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THE STERNUM AS A SEX DISCRIMINATOR IN A CONTEMPORARY SPANISH POPULATION

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Abstract: The sternum is a bone that is useful in the morphological discrimination of sex, especially when other bones with greater discriminating capacity are not available, such as the pelvis and certain long bones.

Satisfactory results obtained in different investigations, as well as the need to have more specific population reference values, have led to a significant increase in studies and publications in this regard.

In the present study, we analyse the utility of the sternum as a sex discriminator in a sample of 202 sternums (117 men, 85 women), from corps exhumed in the last 50 years, corresponding to the contemporary Spanish population. All the metric variables (lengths of manubrium of sternum and body of sternum, total length, and width at the level of the first and third sternebrae) have been statistically classified using discriminant analysis and decision trees. The best results, in agreement with multiple works, are provided by the total sternal length. A measure of the total length, "the 141.5 rule" (the length of the male sternum exceeds 141.5 mm, whereas the length of the female sternum is equal or less) allows us to discriminate 86.1% of the sternums of the sample, with a sex bias of 5.7. Consequently, this bone can be useful in forensic studies of bone remains of unknown identity.

Keywords: sternum, sex estimation, decision tree, discriminant functions, forensic anthropology, forensic science, identification.

INTRODUCTION

The determination of sex through bone remains constitutes a basic parameter in legal medical identification studies and in general studies in anthropology [1,2]. This determination reduces the possible identity by 50% in forensic medical investigations of unidentified skeletons [3]. Knowledge of sex will condition the appraisal of other identifying characteristics, such as age, ancestral group or height [4,5].

Sex assignment from bone remains can be carried out through three methods: 1) morphological, with the subjectivity that it entails; 2) genetic, which, in addition to the economic cost, requires an adequate conservation of the genetic material; and 3) osteometric, conditioned to the availability of population-specific data [6].

Even though the pelvis and, to a lesser degree, some long bones and the skull are still preferred in sex determination by anthropological methods [7,8], in certain circumstances these may be missing or incomplete [1]. This would be the case in major catastrophes, criminal dismemberments, fires and explosions, or as a result of taphonomic phenomena such as animal bites [9-11]. It is in these cases that examination of other bones, such as the sternum, may be most useful [12]. The Forensic Anthropology Data Bank [13] shows that the sternum was recovered in 59% of the events studied, included in the anterior part of the thoracic skeleton [14]. In addition, the sternum is a bone resistant to the effects of putrefaction [15].

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The use of the sternum as a sex discriminator has been the subject of numerous research works. It has also been used in the estimation of height [16-19] or age [20-22], although with uncertain results. For its statistical analysis, different methodology has been used: fundamentally discriminant analysis, regression equations and calculation of limit points and demarcation [23]. Bone dimensions have usually been measured directly in bone [23,24] or indirectly through radiological images or CT images [1,13,25].

The dimensions of the sternum, as it occurs in the entire skeleton, show inter-population variations; therefore, it is important to have reference values that are as specific as possible when investigating the identification of bone remains, and there are an increasing number of publications in this regard [15,26].

The present work analyses the utility of the sternum as a discriminating factor of sex in a contemporary Spanish population, through discriminant analysis and decision trees.

METHODS

The sample consists of a total of 202 complete sternums, 117 male (57.9%) and 85 female (42.1%), from the collections of the Anthropology Laboratory of the Institute of Legal Medicine of Madrid and the Faculty of Medicine of the Complutense University of Madrid (Spain). The collections are part of the donations of bodies exhumed in the last 50 years, in the Community of Madrid, being of Mediterranean Caucasoid origin.

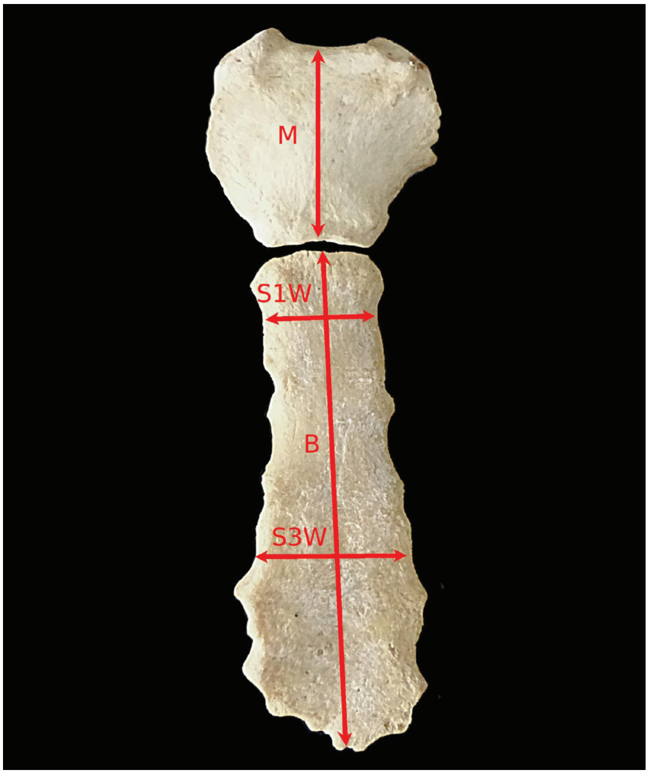

Figure 1. Measures of the sternum.

Measurements have been obtained using a Vernier calliper to the nearest millimetre, according to the technique described by Ashley [27].

Only complete sternums have been analysed, and measurements that could be affected by any type of process, such as congenital alterations, surgeries, fractures or taphonomic processes, have been excluded. Definitions of the sternal measurements, according to various authors, are [4,12,13,28-30] (Fig. 1):

- Manubrium length (M): direct distance, from the anterior aspect and in the midline, from jugular notch to mesoxiphoidal junction.

- Sternal body length (B): direct distance, from the anterior aspect and in the midline, from manubrioesternal to mesoxiphoidal junction.

- Combined length of manubrium and body or total length (CL): sum of the manubrium and body lengths (M+B).

- Sternal body width at first sternebra (S1W): the direct distance between the left and right first sternebra (depressions between the articulation notches for the second and third costal cartilage).

- Sternal body width at third sternebra (S3W): the direct distance between the left and right third sternebra (depressions between the articulation notches for the fourth and fifth costal cartilage).

- Sternal index (SI): calculated as the division of M by B, multiplied by 100. Its mathematical expression is SI = M/B x 100.

- Corpus sternal index (CSI): calculated as the division of S1W by S3W, multiplied by 100. Its mathematical expression is CSI = S1W/S3W x 100.

In cases of fusion of the manubrium with the mesosternum, or the mesosternum with xiphoid process, we have used the fusion scar as a reference. This fusion scar corresponds, in the first case, with a line drawn between the articular facets of the second intercostal cartilage and, in the second case, with a line below the lower margin of the hemifacets for the seventh costal cartilage [13,25].

For the evaluation of intraobserver errors, the Interclass Correlation Coefficient (ICC) was calculated and interpreted according Cicchetti [31]: <0.40 level of significance is poor, 0.40-0.59 is fair, 0.60-0.74 is good and 0.75-1.00 is excellent.

All statistical analyses were performed with SPSS Statistics Base (v 25.0; IBM) with statistical significance set at 95% ($P \leq 0.05$). For the statistical difference between the means, a parametric test, the analysis of variance (ANOVA), was used.

A Kolmogorov-Smirnov test was performed to determine if the variables followed a normal pattern.

All variables were included into a stepwise discriminant function procedure, with CL and S1W being chosen, while CL depends on B and M. Likewise, separate stepwise discriminant functions were also generated for each of the variables. The classification precision was assessed through cross-validation.

The demarcation points were calculated using decision trees, that classify cases into groups or predict values of a dependent (target) variable based on values of independent (predictor) variables.

The four algorithms as growing methods, CHAID (Chi Square Automatic Interaction Detector), CRT (Classification and Regression Tree), Exhaustive CHAID and QUEST (Quick Unbiased Efficient Statistical Tree), have been applied to all the variables in order to select the one that combines greater classification precision with lower sex bias. In all the variables, the best results have been obtained with the QUEST method, a statistical algorithm that selects variables without bias and builds accurate binary trees quickly and efficiently.

Table 1. Age and sex at death distribution

	n	Mean	SD	EE	Range
Male	117	58.86	18.19	1.68	28-93
Female	85	68.59	18.68	2.02	21-97
Total	202	62.96	18.97	1.33	21-97

RESULTS

Population data

The mean age in the whole sample was 62.8 years; 58.79 years in the case of men and 68.59 years in women (Table 1).

Variations intra-observer

ICC provided results greater than 70 in all variables. The best correlation was obtained with the CL, $0.997 \leq ICC \leq 0.983$, and the worst with S1W, $0.987 \leq ICC \leq 0.915$.

Descriptive statistics

The Kolmogorov-Smirnov test showed significance $p>0.05$ for all variables, indicating a normal distribution in all cases.

Statistical results are shown in Table 2. All the variables show a significant difference between the mean of both sexes, higher in the case of CL ($F = 191.361$) and B ($F = 151.435$) and lower in S3W ($F = 21.827$). The superposition of values, as we will see, restricts its discriminant utility.

SI values were lower than 50 in 57.8% of male sternums and higher than 50 in 75% of female sternums (Table 3).

No significant differences were obtained between the CSI means in both sexes (Table 4).

Discriminant analysis

The step-by-step analysis, with a sample size of 148 cases, selects CL and S1W as variables, discriminating 85.1% of the sternums after cross validation, with a sex deviation of 1.8.

Table 2. Descriptive statistics

Male					Female				F	*p*
Variable	***n***	**Mean±SD**	**SE**	**Range**	***n***	**Mean±SD**	**SE**	**Range**		
M	103	51.35±4.79	0.47	40-70	77	46.49±4.03	0.46	38-60	51.564	<0.001
B	98	102.98±9.08	0.91	80-123	71	85.20±9.53	9.53	64-109	151.435	<0.001
CL	87	154.76±10.38	1.11	125-176	64	131.06±10.42	1.30	113-157	191.361	<0.001
S1W	103	26.81±3.25	0.32	20-34	79	23.78±3.09	0.34	19-32	40.235	<0.001
S3W	104	32.70±5.17	0.50	20-48	70	28.93±5.30	0.63	20-44	21.827	<0.001

Table 3. SI statistical values

	n	**Mean**	**SD**	**Range**	**According Hyrtl´s Law**
Male	90	50.15	7.46	34.07-78.57	57.80%
Female	64	54.91	8.12	38.88-78.12	75.00%

Table 4. CSI statistical values

	n	**Mean ± SD**	**Range**	**F**	***p***
Male	101	83.13±11.74	56.25-117.24	0.100	0.752
Female	69	83.71±11.65	63.63-121.73		

Univariate discriminant analysis of manubrium length (M) provided a predictive capacity of 68.9%, with a very high sex bias of 18.3. The sternal body length (B) classified 84.6%, with a sex bias of 7.5. The total length (CL) classified 86.1%, with a sex bias of 5.7.

The S1W width classified 69.2% of the sternums, with an elevated sex bias of 12.8. The S3W width classified 71.3% of the sternums, with a disproportionate sex bias of 35.2. The different discriminant functions are shown in Table 5.

Limiting points

Decision tree classification has been used to calculate limiting points (Table 6). Coinciding with the discriminant analysis, the highest results correspond to the joint measurement of the manubrium and sternal body, CL, where a length of 141.5 mm also discriminates 88.5% of the sternums, with a sex deviation of 5.7.

CL measurements are followed in precision by the limiting point for the sternal body length, which discriminates 84.6% of the sternums. The less reliable results again corresponded to the widths S1W and S3W, with the lowest hit percentage and the highest sex bias, respectively.

DISCUSSION

In the present study, the mean age of the deceased was 58.79 years for men and 68.59 years for women. This mean age is higher than that of some series consulted, such as that of Franklin *et al.* [4] (25.2 years in men and 25.1 years in women) or that of Singh and Pathak [23] (36.38 years in men and 35.25 years in women), while approaching the mean age of other series, such as that of Myint *et al.* [14] (67.34 years in men and 65.84 years in women), Bedalov *et al.* [6] (61.3 years in men and 62.6 years in women) or that of García *et al.* [32] (62.33 years in men and 69 years in women). In relation to the possible influence of age on sternal dimensions, Ashley [33] indicated an increase in sternal length and width between 2 and 7% from the age of 50, with only a partial influence on sexual discrimination. With the same purpose, Ramadan *et al.* [28] divided the sternums of his study into 4 age groups, without finding significant differences between the statistical means of each group.

Similarly, in this study we have grouped the ages into intervals of 20-40, 41-60, 61-80 and >80 years, without finding any significant differences between the means of each variable in each group, obtaining a $p>0.05$.

Table 5. Direct and stepwise discriminant analysis, cross-validated classification accuracies

Variable	Unstandardized coefficient	Group centroid		Correct prediction rates (%)			Sex bias (%)
		Male	Female	Male	Female	Overall	
Direct analysis							
M	0.223	0.463	-0.619	76.7	58.4	68.9	18.3
Constant	-10.977						
B	0.108	0.806	-1.112	87.8	80.3	84.6	7.5
Constant	-10.301						
CL	0.096	0.966	-1.313	88.5	82.8	86.1	5.7
Constant	-13.912						
S1W	0.314	0.412	-0.537	74.8	62.0	69.2	12.8
Constant	-8.006						
S3W	0.190	0.273	-0.420	85.2	50.0	71.3	35.2
Constant	-5.919						
Stepwise analysis (overall sternum)							
CL	0.090	0.953	-1.356	85.9	84.1	85.1	1.8
S1W	0.068						
Constant	-14.776						

Table 6. Limiting points

Variable	Limiting point	Correctly classified (%)			Sex bias
		Male	Female	Overall	
M	>48.2	70.9	72.7	71.7	-1.8
B	>92.5	87.8	80.3	84.6	7.5
CL	>141.5	88.5	82.8	86.1	5.7
S1W	>24.5	74.8	62.0	69.2	12.8
S3W	>27.8	85.6	50.0	71.3	35.6

However, we believe that it would be of interest to study the variations related to age, as well as body size, in depth from larger series, since the existing studies are very limited.

Regarding the value of the sternum as a sex discriminator, this study found a difference between the sexes in all measures, but mainly in total length: 154.76 mm in the male sternums and 131.06 mm in the female sternums.

In general, the sternal measurements obtained correspond to the mean values of other populations consulted (Table 7), being higher than the Indian population and lower than the North American or Canadian population.

Discriminant analysis

In the discriminant analysis, the total length, CL, provided the best results with a predictive capacity of 86.1% and a sex bias of only 5.7 %, while for the sternal body length, B, the classification capacity was 84.6%, although with a higher sex bias of 7.5. The multivariate analysis by steps achieved a slightly lower classification of 85.1%.

The rest of the analysed variables had a predictive capacity close to or less than 70% or a sex bias greater than 5%. These are the minimum values proposed as acceptable [4].

Other studies obtain ratings above 80%, generally through multivariate analysis. Thus Franklin *et al.* [4] obtained 84.5% from the length of the sternal body

Table 7. Data from previous and present research including average measurements (mm)

Region	LM		LC		CL		S1W		S3W	
	M	F	M	F	M	F	M	F	M	F
Africa										
Ashley [33]	45.9	42.4	96.5	82.90	142.6	127.1	24	21.5	30.9	26.8
USA										
Dwight [19]	53.7	49.4	110.4	91.9	164.1	141.3				
Bongiovanni *et al.* [13]	51.84	48.24	104.8	89.38	154.97	136.75	27.35	24.29	34.47	30.15
Canada										
Torwalt *et al.* [43]	54.43	48.79	109.45	93.55	163.84	142.34				
Turkey										
Ramadan *et al.* [28]	53.9	50.3	100.7	85.1	154.6	135.4	28.7	25.2	34.9	30.7
Ateşoğlu *et al.* [38]	51.2	46.7	102.4	86.6	154.1	133.1				
Europe										
Ashley [33]	52.2	47.9	104.7	90.8	156.9	138.7				
Teige [44]	47.7	43.9	103.4	88.5	153.4	133.7	27.1	23.2	34.7	30.9
Spain										
García *et al.* [32]	50.23	44.96	102.98	85.20	154.76	131.06	26.81	23.78	32.70	28.93
Macaluso *et al.* [39]	51.85	45.85	106.25	87.77	158.10	133.62	28.31	24.68	35.36	30.15
Present study	51.35	46.49	101.69	84.07	153.04	129.75	26.91	23.78	32.57	28.93
Australia										
Franklin *et al.* [4]	49.02	45.32	102.94	84.89	151.96	130.22	27.24	27.41	33.17	29.06
Japan										
Torimitsu *et al.* [25]	50.21	46.99	101.18	86.27	151.38	133.25	29.16	24.89	32.93	27.17
Thailand										
Myint *et al.* [14]	48.04	44.32	98.12	83.08	146.20	126.87	25.32	22.34	30.02	27.52
Arabia										
Ahmed *et al.* [9]	47.81	43.37	97.52	81.56	145.33	124.93	24.94	21.83	30.28	26.72
India										
Darwish *et al.* [3]	46.26	43	107.08	104.68	153.08	147.68				
Gautan el al. [22]	53	48	95	76	149	124				
Jit *et al.* [29]	51.73	48.82	95.35	78.6	147.08	127.02	27.45	24.32	32.58	29.19
Singh [23]	52.10	47.17	94.07	78.54	145.69	124.87	27.03	23.11	33.53	28.11
Daphilae *et al.* [35]	48.45	43.78	94.42	70.19	142.19	113.87	27.16	24.44	31.94	28.23
Ankit *et al.* [36]	48.95	44.03	92.11	78.28	141.06	122.31				
Hunnargi *et al.* [37]	51.99	44.88	89.17	72.38	141.16	117.25				
Ganorkar *et al.* [45]	51.44	43.93	89.2	72.39	140.65	116.32	26.98	23.59	32.19	26.08
Chandrakanth *et al.* [24]	48.9	43.7	90.7	78.8	139.8	122.4	27.8	23.2	28.8	25.4
Changani *et al.* [46]	45.6	40.22	92.49	75.89	138.10	116.11				
Brasil										
Queiroz *et al.* [47]			88.87	82.44	134.16	126.12				

and the width at the 1st sternebra; Pons [34] obtained 89% of the total curvilinear and rectilinear lengths, the length of the sternal body, the maximum width of the manubrium and the minimum width of the sternal body; Bongiovanni *et al.* [13] obtained 84.12%, with a bias of 4.12, when including the lengths of the manubrium and the sternal body together with the width S1W and S3W; Ramadan *et al.* [28] obtained 88.2% through the sternal area and the height of the 4th rib; Singh and Pathak [23] obtained 83.7% with a sex bias of -2.8; Dahiphale *et al.* [35] obtained 92% for the male sternums and 87% for the female sternums using the Armitage method and 7 variables; Jit *et al.* [29] obtained 84.9% and 88.6% in each sex; Macaluso [10] obtained 86.4% using the length of the sternal body and the width of the manubrium, and 86.9% through the sternal area, the latter with a sex bias of -7.9; Torimitsu *et al.* [25] reached a global prediction index of 90.5% in the Japanese population; Myint *et al.* [14] obtained 86.4% precision and 9.3 bias in the Thai population; Bedalov *et al.* [6] reported 90.6% by multivariate analysis in a sample of the Croatian population and 84.4% when it included only the total length; Ahmed *et al.* [9] achieved a precision of 90.5% with discriminant analysis and Chandrakanth *et al.* [24] 79.5% with the same method.

Limiting points

The CL variable provides a more precise limiting point, classifying for a value greater than the 141.5 rule, with the same precision and sex bias as the discriminant analysis, 86.1% and 5.7, respectively.

Ashley [27] can be mentioned among the first discriminating rules of sex in the sternum, calculated as the limit point. Based on a study of 573 sternums with European population, this author established a "rule 149", and on 98 sternums with an African population, a "rule 136". Jit *et al.* [29] and Ankit *et al.* [36] verified its behaviour when applied to Indian populations.

In view of Table 8, which shows different rules reported by various authors, the result of the present study is equivalent to a mean value, consistent with the mean value of the anatomical measurements of the sternum.

Limit points in the manubrium: the obtained

Table 8. Rules obtained from sternum total length in different populations

Population	Study	"rule"	Accuracy in identity (%)			Sex bias
			Male	Female	Total	
Europe	Ashley [33]	149	76.7	80.4	78.5	-3.7
USA	Bongiovanni *et al.* [13]	145	82	83	82.5	-1.0
Turkey	Ateşoğlu *et al.* [38]	144	80.41	85.42		-5.01
Turkey	Ramadan *et al.* [28]	142	86.0	80.0		6.0
Australia	Franklin *et al.* [4]	141.09			83.4	0.9
Spain	Present study	141,5	88.5	82.8	86.1	5.7
Africa	Macaluso [10]	136	79.7	88.0	83.0	-8.3
India	Jit *et al.* [29]	136	86.0	78.0		8.0
Africa	Ashley [33]	136	77.6	84.6		7.0
India	Singh *et al.* [11]	133.36	86.9	79.1		7.80
India	Hunnargi *et al.* [37]	131	85.3	77.5		7.8
India	Dahiphale *et al.* [35]	129	91.66	82.97		8.69

Table 9. Hyrtl Law Compliance

Population	Study	% ♂	%♀
India	Darwish *et al.* [3]	89.13	21.05
India	Dahiphale *et al.* [35]	52.20	100
India	Hunnargi *et al.* [37]	18.70	95.00
India	Jit *et al.* [29]	31.08	88.64
India	Jaiswal [15]	89.13	21.05
Turkey	Ramadan *et al.* [28]	34.00	86.00
Bulgaria	Toneva *et al.* [42]	46.8	79.3
Spain	Dorado *et al.* [41]	53,57	78.12
Spain	Present study	57.80	75.00
Europe	Ashley [33]	52.90	69.30
Africa	Ashley [33]	64.70	69.20
USA	Dwight [19]	59.10	60.40
Turkey	Ateşoğlu *et al.* [38]	50.5	67.0
USA	Bongiovanni *et al.* [13]	61.00	55.60

values are better than the values obtained using discriminant analysis. A length of 48.2 mm classifies 71.7% of the sternums, with a sex bias of -2.8. These cut-off values coincide with those of other studies which provide cut-off values of 46.18 mm [10], 49.59 mm [23], 50 mm [37], 50.04 mm [13] or 52 mm [28,38].

Cut points on the sternal body: likewise, the obtained results are more significant than with the discriminant analysis. A length of 92.5 mm classifies 84.6% of the sternums, with a sex deviation of 5.7. Other values reported by researchers have been 77 mm [38], 81 mm [37], 86.64 mm [23], 90.09 mm [10], 91 mm [28], 93.92 mm [4] or 97.09 mm [13].

Cut points in S1W: a width of 24.5 discriminates less than 70%, with a high bias of 14.8. Other authors have provided 25.32 mm [4], 25.82 mm [13], 23.39 mm [10] or 23.98 mm [23].

Cut points in S3W: a width of 27.8 mm classifies 71.3%, but with a disproportionate sex deviation of 35.6%, which makes this measure unreliable. Other authors have provided 32.31 mm [13], 29.54 mm [10] or 29.80 mm [23].

In forensic anthropological analysis, given the type of remains that must usually be analysed, it is of interest to have population references, as well as specific, current ones [4,9]. Factors such as secular changes, physical activity, and nutritional and environmental factors can influence not only skeletal variations between populations, but also make available standards obsolete over time [23].

An example of the variations in skeletal dimensions are those described in the Indian population in relation to the length of the male sternum, varying in the series collected between 153.08 mm [3] and 139.8 mm [24]. On the other hand, it must be considered that, although reference is made to a geographic population, different ethnic groups may coexist within it. These differences could affect anatomical morphology [12]. These possibilities reinforce the interest in testing the equations before using them in a determinate population [1].

In the Spanish population, few studies are found that analyse the utility of the sternum as a discriminating factor of sex [32,39,41]. Macaluso *et al.* [39] obtain the measurements for their analysis through digital radiography (not CT or MR), whose precision with respect to measurements obtained directly may show disadvantages [6,23,28,29,38,40]. Dorado *et al.* [41], using a sample of 98 sternums of the contemporary Spanish population through analysis with decision trees of several nodes, classified more than 90% through CL and B.

Even when the measures are taken rigorously, a distorting factor that must be taken into account when interpreting the results is the inaccuracy derived from variations in bone morphology itself, not dependent on sex. Thus, the distal end of the sternal body is highly variable, as is, to a lesser extent, the jugular notch.

The so-called Hyrtl's Law (1853) is based on the fact that the length of the manubrium is greater than 50% of the length of the sternal body in female sternums, while in men, this proportion would be less. Its mathematical translation is M*100/B. In the present study, only 57.8% of male sternums had a value lower than 50, while 75% of female sternums had a rate higher than 50; thus, the rule is fulfilled, but only partially, fundamentally in the case of women. Therefore, in the present study's cohort, Hyrtl's law does not show a discriminant value for sex. These results agree with those provided by other authors on modern populations, as well as on sternums of medieval dating (Table 9).

The width index is based on the greatest width of the female sternum in its distal portion with respect to the proximal one; this relationship is not fulfilled in males. Ashley [33] proposes the study of the S1W / S3W relationship, which should be lower in women. In the present study, no statistically significant difference was found between the mean of the width indices for both sexes, which were similar. For this reason, in agreement with other researchers [3,8,41], its usefulness for sex discrimination was ruled out.

In conclusion, the sternal bone presents measures of clear utility for the anthropological discrimination of sex, fundamentally in terms of the total length. In the contemporary Spanish population analysed, the "rule 141.5" allows 86.1% of the sternums to be discriminated, with a sex bias of 5.7, which may be of interest in the forensic investigation of human remains with unknown identity.

Given the variation in sternal measurements, it will be of interest to have as many studies of the Spanish population as possible, as well as to study in depth the influence of age or other parameters on sternal measurements.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Peleg S, Pelleg R, Dar G. Steinberg N, Masharawi Y, May H. New methods for sex estimation using sternum and rib morphology. Int J Leg Med. 2020;134:1519-1530.
2. Iscan MY. Forensic anthropology of sex and body size. Forensic Sci Int. 2005;147:107-112.
3. 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;52:154-158.
4. Franklin D, Flavel A, Kuliukas A, Cardini A, Marks MK, Oxnard CH, O´Higgins P. Estimation of sex from sternal measurements in a Western Australian population. Forensic Sci Int. 2012;217:230e1-230e5.
5. Marinescu M, Panaitescu V, Rosu M. Sex determination in Romanian mandible using discriminant function analysis: Comparative results of a time-efficient method. Rom J Leg Med. 2013;21:305-308.
6. Bedalov A, Bašić Z, Marelja I, Dolić K, Bukarica K, Missoni S, Šlaus M, Primorac D, Andjelinović S, Kružić I. 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(3):237-245.
7. Iscan MY, Steyn M. The human skeleton in forensic medicine. 3rd ed. Springfield Illinois: Charles Thomas Publisher; 2013.
8. Sprandley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci. 2011;56(2):289-296.
9. 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(6):411-421.
10. Macaluso PJ. The efficacy of sternal measurements for sex estimation in South African blacks. Forensic Sci Int. 2010;202:111e1-111e7.
11. Singh J, Pathak RK, Singh D. Morphometric sex determination from various sternal widths of Northwest Indian sternums collected from autopsy cadaver: A comparison of sexing methods. Egyptian J Forensic Sci. 2012;2:18-28.
12. Ekizoglu O, Hocaoglu E, Inci E, Bilgili MG, Solmaz D, Erdil I, Can IO. Sex estimation from sternal measurements using multidetector computed tomography. Medicine (Baltimore). 2014;93(27):e240.
13. Bongiovanni R, Spradley MK. Estimating sex of the human skeleton based on metrics of the sternum. Forensic Sci Int. 2012;219:290.e1-290.e7.
14. Myint S, Das S, Ruengdit S, Singsuwan P, Mahakkanukrauh P. Sex determination from different sternal measurements: A study in a Thai population. J Anat Soc India. 2015;64(2):155-161.
15. Jaiswal R. Sternum as an index for determination of sex. Int J Anat Res. 2019;7(4.2):7070-7079.
16. Saraf A, Kanchan T, Krishan K, Ateriya N, Setia P. Estimation of stature from sternum - Exploring the quadratic models. J Forensic Leg Med. 2018;58:9-13.
17. Menezes RG, Nagesh KR, Monteiro FNP, Pradeep G, Kanchan T, Uysal S, Rao J, Rastogi P, Lobo SW, Kalthur SG. Estimation of stature from length of the sternum in South Indian females. J Forensic Leg Med. 2011;18: 242-245.
18. Marinho L, Almeida D, Santos A, Cardoso HFV. Is the length of the sternum reliable for estimating adult stature? A pilot study using fresh sterna and a test of two methods using dry esterna. Forensic Sci Int. 2012;220:292e1-292e4.
19. Dwight T. The sternum as an index of sex, height and age. J Anat 1889/1890; 24:527-535.
20. 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.e1-233.e7.
21. 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 Leg Med. 2012;126(6):863-868.
22. Gautam RS, Jadav GV, Gohil BJ. The human sternum – as an index of age & sex. J Anat Soc India. 2003;52(1):20-23.
23. Singh J, Pathak RK. Morphometric sexual dimorphism of human sternum in a north Indian autopsy sample: sexing efficacy of different statistical techniques and a comparison with other sexing methods. Forensic Sci Int. 2013;228(1-3):174.e1-10
24. Chandrakanth HV, Kanchan T, Krishan K. Osteometric analysis for sexing of modern sternum - an autopsy study from South India. Leg Med (Tokyo). 2014;16(6):350-56.
25. Torimitsu S, Makino Y, Saitoh H, Sakuma A, Ishii N, Inokuchi G, Motomura A, Chiba F, Hoshioka Y, Iwase H. Estimation of sex in Japanese cadavers based on sternal measurements using multidetector computed tomography. Leg Med (Tokyo). 2015;17(4):226-231.
26. Hunnargi SA, Menezes RG, Kanchan T, Lobo SW, Uysal S, Herekar NG, Krishan K, Garg RK Sternal index: Is it a reliable indicator of sex in the Maharashtrian population of India? J Forensic Leg Med. 2009;16(2):56-58.
27. Ashley GT. The relationship between the pattern of ossification and the definitive shape of the mesosternum in man. J Anat. 1956;90(1):87-105.
28. Ramadan SU, Türkmen N, Dolgun NA, Gökharman D, Menezes RG, Kacar M, Kosar U. Sex determination from measurements of the sternum and fourth rib using multislice computed tomography of the chest. Forensic Sci Int. 2010;197:120e1-120e5.
29. Jit I, Jhingan V, Kulkarni M. Sexing the human sternum. Am J Phys Anthropol. 1980;53:217-224.
30. Menezes RG, Kanchan T, Pradeep G, Jagadish Rao J, Lobo SW, Uysal S, Krishan K, Kalthur SG, Nagesh KR, Shettigar S. Stature estimation from the length of the sternum in South Indian males a preliminary study. J Forensic Leg Med. 2009;16:441-443.
31. Cicchetti DV. Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments in Psychology. Psychological Assessment 1994;8(4):284-290.
32. García P, Pérez Á, Djorojevic M, Botella M, Alemán I. Sexual Dimorphism of human sternum in a contemporary Spanish population. Forensic Sci Int. 2014;244:313.e1-9.
33. Ashley GT. The human sternum. The influence of sex and age on its measurements. J Forensic Med. 1956;3(1):27-43.
34. Pons J. The sexual diagnosis of isolated bones of the skeleton. Human Biol. 1955;27:12-21.
35. Dahiphale VP, Baheete BH, Kamkhedkar SG. Sexing the human sternum in Marathwada region. J Anat Soc India. 2002;51(2):162-167.
36. Ankit A, Monika A, Suresh R, Pradip Ch, Hemang J. A study of sexual dimorphism in human sterna. Int J Med Res Health Sci. 2013;2(3):577-581.
37. Hunnargi SA, Menezes RG, Kanchan T, Lobo SW, Binu VS, Uysal S, Kumar RS, Baral P, Herekar NG, Garg RK. Sexual dimorphism of the human sternum in a Maharashtrian population of India: A morphometric analysis. Leg Med (Tokyo). 2008;10:6-10.
38. Ateşoğlu S, Deniz M, Uslu AI. Evaluation of the morphological characteristic and sex differences of sternum by multi-detector computed tomography. Folia Morphol (Warsz). 2018;77(3):489-497.
39. Macaluso PJ, Lucena J. Estimati of sex from sternal dimensions derived from chest plate radiographs in contemporary Spaniards. Int J Leg Med. 2014;128:389-395.
40. Hatfield MK, Gross BH, Glazer GM, Martel W. Computed tomography of the sternum and its articulations. Skeletal Radiol. 1984;11(3):197-203.
41. Dorado E, Santiago A, de Miguel JI. Determinación antropológica del sexo a través del esternón. Rev Esp Med Leg. 2007;6:27-42.
42. Toneva DH, Nikolova Y. Reliability of the sternal index as a sex indicator in medieval skeletal remains from northeastern Bulgaria. J. BioSci. Biotech. 2014, SE/ONLINE:149-152.

43. Torwalt CRMM, Hoppa RD. A test of sex determination from measurements of chest radiographs. J Forensic Sci. 2005;50(4):85-790.
44. Teige K. Morphometric studies of X-rays of the sternum. Z Rechtsmed. 1983;90(3):199-204.
45. Ganorkar YS, Gadade VG, Kawale SG. Study of sexual dimorphism of human sternum in Indian population. JMSCR. 2017;5(5):22042-22048.
46. Changani MV, Javia MD, Varma KA. Determination of sex from various measurements of human sternum and manubrium in Gujarat population. J Res Med Den Sci. 2014;2(1):59-65.
47. Queiroz A, Wada RB, Preza A, Spadacio C. Determinación del sexo por medio de medidas y verificación del peso del hueso esternón (Brasil). Med. Leg. Costa Rica. 2005;22(1):73-78.