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Sexual dimorphism of the clavicle in a modern Spanish sample

Mireya Alcina, Carme Rissech, Ana Clavero and Daniel Turbón

Unit of Physical Anthropology, Department of Animal Biology, University of Barcelona, Barcelona, Spain

SUMMARY

The main objective of this study is to analyze the sexual dimorphism of the Spanish clavicle taking into account lateral asymmetry. A total of 77 adult individuals (45 males and 32 females) from the documented collection of Madrid were used. Twelve measurements were taken: four direct measurements on bone (Maximum length, midshaft circumference, sternal epiphyseal width, acromial epiphyseal width) and eight indirect measurements based on orthogonal photographic images of the clavicles placed on a light box (maximum depth of the lateral and medial curvature, angle of the lateral and medial curvature, lateral and medial curvature, area and perimeter). The asymmetry and sexual dimorphism were analyzed using Student's *t*-test. Posteriorly, a PCA was applied to evaluate the contribution of each variable to sexual dimorphism. Finally, and taking into account previous results, a discriminant analysis was carried out on each clavicular side. Results indicate that the variables that contribute most in sexual dimorphism were five: perimeter, area, maximum length, midshaft circumference, and medial curvature. With them, fifteen formulae for each clavicular side were obtained: five by using individual variables and ten using combinations of two variables. The functions with highest accuracy were those constituted by two variables, specifically those comprising the midshaft circumference and the medial curvature. The obtained results and derived functions are important as they are the first to be obtained using Spanish clavicles to diagnose sex taking into account asymmetry. The new formulae are especially useful for skeletal remains from the Mediterranean area and in particular from the Iberian Peninsula.

Key words: Sex determination – Bilateral asymmetry – Clavicle – Osteology – Adult clavicle

Corresponding author: Carme Rissech. School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LH1 7RH, UK. Phone: (34) 66 1142408. E-mail: carme.rissech@gmail.com

INTRODUCTION

The determination of sex and age are two of the primary diagnostic concerns in any osteological analysis of human remains, whether forensic or archaeological. In the forensic domain, both diagnoses (age and sex) are basic in victim identification, especially in cases of murder or mass disasters where the bodies are in advanced stages of decomposition, or otherwise unidentifiable (Modi, 1988). In osteoarcheaology, accurate age and sex estimation are fundamental in order to make accurate reconstructions of the demographic profiles of past populations; and they also provide information that is useful for interpreting the funerary context (Krogman and Iscan, 1986; Trancho et al., 1996). Apart from age, sex is one of the principal biological indicators necessary to biologically identify a skeleton. Sex determination in adult skeletal remains is relatively uncomplicated to achieve when the remains are complete, but fragmented or dispersed remains result in an incomplete assessment base, which may result in some aspects of biological identity being inconclusive, including sex (Gapert et al., 2009). The most sexually dimorphic areas of the human skeleton are those of the innominate (Ferembach et al., 1980; Rissech and Malgosa, 1991, 1997; Bruzek, 2000), cranium, and mandible (Rogers, 2005; Williams and Rogers, 2006; Walker, 2008), but these regions are often absent or in a fragmentary state. Therefore, metric analysis is fundamental to the anthropologist, be-

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cause frequently only fragmentary bones are available. The metric determination of sex requires the choice of an appropriate standard because there is evidence that populations are metrically distinct (Holden and Mace, 1999; Liu et al., 2004). Genetic, cultural and environmental influences are the causes of these differences (Liu et al., 2004; Carlson and Grine, 2007; Charisi et al., 2011).

Although the utility of the clavicle is well accepted for sex assessment, it has been underrepresented in the forensic literature (Papaioannou et al., 2012). There are a large number of studies on the upper extremity, focusing on the humerus (Holman and Bennett, 1991; Albanese et al., 2005; Sakaue, 2004; Kranioti and Michalodimitrakis, 2009; Charisi et al., 2011), the ulna and radius (Sakaue, 2004; Celbis and Agritmis, 2006; Barrier and L'Abbé, 2008; Kranioti and Michalodimitrakis, 2009; Charisi et al., 2011), and to a lesser extent, the scapula (Scholtz et al., 2010; Papaioannou et al., 2012). Regarding studies on the sexual dimorphism of the clavicle (Terry, 1932; Ray, 1959; Jit and Kaur, 1986; Murphy, 1994; Ríos-Frutos, 2002; Shirley and Jantz, 2009; Tise and Spradley, 2013; Králik et al., 2014) previous researchers have analyzed the clavicle of African American (Terry, 1932), white North American (Spradley and Jantz, 2011), native Australian (Ray, 1959), North Indian (Jit and Kaur, 1986), Guatemalan (Ríos-Frutos, 2002), Mexican (Tise and Spradley, 2013), prehistoric Polynesian (Murphy, 1994), and Greek (Papaioannou et al., 2012; Králik et al., 2014) populations. To the best of our knowledge, there is a lack of studies based on Western European populations, and particularly from Spaniards.

The clavicle is one of the skeletal elements that end development at an older age. In general, later-maturing skeletal elements display more sexual dimorphism and a greater asymmetry than early-maturing elements (Murphy, 1994; Humphrey 1998; Voisin, 2001; Celbis and Agritmis, 2006; Králik et al., 2014). This is because the morphology of later-maturing elements may be more influenced by the individual's physical activity and work distribution within the population, reflecting variation between humans arising from lateralized behaviours (Stirland, 1993; Mays, 2002).

In light of the above, this study was designed to provide information on sexual dimorphism of the clavicle on the basis of possible differences in laterality on a documented skeletal sample originating from central Spain. Specifically, the aims of this study were twofold: 1) to analyze the sexual dimorphism of the clavicle taking into account its asymmetry; and 2) to provide useful algorithms for sex assessment.

Anatomy and functional morphology of the clavicle

The human clavicle is described as a paired long bone with an s-like, curved shape that is situated on the first rib of the thorax (Testud et al., 1932). Laterally, it articulates to the acromion of the scapula, whereas medially it is connected to the upper part of the sternum. The clavicle has anterior and posterior borders, superior and inferior surfaces and medial and lateral extremities. The double curvature of the shaft separates the clavicle into medial two-thirds and a lateral one-third (Ljunggren, 1979; Harrington et al., 1993). The medial two-thirds are somewhat circular in cross-section and anteriorly convex (medial curvature), whereas the lateral one-third of the clavicle is somewhat flattened in and posteriorly convex (lateral curvature). The geometry of the clavicle reflects its biomechanical function, with the various muscles and ligaments attached to it contributing to compressive, bending, and torsional loads (Harrington et al., 1993). All loads on the upper extremity are transmitted to the thorax through the clavicle along its long axis, thus meaning that it serves as a strut (Harrington et al., 1993). The clavicle has four main functions: 1) to transmit the loads of the upper extremity to the axial skeleton; 2) to provide support for the inclusion of numerous muscle groups in the cervical and thoracic area; 3) to protect the neurovascular zone running from the chest to the cervical region and upper extremity;

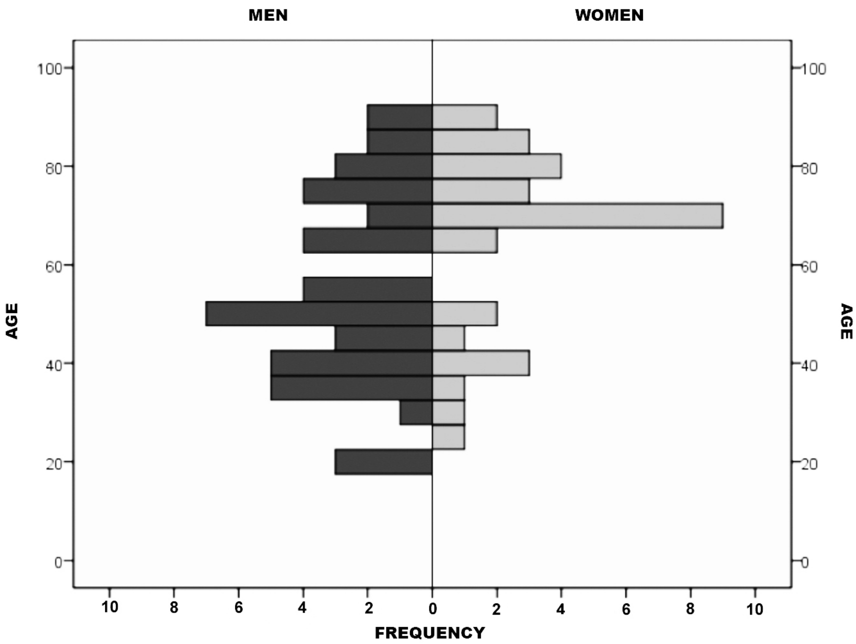

Fig. 1. Age and sex distribution of the 77 individuals sampled from the Madrid collection.

and 4) to help to stabilize the glenohumeral joint.

MATERIALS AND METHODS

The material for this study came from the modern documented skeletal collection of Madrid housed in the Faculty of Legal Medicine of the *Complutense University of Madrid* (Madrid, Spain). This twentieth-century collection includes 195 individuals (115 males and 80 females) ranging from 3 to 97 years of age. Demographic information for each individual, including age, sex, and year of death, was obtained from obituary records (Ruiz et al., 2012). Like most modern collections, the Madrid collection contains a high proportion of older individuals, reflecting increased life expectancy, lower birth rates and the marked improvement in general health (Rissech and Steadman, 2011). From this collection, adult individuals displaying both intact clavicles were selected. Individuals showing any clavicular pathology or fracture were excluded from the study. A total of 77 individuals (45 males and 32 females) from 20 to 92 years of age were selected. Figure 1 depicts the chronological age distribution of females and males examined during the course of the analysis.

The clavicular measurements used in this study are detailed below (Figs. 2 and 3). Measurements 1-4 (Fig. 2) were taken on the bones themselves (direct measurements), while numbers 5 and 12 (Fig. 3) were taken from orthogonal photographic images of the inferior surface of the clavicles placed on a light box (indirect measurements). The purpose of these photographs was to provide a two-dimensional image of the clavicle to facilitate the curvature and angular measurements. The photographs were taken using a Canon EOS 1D Mark III digital camera, equipped with a Canon 50 mm 1.8 fixed lens, positioned vertically at 55 cm from the light box and 65 cm from the floor. An OBT A1681 Benro tripod with built-in spirit level was always placed in an identical position to control the position and angle of the camera. Measurements were taken on the photographs using Thin Plate Spine (TPS) (Rohlf, 2006). The suitability of using orthogonal photographs as material for analysis and the detailed protocol followed when taking these orthogonal images is explained in detail in our preliminary study on the clavicle (Alcina et al., 2012).

The definition of variables number 1, 3, 4 are those of Olivier (Olivier, 1960), number 2 is that of Bass (Bass, 1971), numbers 6 and 12 are those of Mays (Mays, 2002) while numbers 5, 7-11 are depicted in Fig. 3.

1-Maximum clavicular length (ML)
2-Midshaft clavicular circumference (MidC)
3-Sternal epiphyseal width (SEW)
4-Acromial epiphyseal width (AEW)
5-Angle of the lateral curvature (ALC)
6- Maximum depth of the lateral curvature (MDLC)
7-Lateral curvature (LC)
8-Clavicular perimeter (P)
9-Clavicular area (A)
10-Angle of the medial curvature (AMC)
11-Maximum depth of the medial curvature (MDMC)
12-Medial curvature (MC)

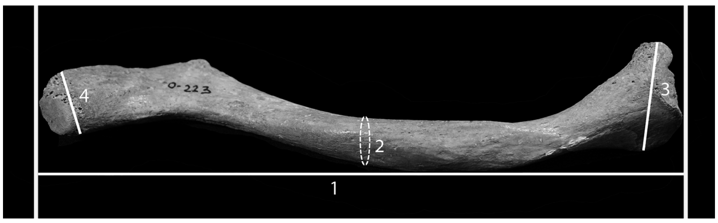

Fig. 2. Superior view of an adult right clavicle. (1) Maximum length of the clavicle - (2) Midshaft circumference of the clavicle - (3) Sternal epiphyseal width - (4) Acromial epiphyseal width.

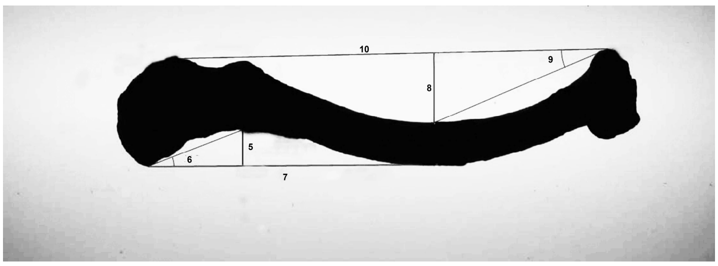

Fig. 3. Orthogonal photography showing the inferior view of an adult left clavicle. (5) maximum depth of lateral curvature – (6) angle of the lateral curvature – (7) lateral curvature - (8) maximum depth of medial curvature – (9) angle of the medial curvature - (10) medial curvature.

Taking into account our results obtained previously in Alcina et al. (2012), the error in both repeatability of the photographic process and variable measurement (direct and indirect) was considered to be negligible.

Statistical analysis

Descriptive statistics (mean, standard deviation, and standard error of the mean) were computed considering sex and side of the clavicle. Lateral differences for the variables between right and left clavicle were evaluated with Student's *t*-test for independent samples, taking sex into account. The presence of sexual dimorphism was also tested by Student's *t*-test for independent samples, considering the right and left clavicles and the results obtained in the evaluation of lateral differences. Furthermore, in each variable, the degree of sexual dimorphism was calculated as a percentage of the male and female mean difference divided by the male mean [((M-F)/M)*100]. A Principal Components Analysis (PCA) was then applied to evaluate the contribution of each of the 12 variables to clavicular sexual dimorphism. Finally, with the aim of providing algorithms useful for sex discrimination, a discriminant analysis was applied according to the PCA results. These discriminant functions were calculated using both individual variables and combinations of two variables. Discriminant analysis was chosen because it is the method of choice when there is some *a priori* reason for presuming that the case in question comes from the same distribution as represented within the reference sample (Konigsberg et al., 1998), and this presumption is generally warranted in forensic settings and in some archaeological remains, for example when the biological origin of the analyzed population is known (Konigsberg et al., 1998).

In this study, Wilks' lambda was the discriminant method chosen, and the criterion selected was the F value, with F to enter = 3.84 and F to remove = 2.71. Eigenvalues, canonical correlations, Wilks' lambda, unstandardized coefficients, and sectioning points were computed. The eigenvalue measures the deviations of the discriminant scores between groups with regard to the deviations within groups. The canonical correlation measures the deviations of the discriminant scores between groups with regard to the total deviations without differentiating groups. In both cases, if the value obtained is high (in the case of the canonical correlation close to 1), the dispersion will be due to the differences between groups; therefore, the function will discriminate well between groups (Ferran, 2001). The unstandardized coefficients are used to compute a discriminant score for the case under study. Due to the limited number of skeletons, the original sample was not split to create a test sample. To prevent a function from fitting the sample from which it is derived better than any other sample, the jack knife method was selected. This method calculates each function by leaving out one of the cases in turn and then classifying the left-out cases. All statistics were computed using SPSS v. 18.0 and SYSTAT v.13.0.

RESULTS

Tables 1 and 2 show the results of lateral differences analysis considering male (Table 1) and female (Table 2) clavicles. Results indicated no significant differences between the two sides, except for the acromial and sternal width in the male

Table 1. Side-based descriptive statistics for male clavicles. Student's *t*-test for independent variables. See the text for acronym meaning

	RIGHT				LEFT				
MEASURES	n	Mean	SD	SE	n	Mean	SD	SE	**p**
ML	45	155.120	10.056	1.499	45	157.020	10.312	1.537	0.379
MidC	45	38.000	3.676	0.548	45	37.260	3.732	0.556	0.343
SEW	45	24.618	3.617	0.539	45	23.049	3.321	0.495	0.035*
AEW	45	24.349	3.877	0.578	45	22.653	3.771	0.562	0.038*
ALC	45	26.230	6.516	0.971	45	24.050	6.082	0.907	0.104
MDLC	45	13.380	3.336	0.497	45	12.784	3.214	0.479	0.391
LC	45	95.318	14.089	2.100	45	94.669	10.087	1.503	0.802
P	45	382.041	24.683	3.689	45	381.230	27.473	4.095	0,622
A	45	2430.939	345.089	51.442	45	2395.805	329.177	49.070	0.883
AMC	45	21.099	2.979	0.444	45	21.055	3.904	0.582	0.952
MDMC	45	18.345	3.012	0.449	45	17.800	4.051	0.604	0.471
MC	45	115.158	10.370	1.545	45	118.000	9.238	1.377	0.173

Table 2. Side-based descriptive statistics for female clavicles. Student's t-test for independent variables. See the text for acronym meaning

	RIGHT				LEFT				
MEASU-RES	n	Mean	SD	SE	n	Mean	SD	SE	**p**
ML	32	132.380	7.955	1.406	32	134.810	7.403	1.309	0.209
MidC	32	31.360	2.301	0.407	32	30.300	2.063	0.365	0.056
SEW	32	21.050	2.728	0.482	32	20.800	2.749	0.486	0.716
AEW	32	20.959	3.352	0.593	32	20.084	3.617	0.639	0.319
ALC	32	23.426	6.533	1.155	32	22.430	5.907	1.044	0.525
MDLC	32	10.660	2.029	0.359	32	10.525	2.108	0.372	0.795
LC	32	79.943	9.209	1.627	32	83.531	8.758	1.548	0.114
P	32	323.928	15.252	2.696	32	328.649	15.358	2.714	0.842
A	32	1701.712	137.382	24.286	32	1694.558	148.093	26.179	0.222
AMC	32	22.036	3.992	0.706	32	22.696	3.638	0.643	0.492
MDMC	32	15.713	2.587	0.457	32	16.034	2.503	0.442	0.615
MC	32	95.375	7.927	1.401	32	97.103	8.774	1.551	0.412

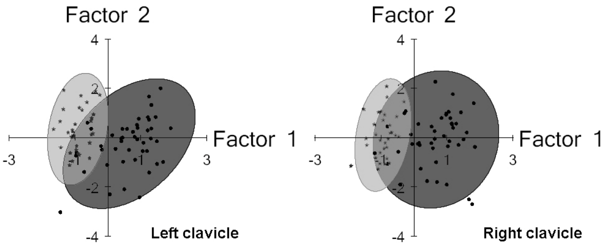

Fig. 4. Scatter plots of the PCA results for right and left clavicles taking into account the sex. Starts indicate females. Circles indicate males. The elliptic colored areas represent 95% confidence interval for each sex sample.

series, where the mean values were higher for the right side than for the left. Despite this lack of significant differences, in both male and female series the right mean values tended to be higher than those of the left, except for the maximum length of the clavicle, which displayed the contrary pattern. In females this tendency was much less clear (Table 2). These observations regarding lateral differences of the clavicle, especially the classical measurements, are consistent with current literature (Parsons, 1916; Mays et al., 1999; Voisin, 2001; Auberbach and Raxter, 2008).

Tables 3 and 4 show the results of sexual dimorphism analysis considering right (Table 3) and left (Table 4) clavicles. These results indicate that, on both sides, males have significantly higher values than females for all the variables analyzed except the two angles (ALC and AMC). In the right clavicle (Table 3) the three variables with the highest degree of sexual dimorphism are the area, maximum depth of lateral curvature and midshaft circumference. In the left clavicle (Table 4) the three variables with the highest degree of sexual dimorphism are the area, midshaft circumference and medial curvature. However, it is necessary to highlight that the area is the variable which always shows the highest degree of sexual dimorphism in both clavicular sides. The remaining variables show different patterns in relation to the degree of sexual dimorphism (Tables 3 and 4), according to the side.

The PCA results (Table 5) summarize the variables of the right and left clavicle into three factors, which explain 77% and 76% of the variance for the right and left clavicles respectively. In the right clavicle, the first component contributes 52%, the second 15% and the third 9.5%. In the left clavicle, the first component contributes 48.5%, the second 15.2% and the third 11.9%. The factorial matrix of the components can be seen in Table 5. The first component (PC1) accounts for most of the size variation, leaving the subsequent components (PC2 and PC3) to account predominantly for shape. In both clavicular sides, the most representative variables of PC1 are the perimeter, area, maximum length, midshaft circumference, and medial curvature. Similarly, the most representative variables of PC2 in both sides are the angle and maximum depth of the medial curvature and the angle of the lateral curvature. In contrast, the most representative variables for PC3 vary according to the clavicular side. For the right clavicle, the variables most representatives of PC3 are the angle of the medial curvature and the angle and maximum depth of the lateral curvature. For the left clavicle, the variables most representatives of PC3 are the angle, the maximum depth of the lateral curvature, and the acromial epiphyseal width. The scatter plot shows the distribution of male and female right and left clavicles in terms of PC1 and PC2 (Fig. 4). PC1 differentiates sex to the greatest degree – with males exhibiting a higher (more positive) score than females. The second (Fig. 4) and third (this graph is not shown as it does not provide any new information) components do not differentiate between the sexes. These results indicate that the most important variables for the sex discrimination of the clavicle are, in order of importance, the perimeter, area, maximum length, midshaft circumference and medial curvature.

Table 6 shows the discriminant functions obtained from the five variables highlighted during

Table 3. Sex-based descriptive statistics for the right clavicle. Student's t-test for independent variables. See the text for acronym meaning

	MEN				WOMEN					
MEASURES	n	Mean	SD	SE	n	Mean	SD	SE	**p**	Degree of Dimorphism
ML	45	155.120	10.056	1.499	32	132.380	7.955	1.406	0.000*	14.659
MidC	45	38.000	3.676	0.548	32	31.360	2.301	0.407	0.000*	17.474
SEW	45	24.618	3.617	0.539	32	21.050	2.728	0.482	0.000*	14.493
AEW	45	24.349	3.877	0.578	32	20.959	3.352	0.593	0.000*	13.923
ALC	45	26.230	6.516	0.971	32	23.426	6.533	1.155	0.067	10.690
MDLC	45	13.380	3.336	0.497	32	10.660	2.029	0.359	0.000*	20.329
LC	45	95.318	14.089	2.100	32	79.934	9.205	1.627	0.000*	16.139
P	45	382.041	24.684	3.679	32	323.928	15.252	2.696	0.000*	15.211
A	45	2430.939	345.089	51.442	32	1701.712	137.382	24.286	0.000*	29.998
AMC	45	21.099	2.979	0.444	32	22.036	3.991	0.706	0.242	-4.441
MDMC	45	18.345	3.012	0.449	32	15.713	2.587	0.457	0.000*	14.347
MC	45	115.158	10.370	1.546	32	95.375	7.927	1.401	0.000*	17.179

Table 4. Sex-based descriptive statistics for the left clavicle. Student's t-test for independent variables. See the text for acronym meaning

	MEN				WOMEN					
MEASU-RES	n	Mean	SD	SE	n	Media	SD	SE	**P**	Degree of Dimorphism
ML	45	157.020	10.312	1.537	32	134.810	7.403	1.309	0.000*	14.145
MidC	45	37.260	3.732	0.556	32	30.300	2.063	0.365	0.000*	18.680
SEW	45	23.049	3.321	0.495	32	20.800	2.749	0.486	0.002*	9.757
AEW	45	22.653	3.772	0.562	32	20.084	3.617	0.639	0.004*	11.341
ALC	45	24.050	6.082	0.907	32	22.430	5.907	1.044	0.248	6.736
MDLC	45	12.784	3.214	0.479	32	10.525	2.108	0.373	0.001*	17.671
LC	45	94.669	10.087	1.504	32	83.531	8.758	1.548	0.000*	11.765
P	45	381.230	27.473	4.095	32	328.649	15.358	2.715	0.000*	13.792
A	45	2395.805	329.177	49.071	32	1694.558	148.093	26.179	0.000*	29.270
AMC	45	21.055	3.904	0.582	32	22.696	3.638	0.643	0.066	-7.794
MDMC	45	17.800	4.052	0.604	32	16.034	2.503	0.442	0.032*	9.921
MC	45	118.000	9.239	1.377	32	97.103	8.774	1.551	0.000*	17.709

Table 5. Factorial matrix of component 1 and 2 for both clavicular sides

		Component 1	**Component 2**
Right clavicle	Maximum length	0.934	-0.099
	Midshaft circumference	0.802	-0.089
	Sternal epiphyseal width	0.670	0.106
	Acromial epiphyseal width	0.711	0.112
	Angle of the lateral curvature	0.255	0.548
	Maximum depth of the lateral curvature	0.608	0.446
	Lateral curvature	0.724	-0.376
	Clavicular perimeter	0.959	0.042
	Clavicular area	0.955	0.127
	Angle of the medial curvature	-0.013	0.827
	Maximum depth of the medial curvature	0.588	0.855
	Medial curvature	0.800	-0.274
Left clavicle	Maximum length	0.926	-0.232
	Midshaft circumference	0.827	0.100
	Sternal epiphyseal width	0.593	0.287
	Acromial epiphyseal width	0.561	0.188
	Angle of the lateral curvature	0.232	0.404
	Maximum depth of the lateral curvature	0.580	0.279
	Lateral curvature	0.642	-0.320
	Clavicular perimeter	0.970	-0.039
	Clavicular area	0.936	-0.177
	Angle of the medial curvature	0.074	0.875
	Maximum depth of the medial curvature	0.574	0.636
	Medial curvature	0.812	-0.314

PCA analysis. Two types of discriminant functions are presented in Table 6: 1) those calculated from a single variable, five functions for each clavicular side, and 2) those calculated from different combinations of two of these five variables, ten functions for each clavicular side. Results indicate that the most reliable calculated functions are those consisting of two variables, showing an accuracy of more than 90% in the great majority of the calculated functions for each clavicular side (Table 6). The functions consisting of a single variable obtained less than 91% accuracy.

The functions comprising a single variable that achieved the highest correct classification values for both clavicular sides are those containing one of the following three variables: the length of the clavicle, the area and the clavicular perimeter (Table 6). For the right clavicle, these three functions correctly classify 90.9% of the individuals (Table 6). For the left clavicle, these functions correctly classify 88.3%, 92.2% and 87.05 of the individuals, respectively (Table 6).

Among the functions constituted by the combination of two variables, three types of discriminant functions can be distinguished depending on whether the variables are directly or indirectly measured. These are: (1) those consisting of only direct measurements; (2) those consisting of only indirect measurements; and (3) those consisting of a combination of the two types of measurements (mixed functions). According to our results, for both the right and left clavicular sides, the function

Table 6. Discriminant functions and their respective accuracy for the direct and direct measurements based on right and left clavicles See the text for acronym meaning

	Single variable	Sectioning point	% of accuracy
Right clavicle	0.108 x CL – 15.755	-0.208	90.9
	0.314 x MidC – 11.080	-0.176	88.3
	0.004 x A – 7.635	-0.221	90.9
	0.470 x P – 16.804	-0.231	90.9
	0.106 x MC – 11.332	-0.177	84.4
Left clavicle	0.108 x CL – 16.027	-0.203	88.3
	0.317 x MidC – 10.905	-0.373	89.6
	0.004 x A – 7.808	-0.440	92.2
	0.043 x P – 15.461	-0.191	87.0
	0.111 x MC – 12.080	-0.195	85.7
	Two variables	**Sectioning point**	**% of accuracy**
Right clavicle	0.077 x LC + 0.171 x MidC -17.313	-0.244	93.5
	0.050 x LC + 0.002 x A – 12.082	-0.236	92.2
	-0.017 x LC + 0.054 x P – 16.740	-0.231	90.9
	0.084 x LC + 0.030 x MC – 15.486	-0.212	90.9
	0.086 x MidC + 0.003 x A – 9.173	-0.226	92.2
	0.146 x MidC + 0.036 x P – 17.933	-0.257	93.5
	0.218 x MidC + 0.074 x MC – 15.608	-0.246	94.8
	0.029 x MC + 0.038 x P – 16.804	-0.237	90.9
	0.028 x P + 0.002 x A – 13.830	-0.245	90.9
	0.003 x A + 0.046 x MC – 10.622	-0.242	92.2
Left clavicle	0.071 x LC + 0.173 x MidC -16.494	-0.236	92.2
	0.046 x LC + 0.002 x A – 11.966	-0.231	92.2
	0.103 x LC + 0.002 x P – 16.051	-0.204	88.3
	0.066 x LC + 0.053 x MC – 15.484	-0.217	87.0
	0.093 x MidC + 0.003 x A – 9.235	-0.225	90.9
	0.180 x MidC + 0.026 x P – 15.561	-0.222	90.9
	0.205 x MidC + 0.076 x MC – 15.337	-0.254	93.5
	0.064 x MC + 0.023 x P – 15.196	-0.215	85.7
	0.013 x P + 0.003 x A – 10.546	-0.225	90.9
	0.003 x A + 0.058 x MC – 11.625	-0.251	92.2

with highest accuracy is that which combines the midshaft circumference and the medial curvature (mixed function), with 94.8% accuracy for the right clavicle and 93.5% for the left clavicle.

Regarding those functions consisting of only direct measurements (Table 6), the discriminant function formed by the maximum length and the midshaft circumference has the highest accuracy for both clavicular sides, with 93.5% accuracy on the right side and 92.2% accuracy on the left side.

Regarding those functions consisting of only indirect measurements (Table 6), the discriminant function with highest accuracy are those formed by the area and the medial curvature which show 92.2% accuracy for both clavicular sides. The obtained results are consistent with current literature regarding classical direct measurements of the clavicle (Ríos-Frutos, 2002; Parsons, 1916; Auberback and Raxter, 2008). The results obtained from the other new variables cannot be compared because this is the first study in which they are analyzed.

DISCUSSION

This is the first study in which the complete Spanish clavicle has been analyzed by direct and indirect measurements. The data presented provide anatomical information and identify sex differences in the clavicle, complementing previously published information. The results for the right and left clavicles indicate that the variables with highest sexual dimorphism are the perimeter, area, maximum length, midshaft circumference, and medial curvature, where the male values are always higher than the female values. In fact, this pattern of sex differences is observed in all the variables analyzed in this study, except for the angles of the lateral and medial curvature in which there are no significant differences. These results are in accordance with previous studies which indicated that female clavicles are less curved and less robust than those of males (Papaioannou et al., 2012; Králik et al., 2014).

As expected, the functions with highest accuracy were those constituted by two variables, specifically those comprising the midshaft circumference and the medial curvature. These mixed functions showed 94.8% accuracy for the right clavicle and 93.5% for the left. The correct classification percentage achieved in the present work is within the range of reliability obtained for other discriminant functions based on skeletal elements of the arm, forearm, and hip (Mall et al., 2001; Yoldi et al., 2001; Celbis and Agritmis, 2006; Albanese et al., 2008; Spardley and Jantz, 2011) and higher than that obtained for the skull (Konigsberk and Hens, 1998; Walker, 2008; Spardley and Jantz, 2011) and other post-cranial elements such as the femur, tibia, and metacarpals (Spradley and Jantz, 2011; Alemán et al., 1997; Barrio et al., 2006). However, it is lower than the accuracy obtained in other Spanish discriminant functions based on long bones of the upper and lower extremity, specifically the humerus (Del Río, 2000; Trancho et al., 2012), ulna (López-Bueis et al., 2000) and radius (Trancho et al., 2000), the femur (Trancho et al., 1996), and the tibia (López-Bueis et al., 2000). Similar results have also been obtained for long bones from other European series, such as Portugal (Carretero et al., 1995) and Greece (Charisi et al., 2011; Papaioannou et al., 2012; Králik et al., 2014).

The results obtained in this study are similar to those of the extremely few published studies on sexual dimorphism of the clavicle, based on U.S. and Guatemalan populations (Parsons, 1916; Steel, 1966; McCormick et al., 1991; Ríos-Frutos, 2002; Shirley and Jantz, 2009), in terms of both accuracy and the classical variables selected (maximum length and midshaft circumference). Comparing the results of this study with other published studies is useful for assessing population variability in clavicle morphology. However, this is constrained by the lack of similar studies based on the newly defined variables in this study. According to previous studies and the results of the present study, the variables related to the dimensions of the clavicle are the best for discriminating sex. As explained before, this seems to be related to the clavicular growth pattern. Indeed, those parts of the skeleton that exhibit a late growth pattern are more dimorphic, and the maximum length and midshaft circumference form part of this group (McCormick et al., 1991).

This study is in accordance with previous studies (Parsons, 1916; Terry, 1932; Humphrey, 1998; Mays et al., 1999; Voisin, 2001), which observed a pattern of asymmetry in which the right clavicle tends to be shorter, more robust and more curved than the left in both sexes, probably due to higher mechanical loads on the side of the dominant hand (Parsons, 1916; Konigsberg et al., 1998). They also show asymmetry in the acromial and sternal epiphyseal width in males (but not in females), with the right values higher than the left values. However it was not possible to compare them with other samples due to the lack of similar studies.

The discriminant functions obtained in this study are based on a modern Spanish population from the twentieth century. Several studies concerning both sex assessment and age and stature estimation have demonstrated the importance of using specific methodologies for specific populations (Ríos-Frutos, 2002; Králik et al., 2014; Iscan and Kedici, 2003; López-Costas et al., 2012; Rissech et al., 2013). Most current methods are based on the current U.S. population and the magnitude of error involved in applying these methods to Iberian and Mediterranean individuals is unknown. For example, the Trotter and Gleser (Trotter and Gleser, 1952) method for estimating stature based on white North Americans overestimates the height of the Spanish and Italian populations systematically (Rissech et al., 2013). The Pearson method (Pearson, 1899), which was developed in the late nineteenth century and is based on a French population, provides the best estimates for these populations (Formicola, 1993; Formicola and Franceschi, 1996). This can be explained by the biological relationship between the French, Spanish and Italian populations and because they are populations of medium stature (Formicola, 1993; Formicola and Franceschi, 1996; Pujol et al., 2014). In light of the above, the notion of the "universality" of osteological methodology must be abandoned and the development of specific methods for each population promoted (Komar and Grivas, 2008; Králik et al., 2014). Further analysis in additional series is necessary in order to reinforce the results obtained. Meanwhile, Iberian and Mediterranean forensic work and anthropological studies can take advantage of these results and functions, which enlarge the possibilities for the analysis of sex in adult skeletons.

Conclusions

This work, which is based on a documented skeletal sample of Spanish origin, has provided information regarding the sexual dimorphism of the clavicle, as well as several useful algorithms for sex determination that are applicable in both archaeological and forensics cases from Spain and the Mediterranean area. Of the measurements taken (in order of importance), clavicular perimeter, area, maximum length, midshaft circumference, and medial curvature are the most useful for sex assessment for both the right and left clavicles. Furthermore, this paper provides additional information concerning clavicular asymmetry, which is in accordance with previous studies, indicating that the clavicle is shorter and more robust on the right (usually the dominant hand) than on the left. The importance of these results and derived functions is that they are the first obtained from Spanish clavicula to determine sex, taking into account the fact that they are based on a documented osteological collection of individuals from Madrid.

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