

Sexual dimorphism in base of skull

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1 Figure and 4 Tables

ABSTRACT: Sex determination is an important task in forensic medicine and physical anthropology. The aims of this study were to assess the presence of sexual dimorphism in the base of the skull and to compare the accuracy of sex estimation by this method with that achieved in other metric studies of this region. The sample comprised 109 individuals (53 males and 56 females) of known sex, age, and cause of death from San José cemetery in Granada (Spain). Six dimensions were analyzed and discriminant function analysis was performed. The discriminant capacity of the selected variables was then evaluated by using a cross-validation procedure. All dimensions were significantly higher in males than in females. The percentage accuracy was 75.7% (77.8% for males and 73.7% for females). Highest dimorphic values were for occipital condyle length and foramen magnum width. Skull base measurements should only serve to corroborate findings

KEYWORDS: forensic anthropology, sexual dimorphism, discriminant function analysis, foramen magnum, occipital condyles, skull base

26 **Introduction**

27 Sex identification is challenging if only parts of the skeleton are available or the pelvic
28 bones have been damaged, and a combination of approaches is usually required, based
29 on morphological and/or anthropometric characteristics (Wescott 2000).

30 Anthropometric methods offer greater objectivity as long as adequate reference data
31 (formulae) are available for the population under study, given that traits that are
32 sexually dimorphic in one population may be less dimorphic in another. For their part,
33 morphological methods are more subjective and dependent on the observer. Other
34 techniques include molecular studies based on the analysis of DNA, when this is
35 preserved (Jiménez-Brobeil 2010), although these are mainly applied in subadult
36 remains or when morphological and metric methods have proven inadequate, given the
37 technical resources required (Suazo et al. 2008). Several studies have quantified the
38 degree of sexual dimorphism in the foramen magnum, and all found the foramen
39 magnum to be significantly larger in males (Holland 1986; Catalina-Herrera 1987;
40 Günay & Altinkök 2000; Murshed et al. 2003; Çiçekcibasi et al. 2004; Suazo et al.
41 2009). In addition, various authors reported that discriminant functions from foramen
42 magnum and occipital condyle dimensions correctly classified 65–81% of individuals
43 (Uysal et al. 2005; Gapert et al. 2008; Suazo et al. 2009; Gapert et al. 2009). However,
44 the accuracy rates in some of these studies represented non-cross-validated values and
45 are likely to overestimate the predictive accuracy of these functions (Uysal et al. 2005;
46 Suazo et al. 2009). Likewise, the classification accuracy rates recorded by Holland
47 (1986) in a metric study of 100 skulls, the highest reported to date, were not cross-
48 validated values. In fact, when he applied his functions to a test sample not involved in
49 the formulation of the regression equations, the accuracy rate decreased from 90% to
50 85%. The skull base is more likely to be preserved than other bones due to its relatively

51 well-protected position and covering with a large volume of soft tissues. It is therefore
52 of interest to examine the usefulness of this region for sex estimation in incomplete or
53 damaged skeletons. The objectives of this study were i) to estimate the degree of skull
54 base sexual dimorphism in a Southern Spanish population, and ii) to compare the
55 accuracy of the resulting sex estimations with that obtained in other metric skull base
56 studies.

57 **Material and Methods**

58 The sample comprised 109 Mediterranean individuals (53 males and 56 females)
59 with a mean of age 69 years old and is part of a large and expanding collection of
60 identified infants, young children and adults from the Granada Municipal Cemetery of
61 San José. Reliable antemortem information was obtained from burial records of the San
62 José Municipal Cemetery, death certificates in the Registry Office and, in cases of
63 judicial death, from forensic reports in the Granada Institute of Legal Medicine. Key
64 data available from these records included the sex, dates of birth and death, and cause of
65 death. These individuals died during the 20th century in Granada and are housed in the
66 Laboratory of Anthropology of the University of Granada. Incomplete skulls or with
67 signs of disease (e.g., fracture) were excluded, only whole skulls were studied.

68

69 **Metric data**

70 Four measurements were taken using a digital caliper (accuracy of 0.01 mm). All
71 measurements were performed by the same examiner, who repeated them after a 15–day
72 interval to test intra–observer error; two weeks was considered sufficient to ensure that
73 the second assessment was not influenced by the learning acquired the first time.

74 In each crania were measured the following dimensions (Fig. 1): length of the
75 foramen magnum (LFM), the anteroposterior width of the foramen magnum in the

76 sagittal plane; width of the foramen magnum (WFM), the width of the foramen
77 magnum in the transverse plane; length of the occipital condyles (LOC) (left and right),
78 the maximum dimension of the occipital condyles; width of the occipital condyles
79 (WOC) (left and right), the maximum transverse dimension of occipital condyles.

80

81 (Insert Figure 1)

82

83 **Statistical analysis**

84 Statistical analyses were performed using SPSS 15.0 software program (SPSS Inc.,
85 Chicago, IL) and the data were expressed as means and standard deviations.

86 Assumptions of normality and equality of variance were tested using one-sample
87 Kolmogorov–Smirnov test and *F*-test respectively. Descriptive statistics were
88 calculated from the measurements. It characterizes the study population, allows to
89 determine the variability of the parameters and to detect possible errors in collecting or
90 processing the database. Intraobserver error was evaluated by means of the intraclass
91 correlation coefficient (ICC), which estimates the mean of correlations among all
92 possible pairs of observations. Its calculation requires a repeated-measures analysis of
93 variance (ANOVA) to be performed, thereby testing whether the variability among pairs
94 of measures is significant or not. The ICC values (range 0–1) were interpreted
95 according to the classification proposed by Fleiss (12).

96 To examine if difference between females and males is statistically significant a
97 two-sample *t*-test was used for each cranial variable.

98 Finally, the effectiveness for sex determination of the basal region of the crania was
99 analyzed by multivariate discriminant function analysis, using a stepwise procedure to
100 select the variables with highest discriminant capacity. The discriminant capacity of the

101 selected variables was evaluated by using a cross-validation procedure which
102 recalculates the discriminate function analysis while sequentially and randomly
103 selecting one of the samples and averaging the results over all of the cross-validation
104 values. Univariate discriminant analyses were then carried out for those variables
105 selected in the stepwise multivariate analysis.

106

107 **Results**

108 All dimensions were normally distributed by sex and equal variance was found
109 across samples (t -test, $p > 0.05$). The intraclass correlation coefficient obtained ($ICC \geq$
110 0.75 ; $p > 0.05$), corresponding to an excellent level of agreement (10) (Table 1).

111

112 (Insert Table 1)

113

114 The t -test indicated that males displayed larger mean values than females for all
115 measured variables of the cranial base (Table 2).

116

117 (Insert Table 2)

118

119 The discriminant function analysis shows the coefficients, classification functions of
120 the two groups, discriminant functions with corresponding sectioning points and F and
121 Wilks' lambda values. The discriminant analysis yielded three functions (Table 3).

122

123 (Insert Table 3)

124

125 The variables selected in multivariate discriminant analysis were WFM and LOC as
126 the greatest discriminant power. Males and females could be readily differentiated
127 because centroids markedly differed by sex, with a sectioning point of 0.019 (Table 3).
128 Females were correctly classified at 73.7% and males at 77.8% using multivariate
129 functions (Table 4). The univariate discriminant analysis for WFM and LOC showed
130 the sexual dimorphism to be greatest for LOC (Table 3). The highest percentage of
131 correct sex determinations was obtained with LOC (Table 4). Females were correctly
132 classified at 71.7% and males at 80.4% using LOC function (Table 4). Multivariate and
133 univariate functions showed greater correct classification rates for males than females
134 (Table 4).

135 It can be concluded from the present study that of all the variables considered in the
136 present study, LOC was found to be the most reliable variable for sex estimation.

137

138 (Insert Table 4)

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140 **Discussion**

141 A significant sexual dimorphism in basal region of crania dimensions was observed
142 in the sample analyzed. These results are consistent with most of the literature analyzed.
143 (4–6, 13, 14) found sexual dimorphism in occipital condyles and foramen magnum. The
144 degree of sexual dimorphism in foramen magnum may be explained by its development
145 compared to many other skeletal elements. Foramen magnum reaches its adult size
146 rather early in childhood (15) and is therefore unlikely to respond to significant
147 secondary sexual changes (16).

148 The lengths of the mean foramen magnum of the males and females in the present
149 study are comparable to values obtained in other Spanish (4), Turkish (6), British (10)

150 and Nigerian (16) populations. These means were between 35-37 mm for males and
151 between 34-35mm for females.

152 The results of the discriminant analysis are in agreement with the report by Aynur et
153 al (7), Uysal et al (9) and Macaluso (14). These authors showed significant sex
154 differences in the length of the occipital condyles. Amores (17) found significant
155 differences in the length of superior facets of the first cervical vertebra (atlas). They are
156 regions of contact between the basal region of the occipital bone and the atlas.

157 The percentage reliability for sex determination was 75.7% for multivariate analysis.
158 It is lower than the percentage of 81% obtained by Uysal et al (9). Holland (3) obtained
159 reliability percentages of 70–90%, Gapert et al (10) of 70.3% and Macaluso of 67.7%
160 (14). These discrepancies may also reflect differences in study populations, given that
161 sexual dimorphism is known to depend on the genetic makeup and environment of
162 individuals (18). Size-related levels of sexual dimorphism are generally population
163 specific due to a combination of genetic, environmental and sociocultural factors, and
164 thus metric standards developed for sexing cranial remains of one population may not
165 be accurately applied to other skeletal samples (11, 14, 19–22). Discriminant functions
166 applied to cases other than the source population used to develop these functions have
167 known incorrect classification percentages between 32% and 48% (21).

168

169 **Conclusions**

170 Results are similar to those of other authors when comparing them with sexual
171 dimorphism. The equations developed in this study distinguish between females and
172 males when applied in populations with similar characteristics. In case of highly
173 fragmentary remains, where no other skeletal remains are preserved, metric analysis of

174 the basal region of the occipital bone may provide a statistically useful indication as to
175 the sex of an unknown skull.

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177 **References**

- 178 1. Jiménez-Brobeil, S.A. (2010): 25 años de estudios osteológicos en Andalucía.
179 Evolución y perspectivas – I Congreso de Prehistoria y Arqueología de Andalucía
180 en Homenaje a Luis Siret.
- 181 2. Suazo, I.C., Zavando, D.A. & Smith, R.L. (2008): Evaluating accuracy and precision in
182 morphologic traits for sexual dimorphism in malnutrition human skull: a comparative
183 study – *Int. J. Morphol.* **26**, 877–881.
- 184 3. Holland, T.D. (1986): Sex determination of fragmentary crania by analysis of the
185 crania base. – *Am. J. Phys. Anthropol.* **70**, 203–208.
- 186 4. Catalina–Herrera, C.J. (1987): Study of the anatomic metric values of the foramen
187 magnum and its relation to sex – *Acta Anat. (Basel)* **130**, 344–347.
- 188 5. Günay, Y. & Altinkök, M. (2000): The value of size of foramen magnum in sex
189 determination – *J. Clin. Forensic Med.* **7**, 147–149.
- 190 6. Murshed, K.A., Cicekcibasi, A.E. & Tuncer, I. (2003): Morphometric evaluation of
191 the foramen magnum and variations in its shape: a study on computerized
192 tomographic images of normal adults – *Turk. J. Med. Sci.* **33**, 301–306.
- 193 7. Çiçekcibasi, A.E., Murshed, K.A., Ziylan, T., Seker, M. & Tuncer, I. (2004): A
194 morphometric evaluation of some important bony landmarks on the skulls base
195 related to sexes – *Turk. J. Med. Sci.* **34**, 37–42.
- 196 8. Suazo, G.I.C., Russo, P.P., Zabando, M.D.A. & Smith, R.I. (2009) Sexual
197 dimorphism in the foramen magnum dimensions – *Int. J. Morphol.* **27**, 21–23.

- 198 9. Uysal, S., Gokharman, D., Kacar, M., Tuncbilek, I. & Kosar, U. (2005) Estimation
199 of sex by 3D CT measurements of the foramen magnum – *J. Forensic Sci.* **50**,
200 1310–1314.
- 201 10. Gapert, R., Black, S. & Last, J. (2009): Sex determination from the foramen
202 magnum: discriminant function analysis in an eighteenth and nineteenth century
203 British sample – *Int. J. Legal Med.* **123**, 25–33.
- 204 11. Gapert, R., Black, S. & Last, J. (2009) Sex determination from the occipital
205 condyle: discriminant function analysis in an eighteenth and nineteenth century
206 British sample – *Int. J. Legal Med.* **138**, 384–394.
- 207 12. Fleiss, J.L. (1986): *The design and analysis of clinical experiments.* – Wiley
208 Classics Library, New York.
- 209 13. Wescott, D.J. & Moore–Jansen, P.H. (2001): Metric variation in the human
210 occipital bone: forensic anthropological applications – *J. Forensic Sci.* **46**, 1159–
211 1163.
- 212 14. Macaluso Jr., P.J. (2011): Metric sex determination from the basal region of the
213 occipital bone in a documented French sample – *Bull. Mém. Soc. Anthropol. Paris*
214 **23**, 19–26.
- 215 15. Scheuer, I. & Black S. (2004): *The juvenile skeleton* – Elsevier, London.
- 216 16. Ukoha, U., Egwu, O.A., Okafor, I.J., Anyabolu, A.E., Ndukwe, G.U. & Okpala, I.
217 (2011): Sexual dimorphism in the foramen magnum of Nigerian adult – *Int. J. Biol.*
218 *Med. Res.* **2**, 878–881.
- 219 17. Amores, A. (2009): El conocimiento de las poblaciones del pasado a través de los
220 restos óseos: determinación del sexo a partir de la primera vértebra cervical. In:
221 Gutiérrez–Redomero, E., Sánchez–Andrés, A. & Galera–Olmo, V. (eds):

222 Diversidad humana y Antropología aplicada – Universidad de Alcalá de Henares,
223 Madrid, pp. 413–425.

224 18. Chevereud, J.M. (1988): A comparison of genetic and phenotypic correlations –
225 Evolution **42**, 958–968.

226 19. Kajanoja, P. (1966): Sex determination of Finnish crania by discriminant function
227 analysis – Arch. Oral Biol. **24**, 29–34.

228 20. Birkby, W.H. (1966): An evaluation of race and sex identification from cranial
229 measurements – Am. J. Phys. Anthropol. **24**, 21–28.

230 21. Calcagno, J.M. (1981): On the applicability of sexing human skeletal material by
231 discriminant function analysis – J. Hum. Evol. **10**, 189–198.

232 22. Kranioti, E.F., Işcan, M.Y. & Michalodimitrakis, M. (2008): Craniometric analysis
233 of the modern Cretan population – Forensic Sci. Int. **180**, 110.e1–110.e5.

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247 **Figure captions**

248 Figure 1. The locations of the measurements. WOC, width of the occipital condyles;
249 LOC, length of the occipital condyles; WFM, width of the foramen magnum; LFM,
250 length of the foramen magnum.

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