

# Estimation of sex from sternal dimensions derived from chest plate radiographs in contemporary Spaniards

P. James Macaluso Jr. · Joaquín Lucena

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**Abstract** A number of previous studies have demonstrated that osteometric analysis of the sternum provides a highly accurate method for discriminating adult sex in diverse population groups. In this study, sternal measurements were recorded from posteroanterior digital radiographs of the chest plate of 116 Spanish individuals (65 males and 51 females). Results demonstrated that all linear dimensions of the manubrium and mesosternum, sternal area, and sternal index were significantly sexually dimorphic in this population group. Discriminant function analyses incorporating several of these variables, individually or in combination, provided sex classification accuracy rates greater than 80.0 %, with associated sex biases below 5.0 %. A stepwise procedure, which can be used when a complete sternum is present, yielded the highest correct sex classification rate at 89.7 %. Only slightly lower allocation accuracy rates were obtained for multivariate equations which incorporated either dimensions of the manubrium or mesosternum (87.1 % for both formulae). Thus, the derived discriminant function equations should prove useful in forensic investigations, particularly those in which the pelvis or bones of the extremities are not available for analysis.

**Keywords** Forensic science · Forensic anthropology · Sex discrimination · Sternum · Digital radiographs · Spain

## Introduction

When unidentified human remains are recovered, the sex of an individual is often the first biological attribute to be assessed, as subsequent methods for age at death and stature estimation are sex dependent. Next to the pelvis, the skull is commonly

regarded as the most accurate indicator of sex [1–3]. However, Spradley and Jantz [4], using a modern forensic sample, demonstrated that most bones of the postcranium outperform the skull in their sex discriminating capabilities.

Although the sternum was not included among the skeletal elements examined by Spradley and Jantz [4], a number of other recent studies have established the high diagnostic value of this bone for osteometric sex assessment. For example, discriminant function analysis incorporating sternal area, which is calculated from five linear dimensions of the manubrium and mesosternum (corpus sterni or sternal body), yielded a classification accuracy rate of 86.9 % for a black South African sample [5]. In addition, the combination of only two measurements, namely, corpus sterni length and manubrium width, provided nearly the same allocation accuracy (86.4 %). Furthermore, length of the sternal body, when used in isolation, yielded a sex prediction success rate of 83.5 % for that study population. Additional investigations of the sternum, utilizing measurements derived from either bone specimens [6–11] or computerized medical images [12–14], have provided similar sex allocation accuracy rates (80–90 %) for diverse population groups.

However, previous studies of the sternum, as well as many other skeletal elements, have also demonstrated that osteometric standards for estimating sex cannot be accurately applied to other disparate samples, as human groups differ with regard to body size, robusticity, and the degree of sexual dimorphism exhibited by the skeleton. In addition, populations may experience secular changes, thus requiring the use of temporally representative skeletal collections in the derivation of anthropological standards, including those for the discrimination of sex [15, 16]. Therefore, the objective of the present study was to develop population-specific discriminant function equations for predicting sex from measurements of the sternum in a contemporary Spanish population sample. These models will be of practical use to forensic

P. J. Macaluso Jr. (✉) · J. Lucena  
Institute of Legal Medicine, 41915 Seville, Spain  
e-mail: p.james.macaluso@hotmail.com

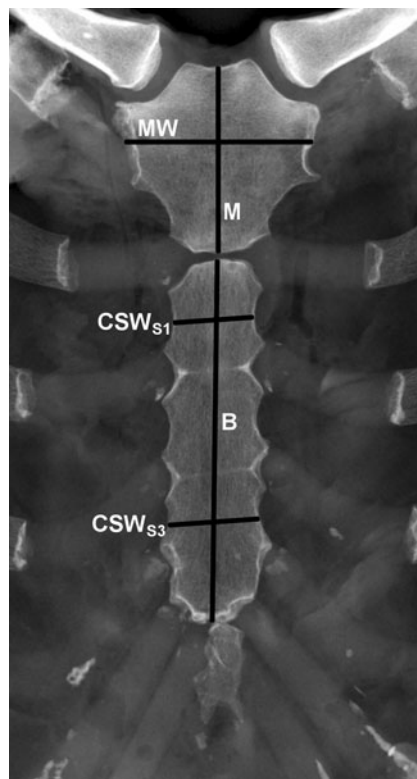
pathologists and anthropologists working in Spain, given that unidentified human remains may be found decomposed, mutilated, or scattered, and thus, reliable standards must be available for a variety of complete and fragmentary bones.

## Materials and methods

The material utilized in the present study was obtained from decedents brought to the Forensic Pathology Service at the Institute of Legal Medicine in Seville, Spain, for postmortem examination between August 2012 and July 2013. The analyzed sample comprised the sterna of 116 adult individuals, including 65 males and 51 females, of Spanish Caucasian descent. All of the individuals included in the study sample were positively identified at the time of autopsy and had associated medical records and personal identification documents which stated that they were Spanish nationals and provided demographic data, such as date of birth. Ethnicity was further supported by soft tissue, interviews with relatives and the Spanish origin of the decedent's surnames which clearly indicated that the individual was of Caucasian descent. The ages at death ranged between 22 and 91 years, with a mean age of  $55.8 \pm 17.3$  years for males and  $63.3 \pm 19.0$  years for females (Table 1). Sterna that exhibited trauma or pathology, as assessed from radiographic images (see below), were excluded from the sample.

The chest plate, consisting of the complete sternum, costal cartilages, and medial ends of the first through seventh ribs, was excised from cadavers during postmortem examination. After removal, calibrated digital radiographs of individual chest plates were obtained using the Carestream DirectView Vita CR (Carestream Health, Rochester, NY, USA) image acquisition and processing system. The same procedure was used for all radiographs, with posteroanterior projection at a focus distance of 100 cm and exposure parameters set at 60 kVp and 6.3 mAs. A posteroanterior orientation was selected to obtain proximity of the sternum to the photostimulable phosphor (PSP) detector plate, resulting in negligible image magnification and distortion.

The following set of standard linear dimensions were then recorded, to the nearest tenth of a millimeter according to the definitions provided by Ashley [17] and McCormick et al. [18], from the digital images using the measurement tools



**Fig. 1** Digital posteroanterior radiograph depicting linear measurements of the sternum

included within the computer-based image analysis program associated with the radiographic system (Fig. 1):

- Manubrium length ( $M$ ): midsagittal distance from the suprasternal notch to the manubriosternal junction.
- Corpus sterni (sternal body or mesosternum) length ( $B$ ): midsagittal distance from the manubriosternal junction to the mesoxiphoidal junction.
- Manubrium width ( $MW$ ): distance between midpoints of the facet for the first costal cartilage on each side of the bone.
- Corpus sterni width at first sternebra ( $CSW_{S1}$ ): distance at the level of the line passing from the midpoint between the facet for the second and third costal cartilages on each side of the bone.
- Corpus sterni width at third sternebra ( $CSW_{S3}$ ): distance at the level of the line passing from the midpoint between the facet for the fourth and fifth costal cartilages on each side of the bone.

The above-listed linear measurements were also used to compute the following sternal dimensions and indices, according to the techniques described by Ashley [17] and McCormick et al. [18]:

- Combined length of the manubrium and corpus sterni ( $CL$ ): calculated as the sum of  $M$  and  $B$  ( $M + B$ ).

**Table 1** Sex and age at death distribution of the study sample

	$n$	Mean	SD	Median	Minimum	Maximum
Male	65	55.8	17.3	56.0	23	88
Female	51	63.3	19.0	65.0	22	91

- Sternal area (SA): calculated by multiplying the sum of  $M$  and  $B$  with the sum of  $MW$ ,  $CSW_{S1}$ , and  $CSW_{S3}$  divided by 3  $[(M + B) \times (MW + CSW_{S1} + CSW_{S3})/3]$
- Manubrium index (MI): calculated as the division of  $MW$  by  $M$ , multiplied by 100  $[(MW/M) \times 100]$ .
- Sternal index (SI): calculated as the division of  $M$  by  $B$ , multiplied by 100  $[(M/B) \times 100]$ .
- Corpus sterni index (CI): calculated as the division of  $CSW_{S1}$  by  $CSW_{S3}$ , multiplied by 100  $[(CSW_{S1}/CSW_{S3}) \times 100]$ .

In sterna with complete fusion (no fusion scar present) of the manubrium and mesosternum, the midpoint of the two articular facets for the second costal cartilage along the lateral borders of the sternum formed the landmark to differentiate the two elements [18]. Similarly, in sterna with complete fusion of the mesosternum and xiphoid process, the inferior margin of the two articular demifacets for the seventh costal cartilage along the lateral borders of the sternal body formed the landmark to differentiate the two structures [19]. The xiphoid process was not included in this study, given the high variability in size and shape of this structure [19, 20].

The five linear measurements of the manubrium and mesosternum were recorded a second time for all specimens by the same observer, with a minimum of 2 weeks between measurement sessions. Intraobserver error was calculated as a percentage to quantify the magnitude of the random measurement error. Following the equation presented by Albanese and colleagues [21, 22], the absolute difference between the two measurements was divided by the first measurement and then multiplied by 100 for each specimen. The mean error for the sample was subsequently calculated. Mean intraobserver error below 2.0–2.5 % is considered acceptable for osteometric sex discrimination as misallocation is possible when measurement error exceeds this threshold [21].

The D'Agostino-Pearson omnibus test was conducted for all variables to determine whether the data was normally distributed [23]. Levene's test was employed to test the homogeneity of variances. A one-way analysis of variance (ANOVA) was then used to calculate the means, standard deviations, and standard errors for the various sternal measurements and indices and to compare the mean differences between the sexes. Following this, the five linear sternal dimensions were entered into a stepwise discriminant function procedure to select the subset of variables which most accurately differentiates the sexes. Separate stepwise discriminant functions were also generated for the manubrium (two variables) and mesosternum (three variables) to account for the presence or absence of either element in medicolegal investigations. In addition, direct discriminant function analysis was also performed on all individual sternal measurements (e.g., manubrium length) and indices (e.g., sternal index) observed to be significantly dimorphic, to obtain formulae that may be

used with more fragmentary remains. Classification accuracies of the derived discriminant functions were obtained by the leave-one-out cross-validation procedure. All statistical analyses were conducted using the SPSS 14.0 statistical software package (SPSS, Inc., Chicago, IL).

## Results

Intraobserver error percentages were low and within acceptable limits, ranging from 0.59 % for manubrium length to 1.60 % for manubrium width. The latter measurement was the most difficult to replicate as the first costal cartilage was at times ossified in individuals above 50 years of age, thus obscuring the lateral borders of the manubrium. The results of the D'Agostino-Pearson omnibus test demonstrated that the data was normally distributed for all sternal variables ( $K^2 \leq 5.534$ ,  $p \geq 0.063$ ). The assumption of homogeneous variances was satisfied for all sternal measurements and indices (Levene's test,  $F \leq 2.947$ ,  $p \geq 0.089$ ).

The descriptive statistics for the linear measurements and calculated sternal dimensions and indices are reported in Table 2. Mean values for the male sample were greater than those for the female sample for all variables except sternal index and corpus sterni index. The ANOVA results demonstrated that the difference between male and female mean values for all linear dimensions and sternal area was highly significant ( $p < 0.0001$ ). For computed indices, mean values for sternal index were also significantly dimorphic ( $p = 0.006$ ), whereas manubrium index and corpus sterni index did not differ significantly between the sexes ( $p \geq 0.357$ ), and thus, these two indices were not included in the classification analysis.

The results of the discriminant function analyses for sternal dimensions are presented in Table 3. The stepwise analysis of the five linear dimensions, in which all measurements except corpus sterni width at the third sternebra were selected, yielded a sex classification accuracy rate of 89.7 % and a sex bias (difference between male and female accuracy rates) of 2.6 %. For the manubrium, both length and breadth measurements were selected in the stepwise analysis, providing a sex prediction success rate of 87.1 % with a sex bias of 1.4 %. The stepwise analysis for the mesosternum, which incorporated corpus sterni length and width at the first sternebra, yielded the same allocation accuracy (87.1 %) and a similar sex bias (4.9 %) as the stepwise analysis of manubrium dimensions. The classification accuracy rates of the univariate discriminant function analyses are lower than those obtained for the multivariate analyses, with the exception of sternal area. Sternal area correctly assigned a similar percentage of specimens as the stepwise analyses of the five linear variables (88.8 %), but with a slightly higher sex bias (6.0 %). Manubrium width correctly estimated the sex of 85.3 % of the individuals in the study sample, with a sex bias of 1.7 %.

**Table 2** Descriptive statistics and ANOVA results for the linear and calculated sternal variables

Variables	Males ( <i>n</i> =65)			Females ( <i>n</i> =51)			<i>F</i> value
	Mean ± SD	SE	Range	Mean ± SD	SE	Range	
<i>M</i>	51.85±4.74	0.59	40.0–64.4	45.85±4.76	0.67	35.2–58.7	45.579**
<i>B</i>	106.25±11.05	1.37	90.0–139.0	87.77±9.61	1.35	66.2–105.5	89.395**
<i>CL</i>	158.10±12.70	1.58	137.1–196.0	133.62±11.22	1.37	102.1–155.7	117.376**
<i>MW</i>	59.78±3.65	0.45	52.8–68.5	51.82±4.34	0.61	41.3–66.1	115.062**
<i>CSW<sub>S1</sub></i>	28.31±3.28	0.41	22.1–38.3	24.68±4.43	0.62	17.3–39.1	25.710**
<i>CSW<sub>S3</sub></i>	35.36±5.00	0.62	25.5–48.5	30.15±5.51	0.77	21.1–45.9	29.276**
<i>SA</i>	6,506.42±703.29	87.23	4,808.1–8,441.1	4,752.66±687.95	96.33	3,463.9–6,573.0	181.728**
<i>MI</i>	116.15±12.35	1.53	97.5–166.0	114.09±14.48	2.03	85.2–156.0	0.679
<i>SI</i>	49.22±6.06	0.75	35.2–65.3	52.80±7.59	1.06	37.6–74.6	7.985*
<i>CI</i>	81.09±11.44	1.42	59.4–112.6	82.87±12.03	1.69	55.1–103.2	0.856

*M* manubrium length, *B* corpus sterni length, *CL* combined length of the manubrium and corpus sterni, *MW* manubrium width, *CSW<sub>S1</sub>* corpus sterni width at first sternebra, *CSW<sub>S3</sub>* corpus sterni width at third sternebra, *SA* sternal area, *MI* manubrium index, *SI* sternal index, *CI* corpus sterni index

\**p*<0.01, statistically significant; \*\**p*<0.0001, statistically significant

The other sternal dimensions, such as manubrium length, mesosternum length, combined length, and corpus sterni width at both the first and third sternebrae, provided less accurate sex classifications, ranging between 70.7 and 81.0 %. Sternal index, which was less sexually dimorphic than the linear variables and sternal area, yielded an allocation accuracy rate only slightly higher than chance (58.6 %).

## Discussion and conclusions

The results of this study demonstrate that osteometric analysis of the sternum is an effective method for estimating adult sex in the contemporary Spanish population. The majority of sternal dimensions and indices are highly sexually dimorphic in this population group, and thus, several of these variables, individually or in combination, provide sex classification accuracy rates greater than 80.0 %, with associated sex biases below 5.0 %. Multivariate discriminant function equations, incorporating dimensions of the manubrium, mesosternum, or both, generally provide the highest sex allocation accuracies (87.1–89.7 %). Sternal area also provides a sex prediction success rate approaching 90 %; however, as with the multivariate equations, a largely complete sternum is required to utilize this discriminant function, given that length and breadth dimensions of both the manubrium and mesosternum are needed to calculate sternal area.

Individual sternal dimensions, which can be utilized with fragmentary human remains, may also be of value in the estimation of sex, as all variables provide classification rates over 70 %. In particular, the univariate discriminant function equation for manubrium width yields an allocation accuracy rate (85.3 %) which is only slightly lower than that of the

multivariate equation (87.1 %) which also incorporated manubrium length, and thus, the univariate equation should prove to be more useful in forensic contexts, as it can be employed in situations in which the superior or inferior margin of the manubrium is damaged or missing. Furthermore, the discriminant function equations incorporating manubrium dimensions may have more practical utility, given that this section is the thickest and most robust part of the sternum [20], and as a result, it may more often be recovered intact.

The results of this study also reaffirm the effectiveness of the sternum for estimating the sex of human remains recovered in forensic contexts. As reviewed in a previous investigation by the first author [5], osteometric analysis of this skeletal structure, either directly through the measurement of dry bone or indirectly via medical imaging techniques, provides a classification accuracy rate at a level approaching and even surpassing 85 % for a range of population groups [7, 12, 13, 18, 24, 25]. Additional studies published subsequently have yielded results consistent with this observation [9–11]. For example, a recent investigation concerning the discrimination of sex from sternal dimensions obtained from multislice spiral computed tomography (MSCT) scans of Western Australians demonstrated that multivariate analysis, incorporating mesosternum length and corpus sterni width at the first sternebra, provides a maximum allocation accuracy rate of 84.5 % [14]. However, the results of the current study, as well as those just mentioned, also confirm the population-specific nature of the osteometric standards, as mean values for sternal measurements generally differ between disparate population samples (see Table 4 in [9] and Table 7 in [11] for a comparison of population statistics).

**Table 3** Discriminant function equations and cross-validated classification accuracies for sternal dimensions

Variable(s)	Unstandardized coefficient	Group centroid		Sectioning point	Correctly classified (%)		
		Male	Female		Male	Female	Overall
Stepwise analysis (5 variables) <sup>a</sup>							
MW	0.069	1.147	-1.462	-0.1575	90.8	88.2	89.7
<i>B</i>	0.054						
<i>M</i>	0.114						
CSW <sub>S1</sub>	0.078						
Constant	-17.238						
Stepwise analysis (manubrium)							
MW	0.085	0.960	-1.223	-0.1315	87.7	86.3	87.1
<i>M</i>	0.210						
Constant	-16.011						
Stepwise analysis (mesosternum) <sup>a</sup>							
<i>B</i>	0.087	0.945	-1.205	-0.1300	89.2	84.3	87.1
CSW <sub>S1</sub>	0.150						
Constant	-12.533						
Direct analysis							
<i>M</i>	0.211	0.555	-0.708	-0.0765	72.3	72.5	72.4
Constant	-10.361						
<i>B</i>	0.096	0.778	-0.991	-0.1065	75.4	84.3	79.3
Constant	-9.393						
CL	0.083	0.891	-1.136	-0.1225	80.0	82.4	81.0
Constant	-12.201						
MW	0.252	0.882	-1.124	-0.1210	84.6	86.3	85.3
Constant	-14.188						
CSW <sub>S1</sub>	0.261	0.417	-0.531	-0.0570	73.8	72.5	73.3
Constant	-6.980						
CSW <sub>S3</sub>	0.189	0.445	-0.567	-0.0610	69.2	72.5	70.7
Constant	-6.277						
SA	0.001	1.109	-1.413	-0.1520	86.2	92.2	88.8
Constant	-8.219						
SI	0.148	-0.232	0.296	-0.0440	60.0	56.9	58.6
Constant	-7.497						

<sup>a</sup> Variable CSW<sub>S3</sub> was not selected in the analysis

In addition, different sternal variables, either individually or in combination, yield the most accurate sex classification results for the various population groups investigated.

The sex classification results of the present study are broadly similar to those observed by Fernández and colleagues [26] in an earlier investigation concerning the sex discrimination potential of sternal dimensions in the Spanish population. In that study, the authors reported a maximum allocation accuracy rate of 90 % for both combined sternal length and length of the mesosternum, using decision trees with optimum cutoff points for the two dimensions. The maximum sex prediction success rate obtained in the current study was nearly identical to that observed by Fernández et al. [26], although the accuracy rates of the univariate discriminant function equations for mesosternum and combined sternal length dimensions were lower, with values around 80 %.

However, in the current study, the sex classification accuracies obtained from the discriminant function analyses represent cross-validated values, and thus, these accuracy rates more likely depict the true discriminatory ability of sternal dimensions, given that the same data was not used for generating the osteometric standards and evaluating their accuracy. In addition, sample size in the current study was considerably larger than that utilized by Fernández et al. [26], as poor bone preservation precluded the measurement of various sternal dimensions for a number of individuals in their investigation. For example, the largest number of specimens analyzed was 76 for manubrium length, while a minimum of only 60 individuals was examined for combined sternal length, which was used to establish one of the most effective cutoff points for discriminating sex. Therefore, the results obtained in the present study may more accurately reflect the range of variation,



both within and between sexes, present in sternal dimensions in the Spanish population. Nonetheless, additional research utilizing even larger samples and from other geographic regions of Spain should be conducted in order to validate the results of the current study as well as to determine the extent of the applicability of the derived discriminant functions.

The classification results of the current study are also generally consistent with those reported in previous investigations concerning the discrimination of sex in the contemporary Spanish population using linear dimensions of other postcranial bones, including the femur [27], metacarpals [28], and carpal bones [29]. Likewise, the allocation accuracy results observed in the present study are fairly similar to those reported in a recent investigation regarding the estimation of sex from measurements of the sternal extremity of the left fourth rib [30]. In the latter investigation, multivariate analysis incorporating both superior–inferior height and anterior–posterior breadth dimensions yielded a sex prediction success rate of 86 %, while univariate analysis provided accuracy rates of 84 and 77 % for height and breadth dimensions, respectively. In addition, Ruiz-Mediavilla and colleagues [31] obtained comparable, although slightly higher, allocation results for bone volume measurements of the radius and talus recorded from 3D images of scanned specimens. In that study, the authors observed correct sex classification accuracy rates of 91 and 94 % for total volume of the talus and radius, respectively. Furthermore, the volumes of different anatomical regions of the two bones, such as the diaphysis and radial head, yielded allocation rates ranging from 80 to 97 %. However, it should be mentioned that a 3D scanner and the associated computer software programs used to process the data may not be available to forensic investigators in many contexts. Therefore, although bone volume measurements may provide superior sex allocation accuracy rates, osteometric methods based on the direct examination of bone specimens or the analysis of radiographic images, as proposed in the present study, currently have more practical utility.

In summary, osteometric analysis of the sternum provides a sex classification accuracy rate of approximately 80–90 % in the Spanish population, an accuracy level similar to that observed for a number of other population groups. Thus, the discriminant function equations developed in this study should prove useful in forensic investigations, particularly those in which the pelvis or bones of the extremities are not available for analysis. The previously derived osteometric standards for the left fourth rib, which provide sex allocation accuracy rates within the range mentioned above, may also be used in these contexts [30]. However, the advantage of using the method proposed in the current study is that when human remains are disarticulated or fragmentary, the sternum or even a part of this bone such as the manubrium is easier to identify than the left fourth rib. Furthermore, if the remains are not completely skeletonized, no pre-analysis processing is

required to remove any soft tissue adhering to the sternum, as is necessary for the fourth rib. It is important to note, however, that the discriminant function equations generated in the current study should only be applied to sternal measurements recorded from digital radiographs, as there may be a slight discrepancy between those obtained from radiographs and dry bone specimens, due to the small magnification produced by radiographic images and the possible shrinkage of skeletonized remains [32, 33]. Finally, given the relatively small size of the study sample, it is further recommended that additional investigations be conducted on other documented Spanish population samples to confirm the findings of the present research.

### Key points

1. Sternal measurements were recorded from posteroanterior digital radiographs of the chest plate of 116 individuals, including 65 males and 51 females, of Spanish Caucasian descent.
2. ANOVA results demonstrated that the difference between male and female mean values for all linear dimensions of the manubrium and mesosternum, as well as sternal area and sternal index, was significant, whereas manubrium index and corpus sterni index did not differ significantly between the sexes.
3. A number of univariate and multivariate discriminant function equations incorporating the significantly dimorphic variables provided sex classification accuracy rates between 80 and 90 %, with associated sex biases below 5.0 %.
4. These osteometric equations therefore provide an effective method for assessing sex in this population group, particularly in situations in which the pelvis or bones of the extremities are not preserved.

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**Conflict of interest** The authors declare that they have no conflict of interest.

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