Sexual dimorphism in the 7th cervical and 12th thoracic vertebrae from a Mediterranean population

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ABSTRACT: Sex determination is an important task in physical anthropology and forensic medicine. The study sample comprised 121 individuals of known sex, age and cause of death from San Jose cemetery in Granada (Spain). Eight dimensions were analyzed, and discriminant function analysis was performed for each vertebra in order to obtain discriminating functions and study the percentage of correct assignations of these functions**.** The percentage accuracy was approximately 80% for both vertebrae but varied according to the sex, being higher for the 7th cervical in males and higher for the 12th thoracic in females. As reported in other populations, the greatest dimorphism values were found for the length of the inferior surface of the vertebral body and the width and length of the vertebral foramen of the 7th cervical vertebra, and for the length of the inferior surface of the vertebral body of the 12th thoracic vertebra.
KEYWORDS: Forensic science; forensic anthropology; sex determination; discriminant function analysis; 7th cervical vertebra; 12th thoracic vertebra

In physical anthropology and forensic medicine, sex determination is the cornerstone for establishing a biological profile of human remains. This task is more challenging if only parts of a skeleton are available or if bones have been damaged (e.g., by fire, explosion or violence). Sex determination methods are based on morphological or anthropometric characteristics. The latter offer a more objective method when adequate reference data (formulae) are available for the population in question, because traits that are sexually dimorphic in one population may be less dimorphic in another, besides anthropometric differences. Thus, Kajanoja (1) and Williams (2) reported that discriminant functions for sex determination developed in one population can incorrectly classify 32–48% of individuals from different populations.

Various vertebral measurements can be used to distinguish between males and females by the application of discriminant functions. Researchers have reported sexual dimorphism in different vertebrae from cervical, thoracic, and lumbar regions of the spinal column (3–7) and, specifically, various studies have quantified the degree of sexual dimorphism in the 7th cervical vertebra (8–13) and 12th thoracic vertebra (14–16). The main reason for studying these two vertebrae is that they are both readily identifiable. The 7th cervical is situated between the cervical vertebrae and the thoracic vertebrae and is known as the *vertebra prominens* (17) because of its distinctive long and prominent spinous process. This vertebra articulates with the inferior facets of the 6th cervical vertebra and with the superior facets of the 1st thoracic vertebrae. The 12th thoracic is between the thoracic vertebrae and the lumbar vertebrae and is distinguished by the sagittal plane orientation of its inferior facets (as in lumbar vertebrae) and the coronal plane orientation of its superior facets (as in other thoracic vertebra); this vertebra also bears a costal facet on the transverse process articulating with the ribs.

The objectives of this study were *i)* to estimate the degree of vertebral sexual dimorphism in a Southern Spanish population, *ii)* to establish the usefulness of the 7th cervical and 12th thoracic vertebrae for sex estimation, *iii)* to develop a discriminant function formula based on metric data from these vertebrae; and *iv)* to compare the accuracy of sex estimation by this method with that obtained in other studies.

Materials and Methods

Adult skeletons of known sex, age, and cause of death from the San José collection at the Physical Anthropology Laboratory of the University of Granada, derived from the municipal cemetery of Granada city (Southern Spain) were analyzed in this study**.**

The 7th cervical and 12th thoracic vertebrae were selected for study, excluding those that were incomplete or with signs of disease (e.g., osteoarthritis, fracture). The final sample comprised vertebrae from 121 Mediterranean individuals (60 females, 61 males) who died in Granada during the 20th century. Age-at-death ranged from 22 to 93 years (mean of 69 years), and the main causes of death were, in descending order, trauma, myocardial infarction, bronchitis, atherosclerosis, and cancer. Measurements were taken on the superior and inferior surfaces of these vertebrae with a digital caliper (accuracy of 0.01 mm). All measurements were performed by the same examiner, who repeated them after a 15-day interval to test intra–observer error; two weeks was considered sufficient to ensure that the second assessment was not influenced by the learning acquired the first time**.**

Metric data

The following dimensions were measured in each vertebra (Fig. 1): *length of superior facets (left and right) (LSF)*, the maximum superior dimension of the superior articular facets; w*idth of the superior facets (left and right) (WSF)*, the maximum

transverse dimension of the superior articular facets; *length of the inferior facets (left and right) (LIF),* the maximum inferior dimension of the inferior articular facets; *width of the inferior facets (left and right) (WIF),* the maximum transverse dimension of the inferior articular facets; *length of the vertebral foramen (LVF),* the anteroposterior width of the vertebral canal in the sagittal plane; *width of the vertebral foramen (WVF),* the width of the vertebral canal in the transverse plane; *length of the inferior surface of the vertebral body (LIVB),* the anteroposterior width of the inferior surface of the vertebral body in the sagittal plane; and *width of the inferior surface of the vertebral body (WIVB),* the transverse width of the inferior surface of the vertebral body.
(Figure 1)

Statistical analysis

The data were analyzed in SPSS 15.0 (18). A descriptive analysis was performed, and the data were expressed as means and standard deviations. The distribution of the data was assessed by using the one–sample Kolmogorov–Smirnov test. Intraobserver error was evaluated by means of the intraclass correlation coefficient (ICC), which estimates the mean of correlations among all possible pairs of observations. Its calculation requires a repeated-measures analysis of variance (ANOVA) to be performed, thereby testing whether the variability among pairs of measures is significant or not. The ICC values (range 0-1) were interpreted according to the classification proposed by Fleiss (19)

General linear model univariate analyses were conducted to compare the mean values of all variables between the left and right side. Because no significant laterality differences were observed, values for both sides were pooled for each variable. A *t*–

test was then used to compare these data between the sexes and evaluate the homogeneity of variance (*F*–test).

The effectiveness of the dimensions of the 7th cervical and 12th thoracic vertebrae for sex determination was analyzed by discriminant function analysis, using a stepwise procedure to select the variables with the highest discriminant capacity. New discriminant analyses were performed on the 7th cervical and 12th thoracic variable. The discriminant capacity of the selected variables was then evaluated by using a cross–validation procedure that recalculates the discriminate function analysis, sequentially and randomly selecting one of the samples and averaging the results over all of the cross–validation values.

Results

The Kolmogorov–Smirnov test results showed that all dimensions were normally distributed by sex, and equal variance was found across samples (*t*–test, $p>0.05$). Table 1 exhibits the intraclass correlation coefficient obtained (ICC ≥ 0.75; $p > 0.05$), corresponding to an excellent level of agreement (19).

(Table 1)

The results in Table 2 show that no significant asymmetry was observed for any variable. Mean values of all variables were significantly higher (*t*–test, $p < 0.05$) in males than in females with the exception of the LSFc7, LIFc7, LVFt12 and WVFt12 measurements, which did not significantly differ between the sexes (Table 3).

(Table 2)

(Table 3)

Results of the initial stepwise discriminant function analysis are reported in Table 4, which lists the coefficients (relative contribution of each dimension), classification functions of the two groups, discriminant functions with corresponding sectioning points, and *F* and Wilks' lambda values. The discriminant analyses yielded five functions: four for the 7^{th} cervical vertebra and one for the 12^{th} thoracic vertebra (Table 4).

(Table 4)

Sex was determined by multiplying the value of each dimension in a particular function by its respective unstandardized coefficient and adding the constant to the product. The individual is considered male if the result is higher than the sectioning point given for the function and female if it is lower. For example, if LVFc7 = 13.81, LIVBc7 = 12.95 and WIVBc7 = 24.66, the sex is determined by the following equation (see table 4): Function 1 = –19.326 + (0.505 × 13.81) + (0.394 × 12.95) + (0.237 × 24.66) = –1.411. This result is below the sectioning point (0.018); therefore the individual can be classified as female with a reliability of 80%.

For the 7^{th} cervical vertebra, discriminant analysis selected LVFc7, LIVBc7 and WIVBc7 (in this order) as having the greatest discriminant power. Centroids markedly differed by sex, and the males and females could be readily differentiated, with a sectioning point of 0.018 (Table 4). In a cross–validation procedure, 81% of the males and 79% of the females were correctly classified (Table 5). The separate discriminant analyses for LVFc7, LIVBc7, and WIVBc7 showed the sexual dimorphism to be greatest (highest coefficient) for LVFc7 and lowest for WIBVc7 (Table 4). The correct classification was most frequent (70%) utilizing LVFc7 (67% for males and 73% for females). In the univariate analyses for C7, the highest percentage of correct sex determinations was obtained with LVFc7. Table 5 displays the data for the reliability values of these functions.

(Table 5)

For the 12th thoracic vertebra, LIBV was selected for its discriminant capacity. Centroid values differed widely between the sexes, and the sectioning point was 0.058 (Table 4). The cross–validation procedure showed a mean reliability of 80% (77% for males and 84% for females) (Table 5).

Discussion

In this study of 7th cervical vertebrae and 12th thoracic vertebrae of 20th century individuals from Southern Spain, no significant asymmetry was observed between the left and right side. Significant differences were found between males and females, consistent with previous reports of longer and wider vertebral bodies in males than in females (8–10, 12–14, 16, 20), although no significant differences were found in the length of superior or inferior facets in the 7th cervical vertebra or in the length of the inferior facets or width of the vertebral foramen in the 12th thoracic vertebra.

7th cervical vertebra

The present finding of a greater length and width of the vertebral body in males is in agreement with the report by Katz et al. (8). Grave et al. (5) also found that the vertebral bodies from 3rd to 7th cervical vertebrae were significantly longer in males than in females and reported that the sexual dimorphism was more significant for the length versus width measurements. Rühli et al. (7) found a greater vertebral width in females than in males which they attributed to a higher growth in the width than length of vertebrae in females, while Soulare (14) demonstrated that the entire cervical region is longer in males than in females. Our finding of a significant sex difference in the anteroposterior diameter of the 7th cervical vertebra concurs with the results of Liguoro et al. (9). Our results support the proposal that widths of the 7th vertebral body are useful variables for sex determination. The length and width of vertebral bodies are integrated into the bone structure and were described as the most useful vertebral variables for sex determination by Del Río et al. (11)**.** It was reported in a publication by Martín (13) that the diameter of the 7th cervical vertebra was significantly larger in males than in females, and MacLaughlin and Oldale (4) observed that the diameter of vertebral bodies in general was larger in males.

The percentage reliability for sex determination was 65.5% for LIBV (function 3) in the 7th cervical vertebra, lower than the percentage of 90% obtained by MacLaughlin and Oldale (4) using the diameters of all vertebrae**.** This discrepancy may also reflect differences in study populations, given that sexual dimorphism is known to depend on the genetic makeup and environment of individuals (21). The classification percentage of individual functions was low (65.5-70.1%) in the univariate analysis but high (80%) when combined in the same function.

12th thoracic vertebra

We found a significant sexual dimorphism in the length of the inferior body, as previously reported by MacLaughlin and Oldale (4). Anderson (22) observed that the transverse diameters of the vertebral body increase from the cervical to the thoracic region and that the 12th thoracic vertebra is the longest, and Yu et al. (20) reported high sexual dimorphism values for vertebral bodies in the thoracic region. Soularue (14) found the last three thoracic vertebrae to be longer in females than in males, which was attributed to the need for the female abdomen to enlarge during pregnancy.

The 12th thoracic vertebra yielded an average reliability of 80.2% (76.7% for males and 84.2% for females) for sex determination in the present study, lower than the 87% achieved by MacLaughlin and Oldale (4) for the anteroposterior diameter of the third vertebra. Yu et al. (20) obtained reliability percentages of 62.7–85.3% for the 12th thoracic vertebra, which appears to be a useful variable for sex determination in the absence of other bones with identifiable sex–specific characteristics.

For both vertebrae analyzed in the present study, the length of the vertebral body offered the greatest discriminant capacity. Franklin et al. (23) indicated that a reliability of 75–76% is adequate when the material is damaged, whereas Bruzek and Murail (24) claimed that 95% reliability is necessary for medico–legal investigations, although this was acknowledged to be challenging when skeletal remains are fragmented.

An unexpected finding was that the most dimorphic value is related to the vertebral canal, given that this relates to the volume of neurological tissue in the spinal cord and the maturation of the CNS is very precocious. Roderick et al. (25) reported that the spinal cord weight is significantly higher in females, but further research is required to explain this result.

Conclusions

In this Mediterranean population, the length of vertebral bodies of the 7th cervical and 12th thoracic vertebrae offered the greatest discriminant power for sex determination. The results obtained in this study were similar to previous reports in other populations, although there was a difference in the reliability percentages obtained. The equations developed in this study distinguish between males and females when applied in populations with similar characteristics. This approach is highly valuable for archeological and forensic situations in which the sex cannot be identified by standard methods.

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