating the consistency, repeatability, and reproducibility of osteometric data on dry bone surfaces, scanned dry bone surfaces, and scanned bone surfaces obtained from living individuals. BMSAP 2017;29:33–53.
[25] Lou L, Lagravere MO, Compton S, Major PW, Flores-Mir C. Accuracy of measurements and reliability of landmark identification with computed tomography (CT) techniques in the maxillofacial area: a systematic review. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:402–11.
[26] Sakuma A, Ishii M, Yamamoto S, et al. Application of postmortem 3D-CT facial reconstruction for personal identification. J Forensic Sci 2010;55:1624–9.
[27] Darwish RT, Abdel-Aziz MH, El Nekiedy AM, Sobh ZK. Sex determination from chest measurements in a sample of Egyptian adults using Multislice Computed Tomography. J Forensic Leg Med 2017;52: 154–8.
[28] Monum T, Makino Y, Prasitwattanaseree S, et al. Age estimation from ossification of sternum and true ribs using 3D post-mortem CT images in a Japanese population. Leg Med (Tokyo) 2020;43:101663.
[29] Monum T, Mekjaidee K, Pattamapaspong N, Prasitwattanaseree S. Age estimation by chest plate radiographs in a Thai male population. Sci Justice 2017;57:169–73.
[30] McCormick WF, Stewart JH. Age related changes in the human plastron: a roentgenographic and morphologic study. J Forensic Sci 1988;33: 100–20.

[31] Chandrakanth HV, Kanchan T, Krishan K, Arun M, Pramod Kumar GN. Estimation of age from human sternum: an autopsy study on a sample from South India. Int J Legal Med 2012;126:863–8.
[32] Jit I, Kaur H. Time of fusion of the human sternebrae with one another in northwest India. Am J Phys Anthropol 1989;80:195–202.
[33] Ashley GT. The relationship between the pattern of ossification and the definitive shape of the mesosternum in man. J Anat 1956;90:87–105.
[34] Bacci N, Nchabeleng EK, Billings BK. Forensic age-at-death estimation from the sternum in a black South African population. Forensic Sci Int 2018;282: 233 e231-233 e237.
[35] Ramadan SU, Turkmen N, Dolgun NA, et al. Sex determination from measurements of the sternum and fourth rib using multislice computed tomography of the chest. Forensic Sci Int 2010;197:120e121-125.
[36] Macaluso PJJr. The efficacy of sternal measurements for sex estimation in South African blacks. Forensic Sci Int 2010;202: 111e111-117.
[37] Ahmed AA, Alshammari FO, Alrafiaah AS, Almohaisani AA, Al-Mohrej OA, Alkubaidan FO. Estimation of sex in a contemporary Saudi population based on sternal measurements using multidetector computed tomography. Homo 2017;68:411–21.
[38] Macaluso PJ Jr, Lucena J. Estimation of sex from sternal dimensions derived from chest plate radiographs in contemporary Spaniards. Int J Legal Med 2014;128:389–95.
[39] Zhang K, Luo Y-z, Chen X-g, Deng Z-h. Sexual dimorphism of sternum using computed tomography—volume rendering technique images of Western Chinese. Aust J Forensic Sci 2016;48:297–304.