Research Article

Estimating Sex of Modern Greeks Based on the Foramen Magnum Region

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Sex determination is one of the principal aims when examining human skeletal remains. One method for sex determination is based on metric criteria using discriminant functions. However, discriminant function sexing formulas are population-specific. In the present study, we determined the use of the foramen magnum as well as the occipital condyles for sex determination on adults from a modern Greek population. Seven parameters were examined (4 obtained from the foramen magnum; 3 obtained from the occipital condyles) and the sample consisted of 154 adult crania (77 males and 77 females). The results indicate that the foramen magnum region exhibits sexual dimorphism and the mean values for all parameters were higher in males than females. In comparison, the occipital condyles provide a higher determination of the correct sex than the foramen magnum. The combination of the occipital condyle variables allowed for the development of discriminant functions that predicted the correct sex in 74% of all cases. Finally, although other anatomical regions can discriminate the sexes with higher accuracy, the functions developed in this study could be cautiously used in cases of fragmented crania.

1. Introduction

Reliable sex determination is one of the principal aims when examining human skeletal remains. In forensics or anthropology, the occipital bone is frequently used in sex determination because the cranial base tends to withstand both physical insults and inhumation more successfully than many other areas of the cranium [1].

There are two major methods for sex determination from the cranium. The first one is based on morphological criteria [2–4]. The roughness of the nuchal lines and the prominence of the external occipital protuberance are good indicators for the qualitative diagnosis of sex [5]. The second one is based on metric criteria using discriminant functions [6, 7]. The dimensions of the occipital condyles and the foramen magnum have been reported as useful for quantitative diagnosis of sex by several authors [8–10]. According to Gapert and his colleagues [11], the correctly classified crania ranged from 65.8% for univariate functions to 70.3% for multivariate functions. Gapert and his colleagues [11] evaluated the foramen magnum of eighteenth and nineteenth century

British adult skulls. However, discriminant functions should be used only when the individual is known to come from the same population from which the functions were derived [12, 13], since sexual dimorphism is population-specific [14].

The aim of the present study is to assess the use of the foramen magnum as well as the occipital condyles for sex determination on adults by developing discriminant functions for a modern Greek population. Previous research regarding the foramen magnum region in a Greek population was conducted by Natsis and his colleagues in 2013 [15]. Natsis and his colleagues [15] classified the foramen magnum region according to its shape and they investigated possible correlations between anatomic metric values and various parameters. According to their results, the foramen magnum region exhibits sexual dimorphism.

2. Material and Methods

The sample consisted of 154 adult crania of Greek individuals of known sex and age at death: 77 males and 77 females. These crania constitute part of the modern skeletal reference

FIGURE 1: Foramen magnum region parameters. (1) FML: foramen magnum length; (2) FMB: foramen magnum breadth; (3) OCL: occipital condyle length; (4) OCB: occipital condyle breadth; (5) MID: minimum intercondylar distance.

collection (known as the Athens Collection) housed in the Department of Animal and Human Physiology (Faculty of Biology, National and Kapodistrian University of Athens). All individuals are Greek nationals who died in Athens and were buried and then exhumed from local cemeteries. The age at death of the individuals ranges from 19 to 99 years old and their year of birth from 1879 to 1965. Year of death for all individuals ranges between 1960 and 1996, while the place of birth covers the entire country. Individuals without any evidence of trauma or dysmorphism were selected. The parameters examined were as follows:

- (1) The foramen magnum length (FML) direct distance from basion to opisthion
- (2) The foramen magnum breadth (FMB) maximum distance between the lateral margins of foramen magnum
- (3) The foramen magnum index (FMI) calculated using the formula: $(FMB \times 100)/FML$
- (4) The foramen magnum area (FMA) calculated using Radinsky's [16] formula: $(1/4) \times \pi \times FMB \times FML$
- (5) The occipital condyle length (OCL) direct distance along the long axis from the most anterior to the most posterior point on the margin of the occipital condyle
- (6) The occipital condyle breadth (OCB) direct distance perpendicular to the long axis from the most lateral to the most medial point on the margin of the occipital condyle
- (7) The minimum intercondylar distance (MID) direct distance from the most medial point on the margin of the left occipital condyle to the most medial point on the margin of the right occipital condyle

The 3D coordinates of the foramen magnum region were collected using an Immersion Corporation MicroScribe 3DX digitizer with a standard error of 0.23 mm. Microsoft Excel was used with MicroScribe 3DX to obtain the coordinates (x, y, z) of each landmark and to calculate the equivalent interlandmark distances (Figure 1).

Initially, descriptive statistics (mean, standard deviation) were carried out for each parameter. Additionally, regarding

the occipital condyles parameters, an independent samples t -test was performed in order to ascertain whether any bilateral asymmetry exists. Finally, to analyze sex differences, independent samples t -test and discriminant function analysis (DFA) were used. The DFA was calculated for all parameters. However, the foramen magnum index as well as the area of the foramen magnum was not combined with the foramen magnum length or breadth, since a DFA is optimal when few of the single variables correlate.

All the statistical analyses were performed using the Statistical Package for Social Sciences (IBM SPSS version 23.0, Armonk, NY).

3. Results and Discussion

3.1. Results. The results of the descriptive statistics are presented in Table 1. The mean values for all parameters were higher in males than females. All data were normally distributed according to the results of the Shapiro-Wilk test. Consequently, a parametric test was performed in order to ascertain whether any bilateral asymmetry exists regarding the dimensions of the occipital condyles and to analyze sex differences. According to Table 2, no statistically significant difference between right and left side was found in either the occipital condyle length or the occipital condyle breadth. Therefore, the averages of the distances obtained from both sides were used in the subsequent analysis.

The results shown in Table 3 indicate that, with the exception of the foramen magnum index, all parameters are influenced by sex ($p < 0.05$). The discriminant functions for each single parameter and five possible combinations of them are given in Table 4. Additionally, Table 4 shows the results of the cross-validation based on "leave-one-out" principle. The most reliable single parameter for sex determination was the occipital condyle length (69.5%) followed by Radinsky's area (66.9%). Finally, the minimum intercondylar distance combined with the occipital condyle length as well as the occipital condyle breadth proved to be the best combination of parameters regarding sex determination (74.0%) followed by the combination of Radinsky's area, the occipital condyle length, and the occipital condyle breadth (72.1%).

3.2. Discussion. Regarding the nonexistence of bilateral asymmetry of the occipital condyles, our results are in agreement with those of other populations [17, 18]. Additionally, the present study confirms the results of Natsis and his colleagues [15] regarding the presence of sexual dimorphism in the foramen magnum region in the modern Greek population. Natsis and his colleagues' [15] sample included skulls of unknown age, mainly from the collection of the Departments of Anatomy of Aristotle University (Thessaloniki). On the other hand, all the individuals we examined were acquired from cemeteries in the Athens area with known age at death and year of birth. The mean values of length and width of the foramen magnum and the mean value of breadth of the occipital condyle of our sample are similar to Natsis and his colleagues sample. However, when comparing the mean values of the length of the occipital condyle and minimum intercondylar distance, our sample shows smaller and bigger

TABLE 1: Descriptive statistics: dimensions, index, and area of the foramen magnum and the occipital condyles (in mm).

	Mean	Std. deviation	Minimum	Maximum
FMB				
Male	32.48	2.70	26.92	40.01
Female	30.62	2.18	24.80	36.52
FML				
Male	36.69	2.47	30.02	42.18
Female	34.87	2.41	27.97	40.98
FMI				
Male	88.70	6.87	74.43	104.55
Female	88.04	6.76	75.73	108.67
FMA				
Male	938.12	123.20	669.14	1238.50
Female	839.82	99.91	613.63	1144.62
OCL-left				
Male	24.36	2.68	17.76	30.83
Female	22.21	2.33	16.41	26.57
OCL-right				
Male	24.52	3.07	16.43	30.46
Female	22.51	2.41	15.51	28.46
OCB-left				
Male	13.99	1.96	10.03	20.37
Female	13.17	1.84	9.14	17.72
OCB-right				
Male	13.80	1.92	10.33	18.68
Female	12.76	1.76	8.78	17.51
MID				
Male	24.28	3.01	15.95	32.53
Female	22.21	2.58	16.34	28.06

TABLE 2: Mean differences in dimensions of the occipital condyles between right and left side.

	<i>t</i>	df	Sig. (2-tailed)
OCL			
Male	-.347	152	.729
Female	-.795	152	.428
OCB			
Male	.607	152	.545
Female	1.415	152	.159

p value ≤ 0.05 is accepted as statistically significant.

TABLE 3: Mean differences of the parameters of the foramen magnum and the occipital condyle between males and females.

	<i>t</i>	df	Sig. (2-tailed)
FMB	4.716*	152	.000
FML	4.626*	152	.000
FMI	.592	152	.554
FMA	5.438*	152	.000
OCL	5.326*	152	.000
OCB	3.410*	152	.001
MID	4.522*	152	.000

*Parameters are significant at the 0.05 level.

values, respectively (Table 5). According to our observations, there might be variation in the occipital condyles among different parts of Greece.

Comparison of the distance parameters in different populations is given in Table 5. When observing the description of the foramen magnum length and the foramen magnum breadth, the modern Greek population seems to show similar values for males and females, as the Turkish [19, 20], British

[11], and Spanish [21] populations. The Indian [22] population, especially the Indian females, seems to show smaller values, when compared to the aforementioned populations.

In regard to the occipital condyle variables, the Greek population has higher OCB value than the European American [23], the African American [23], the Turkish [20], and the British [24] populations. According to Uysal and her colleagues [20], the Turkish population demonstrates by far

TABLE 4: Discriminant function (DF) equations for the foramen magnum region.

Variables	Wilk's lambda	χ^2	Sig.	Function coefficients		Cross-validation* hit ratio
FMB	0.872	20.689	0.000	Constant	-12.851	65.6%
				FMB	0.407	
FML	0.877	19.955	0.000	Constant	-14.658	63.6%
				FML	0.410	
FMA	0.837	26.932	0.000	Constant	-7.926	66.9%
				FM area	0.009	
FMB + FML	0.836	26.980	0.000	Constant	-16.026	65.6%
				FMB	0.244	
				FML	0.233	
OCL	0.843	25.924	0.000	Constant	-9.670	69.5%
				OCL	0.413	
OCB	0.929	11.170	0.001	Constant	-7.954	57.1%
				OCB	0.592	
MID	0.881	19.124	0.000	Constant	-8.199	64.3%
				MID	0.353	
OCL + OCB	0.831	27.884	0.000	Constant	-10.616	67.5%
				OCL	0.350	
				OCB	0.180	
OCL + OCB + MID	0.698	54.052	0.000	Constant	-15.026	74.0%
				OCL	0.317	
				OCB	0.108	
				MID	0.265	
FMA + OCL + OCB	0.753	42.693	0.000	Constant	-12.167	72.1%
				FM area	0.006	
				OCL	0.176	
				OCB	0.211	
FMA + OCL + OCB + MID	0.681	57.681	0.000	Constant	-15.113	71.4%
				FM area	0.003	
				OCL	0.244	
				OCB	0.140	
				MID	0.214	

*Based on "leave-one-out" principle. p value ≤ 0.05 is accepted as statistically significant.

the lowest values of MID. The extreme values for MID in Uysal et al.'s [20] paper suggests an error in reporting or a typo in the final manuscript. Finally, according to our results, the Greek population has similar OCL value with the European American [23] and the British [24] populations.

In the Greek population, the best determination of the correct sex, regarding the foramen magnum variables, was achieved through the foramen magnum area (66.9%), while the combination of the foramen magnum variables achieved only 65.6% (Table 4). In comparison, the occipital condyles provide a higher determination of the correct sex than the foramen magnum. The combination of the occipital condyle variables allowed for the development of discriminant functions that predicted the correct sex in 74% of all cases, while the best single variable (OCL) achieved 69.5%. These relatively low classification accuracies reflect the low amount of sexual dimorphism and indicate that these variables should be used with caution when attempting to estimate sex.

The low degree of sexual dimorphic expression within the foramen magnum may be explained by the fact that it reaches the end of growth rather early in childhood [25]. Therefore, no significant secondary sexual changes are expected to develop. Additionally, the prime function of the foramen magnum is to transmit the medulla oblongata and its membranes as well as the spinal component of the accessory nerve into the skull and no muscles act upon its shape and size. Although sex differences of the occipital condyles, whose prime function are to enable the head to move relative to the cervical vertebral column, are low compared to other anatomical regions [26], they are still higher when compared to the foramen magnum. The cranial base's cartilages are known to resist compression [27] and the atlantooccipital joint is primarily under static strain [28]. However, although loading stresses do not seem to play a major role in influencing dimorphic expression in the occipital condyle, the biomechanical function of the craniocervical joint could be

TABLE 5: Comparison of the distance parameters (mean $\pm$ SD in mm) in various studies.

Authors	Sample origin	N Total	FML		FMB		OCL		OCB		MID	
			Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Routal et al. (1984)	Indian	141	35.5 $\pm$ 2.8	32.0 $\pm$ 2.8	29.6 $\pm$ 1.9	27.1 $\pm$ 1.6	—	—	—	—	—	—
Catalina-Herrera (1987)	Spanish	100	36.2 $\pm$ 0.3	34.30 $\pm$ 0.4	31.1 $\pm$ 0.3	29.6 $\pm$ 0.3	—	—	—	—	—	—
Wescott and Moore-Jansen ^a (2001)	African American	133	—	—	—	—	23.2 $\pm$ 2.9	22 $\pm$ 1.2	12.8 $\pm$ 1.2	12 $\pm$ 1.5	20.1 $\pm$ 3.0	18.6 $\pm$ 2.5
	European American	389	—	—	—	—	24.7 $\pm$ 2.7	22.8 $\pm$ 2.2	12.3 $\pm$ 1.2	11.7 $\pm$ 1.3	20.9 $\pm$ 2.4	19.2 $\pm$ 2.0
Murshed et al. (2003)	Turkish	110	37.2 $\pm$ 3.43	34.6 $\pm$ 3.16	31.6 $\pm$ 2.99	29.3 $\pm$ 2.19	—	—	—	—	—	—
Uysal et al. ^a (2005)	Turkish	100	37.08 $\pm$ 1.93	34.87 $\pm$ 2.6	30.83 $\pm$ 2.04	28.93 $\pm$ 2.43	22.73 $\pm$ 2.26	20.58 $\pm$ 2.24	12.5 $\pm$ 1.57	11.78 $\pm$ 1.06	5.6 $\pm$ 0.97	4.91 $\pm$ 0.83
Gapert et al. ^b (2009)	British	158/146 ^c	35.91 $\pm$ 2.41	34.71 $\pm$ 1.91	30.51 $\pm$ 1.77	29.36 $\pm$ 1.96	24.95 $\pm$ 2.53/25.16 $\pm$ 2.51	23.30 $\pm$ 2.28/23.74 $\pm$ 2.44	12.01 $\pm$ 1.41/12.05 $\pm$ 1.69	11.42 $\pm$ 1.21/11.57 $\pm$ 1.16	21.12 $\pm$ 3.18	19.0 $\pm$ 2.40
							26.30 $\pm$ 2.92/26.48 $\pm$ 2.80	24.70 $\pm$ 2.66/24.57 $\pm$ 2.13	13.13 $\pm$ 2.01/13.24 $\pm$ 2.20	13.04 $\pm$ 1.99/12.74 $\pm$ 1.63	19.82 $\pm$ 3.19	18.77 $\pm$ 3.26
Natsis et al. ^b (2013)	Greek	143	36.20 $\pm$ 3.39	34.79 $\pm$ 2.39	30.92 $\pm$ 3.15	29.61 $\pm$ 2.08	—	—	—	—	—	—
Present study ^b (2017)	Greek	154	36.69 $\pm$ 2.47	34.87 $\pm$ 2.41	32.48 $\pm$ 2.7	30.62 $\pm$ 2.18	24.52 $\pm$ 3.07/24.36 $\pm$ 2.68	22.51 $\pm$ 2.41/22.21 $\pm$ 2.33	13.8 $\pm$ 1.92/13.99 $\pm$ 1.96	12.76 $\pm$ 1.76/13.17 $\pm$ 1.84	24.28 $\pm$ 3.01	22.21 $\pm$ 2.58

^aLeft; ^b right/left; ^cforamen magnum/occipital condyles.

one reason for the increased expression of sex dimorphism in occipital condyles when compared to the foramen magnum. According to Gapert and his colleagues [24], it is more likely that the expression of sexual dimorphism in the occipital condyles is mainly due to genetic rather than epigenetic factors. Therefore, it is important to know the origin of any unidentified skull in order to choose the appropriate population-specific discriminant function formula for estimating sex.

4. Conclusions

This study confirms that the foramen magnum region exhibits sexual dimorphism; however, the dimorphic expression is low to moderate. Although other anatomical regions, such as the pelvis, can discriminate between sexes with higher accuracy, the functions developed in this study could be used in cases of fragmented cranial remains. Finally, since the discriminant function sexing formulas are population-specific, this method should be applied on samples that belong to Greek populations or at least to populations with similar expression of sexual dimorphism in the foramen magnum region. Because error rates are expected to be relatively high (26% or higher), sex estimation using these discriminant functions should be done with extreme caution.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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