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Forensic anthropology population data

Craniometric analysis of the modern Cretan population

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ABSTRACT

Despite the fact that sex assessment using craniofacial characteristics is commonly made worldwide, a lack of such investigation is noted in the Balkan area and in Greece in particular. The aim of this study is to develop a sex determination technique using osteometric data from skeletal remains of a contemporary Cretan cemetery population.

A total of 90 males and 88 females are measured according to standard osteometric techniques. Age differences are not significant (mean age for men = 68.94 ± 13.41, N = 66; for women = 73.21 ± 16.77, N = 66). A total of 16 dimensions taken from the craniofacial skeleton are used and data are analyzed using SPSS subroutines. A comparison is made with other contemporary populations, including Americans (Terry collection) and South Africans (Dart and Pretoria collections), as well as an archaeological sample (Middle and Late Helladic) from Crete.

Results indicate that males are statistically significantly greater than females in all dimensions. Bizygomatic breadth is the most discriminatory single dimension and can provide an accuracy rate of 82% on average. Using a stepwise method involving five dimensions (bizygomatic breadth, cranial length, nasion–prosthion and mastoid height and nasal breadth), accuracy is raised to 88.2%. Interestingly, cranial length is selected as the first discriminating variable by the stepwise analysis when only the neurocranium is available for measurement.

1. Introduction

The existence of sexual dimorphism in human skeletons and its importance in medicolegal investigations has long been acknowledged. The skull is probably the most studied bone in that context. Krogman and İşcan [1] stated that sex assessment in a collection of 750 skeletons was possible, with levels of reliability of 100% when the entire skeleton was present, 92% using the skull alone, and 98% when combining the pelvis and skull. Even though several postcranial elements have more recently proved to be more effective sex predictors [2], the skull remains among the most dimorphic parts of the skeleton.

Skeletal morphological observations are easier to make but difficult to judge. More of the morphological features depend on nutrition, occupation, race and geographical regions, and thus their reliability is questioned since this information is nearly never available. In that respect metric studies may provide certain advantages because it is a more objective way of attaining data [1,3]. With the use of osteometric techniques, determination of sex from skulls relied very much on statistical analysis. Some of the earlier studies following this approach include those on Europeans [4,5], Americans [6], South Africans [6–9], Japanese [10,11] and Chinese [12]. The number of research papers has increased even more when one surveys the postcranial skeleton in different populations [1,13].

Apart from the classical osteometric techniques, one should remark the use of the geometric morphometric method in order to explore the implications of shape on sexual dimorphism of the craniofacial skeleton. In that vein, Rosas and Bastir [14] studied a sample of Portuguese (Coimbra), while Kimmerle and associates [15] in a more recent study dealt with American Blacks and Whites.

Cranial characteristics of modern Greeks have not been well studied. Most of the research deals with the demography of archaeological remains, with the exception of few roentgenometric studies on cephalo-dentofacial morphology of contemporary populations [16–18]. The availability of skeletal material representing modern Europeans to carry out population-based analysis is limited. The situation is different in Greece where remains are exhumed 3–5 years after burial, placed in boxes and kept in ossuaries for as long as the relatives keep paying the "rental fee" [19].

The purpose of the study is to develop a sex determination technique using osteometric data from remains exhumed from two contemporary Cretan cemeteries in Heraklion, Crete. The

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population of Crete is thought to have a complicated political history with many different civilizations ruling its people. It seems though that the native Cretan islanders remained relatively uninfluenced despite the many different forces that ruled and administered the island.

2. Materials and methods

The skeletal material for this study is selected from the cemeteries of St. Konstantinos and Pateles, Heraklion, Crete. The bones are gathered, cleaned and placed in boxes and stored in a special room all together or in family tombs where existing. Unless living members of a deceased person can afford to keep the body in the grave with a "rental fee", it is inhumed in a designated area by the city. Authors were given permission by the local District Attorney according to standard procedure, to analyze a limited number of unearthed remains in order to carry out a population-based osteometric study. The study population consists of individuals who were born in Crete between 1867 and 1956, and died between 1968 and 1998. A number of people who may have migrated from Turkey, other islands and mainland Greece are excluded from the study. All individuals with obvious bone pathology are also removed from the sample. Age and cause of death are obtained from the Heraklion City Hall census archives for only part of the skeletal material while sex is obvious from the names written on the boxes that contained the remains.

A total of 178 well-preserved, adult skulls (90 males and 88 females) of Cretan origin are measured.[1] Sixteen dimensions are taken from the neural and facial portion of the skull. These dimensions are maximum cranial length, basion–nasion length, maximum vault breadth, maximum frontal breadth, minimum frontal breadth, bizygomatic breadth, foramen magnum length, foramen magnum breadth, basion–bregma height, basion–prosthion length, nasion–prosthion height, mastoid height, biorbital breadth, interorbital breadth, nose breadth and nose height. Measurements are taken by the senior author according to Martin and Saller's procedure [20]. All dimensions are recorded in millimeters using a sliding and spreading caliper.

A comparison is made with several populations geographically and time wise distant from Cretans. The data are from the early 20th century White Americans (Terry collection) and South Africans Whites (Dart and Pretoria collections) [21,22], all gathered by the author İşcan. Archaeological data are obtained from a published work [18] and derive from the remains of Middle (1900–1600 B.C.) and Late Helladic (1600–1100 B.C.) periods in Crete.

Stepwise discriminant function analysis is used (Method = Wilk's lambda with $F = 3.84$ to enter and $F = 2.71$ to remove) to select the combination of variables that best discriminate sexes. Single variables with high F-ratios are analyzed using direct discriminant function analysis. A "leave one out classification" procedure is applied in order to demonstrate the accuracy rate of the original sample and the one created by cross-validation. Differences between means are measured using Student's *t*-test. Data analysis is carried out using canonical discriminant function subroutines of SPSS.

3. Results

Descriptive statistics of 16 skull measurements and associated univariate *F*-ratio to measure the differences between the sexes are shown in Table 1. All but interorbital breadths are found to be significantly different between the sexes. Mean age difference is not significant (mean age for men = 68.94 ± 13.41, $N = 66$; for women = 73.21 ± 16.77, $N = 66$). Table 2 provides various discriminant functions statistics where the sex of an unknown skull can be determined. These functions are constructed so that different preservation conditions can be considered to make identification. Function 1 (F1) is designed to analyze a complete skull which is commonly seen in a protected area, not so seriously damaged, thus many dimensions can be measured. The table shows the result of a stepwise discriminant function analysis using 15 dimensions. Function 2 (F2) assumes that the face is not fully available for measurement. Eight dimensions (maximum cranial length, maximum vault breadth, maximum frontal breadth, minimum frontal breadth, bizygomatic breadth, foramen magnum length, foramen magnum breadth, basion–bregma height, mastoid height) are entered into another stepwise analysis and five of them are selected (Table 2). Forming F3–F8, cranial length, basion–bregma height, basion–nasion length, bizygomatic breadth, biorbital breadth and nose height are used with direct discriminant function procedure (Table 2).

Table 3 summarizes the accuracy rate for both the original data and "leave one out classification" in all functions. This classification provides a test to determine the sex of an unknown individual. The highest accuracy rate is obtained using F1 (88.2%), followed by F2 (83%). Correct group membership reaches 82% when bizygomatic breadth (F3) is used alone and 75% in the case of basion–bregma height (F4) and biorbital breadth (F5).

The sex can be calculated from these functions by multiplying the values of the cranial dimensions by the corresponding

[1] Original data are available from the first author upon request.

Table 1
Descriptive statistics of cranial dimensions (in mm) and univariate *F*-ratio of the differences between the sexes

Dimensions	Males		Females		*F* ratio[a]
	Mean	S.D.	Mean	S.D.	
Max cranial length	181.07	6.63	172.89	6.48	64.92
Basion–bregma height	139.70	4.87	132.47	6.83	62.14
Max vault breadth	137.64	6.63	133.92	5.85	14.84
Max frontal breadth	122.46	5.79	118.99	5.42	16.03
Min frontal breadth	96.33	4.52	93.23	4.50	19.63
Bizygomatic breadth	130.54	5.13	122.07	4.57	126.57
Foramen magnum length	36.19	2.80	34.49	2.31	18.38
Foramen magnum breadth	31.37	2.80	28.85	2.51	37.60
Mastoid height	31.69	3.71	28.56	3.50	31.50
Basion–nasion length	102.01	3.85	96.25	6.54	48.36
Basion–prosthion length	93.11	5.05	88.76	5.70	27.33
Nasion–prosthion height	69.38	6.56	64.12	6.40	27.44
Biorbital breadth	97.86	4.25	93.14	4.17	52.41
Nose breadth	23.98	2.54	23.16	2.11	5.17*
Nose height	51.60	3.04	48.20	2.98	53.03

*Significant at $p < 0.05$, all others significant at $p < .001$.
[a] d.f. = 1.165.

Table 2
Discriminant function statistics, *F*-ratios and statistical significance in Cretans

Step variables entered	Exact *F*	d.f.	Raw coefficient
F1: Total cranium[a]			
1. Bizygomatic breadth	129.48	1.168	0.073045296
2. Max cranial length	83.57	2.167	0.149499711
3. Nasion–prosthion height	60.55	3.166	0.063250835
4. Mastoid height	47.39	4.165	0.039003053
5. Nose breadth	39.37	5.164	−0.096952844
Constant			−34.02400303
F2: Neurocranium[b]			
1. Max cranial length	70.41	1.176	0.088868759
2. Basion–bregma height	52.78	2.175	0.059044917
3. Mastoid height	41.41	3.174	0.047681315
4. Foramen magnum breadth	34.62	4.173	0.117936068
5. Max vault breadth	30.08	5.172	0.081852746
Constant			−36.20808823
			Demarking point
F3: Bizygomatic breadth	132.17	1.175	Female < 126.19 < male
F4: Basion–bregma height	52.644	1.176	Female < 135.81 < male
F5: Biorbital breadth	54.274	1.176	Female < 95.42 < male
F6: Nose height	55.918	1.169	Female < 49.87 < male
F7: Basion–nasion length	49.099	1.176	Female < 99.1 < male
F8: Max cranial length	70.409	1.176	Female < 176.80 < male

Sectioning point for F1 and F2 is set to zero.
[a] Variables not selected for Function 1 include basion–nasion length, maximum vault breadth, maximum frontal breadth, minimum frontal breadth, foramen magnum length, foramen magnum breadth, basion–bregma height, basion–prosthion length, biorbital breadth, interorbital breadth and nose height.
[b] Variables not selected for Function 2 include maximum frontal breadth, minimum frontal breadth and foramen magnum length.

Table 3
Classification accuracy on cranial dimensions in Cretan population

Cranial dimensions and functions	Male[a]		Female[a]		Total (%)
	N	%	*N*	%	
F1: Total cranium					
Original	75/86	87.21	75/84	89.29	88.20
Cross-validated	75/86	87.21	73/84	86.90	87.10
F2: Neurocranium					
Original	77/90	85.56	71/88	80.68	83.10
Cross-validated	77/90	85.56	70/88	79.55	82.60
F3: Bizygomatic breadth					
Original	71/90	78.89	74/87	85.06	81.90
Cross-validated	71/90	78.89	74/87	85.06	81.90
F4: Basion–bregma length					
Original	68/90	75.56	66/88	75.00	75.30
Cross-validated	68/90	75.56	66/88	75.00	75.30
F5: Biorbital breadth					
Original	67/90	74.44	67/88	76.14	75.30
Cross-validated	67/90	74.44	67/88	76.14	75.30
F6: Nose height					
Original	63/86	73.26	64/85	75.29	74.30
Cross-validated	63/86	73.26	64/85	75.29	74.30
F7: Basion–nasion breadth					
Original	68/90	75.56	60/88	68.18	71.90
Cross-validated	68/90	75.56	60/88	68.18	71.90
F8: Max cranial length					
Original	62/90	68.89	63/88	71.59	70.20
Cross-validated	62/90	68.89	63/88	71.59	70.20

[a] Predicted group membership.

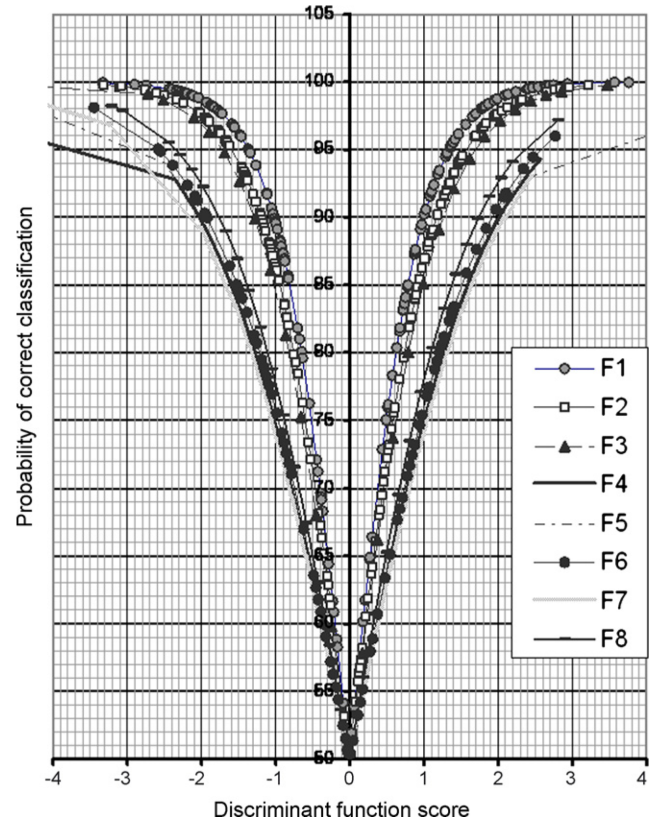

Fig. 1. Probability levels of correct sexing according to the discriminant scores of each individual. Negative discriminant scores correspond to females, and positive discriminant scores correspond to males.

coefficients plus the constant. If the resulting discriminant function score is greater than zero it is classified as male. In the situation that only one dimension is used for the analysis the sex can be easily determined by evaluating the measurement of the unknown according to the demarking point, which in the case of bizygomatic breadth is 126.19 (mean of both sexes). For example, a skull of an unknown person with a bizygomatic breadth of 120 mm will be classified as female.

The "leave one out classification" statistic surveys to a comparison of accuracy rate between the original sample and the one created by cross-validation. Fig. 1 demonstrates the probability levels of correct sexing according to the discriminant scores of each individual. Initially the posterior probability values for each function are produced using a discriminant subprogram of SPSS, then misclassified cases are removed and probability of correct classification for both sexes is combined. Plotting the data with Excel program for Windows resulted in the diagram presented in Fig. 1. For example, if a discriminant score based on the neurocranial measurements (Function 2) is −1.40337 (x coordinate) the posterior probability of that individual to be female is 93.03% (y coordinate).

A comparison of the modern Cretans is made with American and South Africans Whites of approximately the same period (Table 4). One would note that Cretans are closer in size to American Whites in most dimensions and furthest from African Whites. African Whites demonstrate a significantly larger cranial length (over 7 mm for males and over 6 mm for females), while means for maximum frontal breadth are greater in Cretans for both sexes. Mean values for cranial length are greater in White Americans (Terry) as well, but all other dimensions are very close to contemporary Cretans. A Middle to Late Helladic population of Crete is also compared with the cemetery sample. Due to the lack of sufficient sample size, only six measurements (maximum cranial length, maximum vault breadth, basion–bregma height, maximum frontal breadth, minimum frontal breadth and bizygomatic breadth) are available for comparison and it is observed that the archaeological Cretans are relatively smaller than the recent descendents in all dimensions but cranial length. Mean values for cranial length are almost 5 mm greater in Helladic males and 7 mm in Helladic females compared with modern Cretans.

In order to test the efficacy of the equations deriving from modern Cretans, it is attempted to classify the archaeological sample using the most effective single dimension: bizygomatic breadth. This measurement is available in 46 of the 126 Helladic crania and correct group membership is found as follows: 83.3% for females, 64.3% for males and 71.7% in total. Classification results yield about 10% less than in the original sample.

4. Discussion

Accurate determination of sex from the human skull is of great importance in anthropologic and forensic investigations. While the overlap in the size of the male and female range is still the most important aspect of sexual dimorphism, the accuracy depends on factors causing variation in sex. It must be stressed that a population-specific study is required in order to have accurate results in sexing a skeleton deriving from that population [23,24]. A recent study evaluating standard methods used for North American Whites concluded that they can be applied only partially in modern Greeks [25]. Furthermore, the unique biological characteristics of Cretans, formed due to geographical isolation, raise the need for the development of population-specific standards.

Table 4
A t test comparison of the Cretans with the Helladic population, White Americans and South Africans

	Cretans			White Americans			White Africans			Helladic population			t-Test differences between Cretans and		
	N	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	White Americans	White Africans	Helladic population
Male															
Max cranial length	90	180.82	6.54	46	182.28	6.95	44	187.77	5.44	82	185.07	9.19	−1.207	−6.09[c]	−3.52[b]
Basion–bregma	90	139.19	5.89	43	133.42	9.28	44	136.84	4.06	36	127.81	6.73	4.35[c]	2.38[a]	9.41[c]
Max vaultl breadth	90	137.73	6.50	46	142.76	5.20	44	139.59	5.83	82	133.82	4.83	−4.55[c]	−1.61	4.45[c]
Max frontal breadth	90	122.46	5.66	46	123.93	5.87	44	119.45	4.92	71	113.27	6.23	−1.425	3.01[b]	9.79[c]
Min frontal breadth	90	96.24	4.44	46	96.13	5.49	44	97.89	3.84	66	94.83	4.35	0.129	−2.1[a]	1.99[a]
Bizygomatic breadth	90	130.30	5.07	46	130.80	4.69	44	128.93	4.37	28	126.32	6.72	−0.563	1.53	3.35[b]
Foramen magnum length	90	36.19	2.78	45	37.02	2.74	44	37.68	2.59				−1.649	−2.99[b]	
Foramen magnum breadth	90	31.30	2.74	45	31.49	2.98	44	31.57	1.81				−0.371	−0.59	
Mastoid height	90	31.68	3.62	46	30.59	3.07	44	33.95	3.35				1.745	−3.51[c]	
Basion–nasion length	90	101.82	3.82	46	101.22	6.83	44	102.48	4.48				0.663	−0.88	
Basion–prosthion length	89	92.99	4.96	38	108.68	96.98	43	95.42	5.39				−1.530	−2.56[a]	
Nasion–prosthion height	89	69.15	6.49	27	70.33	8.55	44	71.43	4.04				−0.770	−2.13[a]	
Nose breadth	86	23.98	2.51	46	23.87	1.54	44	24.75	2.20				0.280	−1.72	
Nose height	86	51.58	3.03	46	52.07	2.50	44	53.75	3.56				−0.932	−3.64[c]	
Female															
Max cranial length	88	172.68	6.40	46	176.78	7.77	47	178.81	5.87	41	179.22	6.26	−3.27[b]	−5.45[c]	−5.44[c]
Basion–bregma	88	132.35	6.67	44	129.32	4.48	47	130.64	5.30	25	125.80	8.31	2.723	1.52	4.10[c]
Max vault breadth	88	133.70	5.79	46	139.28	5.40	47	137.81	4.79	40	132.18	5.35	−5.41[c]	−4.15[c]	1.42
Max frontal breadth	88	118.85	5.42	45	119.04	5.66	47	115.60	5.86	38	109.55	6.05	−0.190	3.23[b]	8.53[c]
Min Frontal breadth	88	93.19	4.41	46	94.33	4.61	47	93.62	4.74	36	92.47	4.78	−1.394	−0.52	0.80
Bizygomatic breadth	87	121.93	4.60	46	122.78	4.01	47	122.02	3.54	18	120.61	6.17	−1.061	−0.12	1.04
Foramen magnum length	88	34.52	2.33	46	36.02	2.50	47	36.17	1.88				−3.46[b]	−4.18[c]	
Foramen magnum breadth	88	28.91	2.49	46	30.28	1.89	47	30.55	1.89				−3.26[b]	−3.94[c]	
Mastoid height	88	28.51	3.56	46	27.89	2.74	47	30.89	3.89				1.027	−3.59[c]	
Basion–nasion length	88	96.31	6.38	45	96.62	4.61	47	96.32	4.10				−0.289	−0.01	
Basion–prosthion length	88	88.84	5.57	33	87.79	5.55	47	90.04	5.03				0.922	−1.24	
Nasion–prosthion height	88	64.13	6.31	6	68.50	4.64	46	66.02	5.13				−1.664	−1.76	
Nose breadth	85	23.15	2.09	46	23.35	1.72	47	22.89	2.05				−0.561	0.67	
Nose height	85	48.14	2.98	46	49.46	3.28	47	49.83	2.21				−2.33[a]	−3.40[c]	

T test values are significant at [a]$p < 0.05$; [b]$p < .01$; [c]$p < .001$.

Skeletal remains have not been investigated in Greece, at least for the modern population, most probably because of the religious and local superstition. The Greek Church does not allow human remains to be removed or studied. Cemeteries are now all being "rented" for a couple of years. Bones are exhumed and later destroyed and put in a mass grave without any individual identification [19]. A positive step towards the utilization of this remarkable osteological bank is the formation of the Athens reference collection, completed in 2003 [19]. Around the same time authorization was given to the Department of Forensic Sciences, University of Crete in order to analyze a certain number of remains from two cemeteries in Heraklion, Crete.

Despite the fact that sex assessment using craniofacial characteristics is commonly made worldwide, a lack of such investigation is noted in the Balkan countries. Among the few published studies, morphological sex determination of crania deriving from a mass murder grave in Serbia should be mentioned [26]. Their sample, consisting of individuals of Albanian descent killed in the recent Kosovo war, was sexed with an accuracy rate of only 70.6% using a combination of nine cranial traits while a single variable approach gave an accuracy rate of 71.0%. Obviously these results are relatively poor compared with the ones anticipated according to the literature [3,27]. There is beyond any doubt interpopulation variation seriously affecting cranial sex accuracy [26]. However, even in studies that provided greater accuracy in morphological sex determination in crania, a significant amount of intraobserver error is noted, deriving naturally from the subjective nature of the study [3].

Obviously, metric studies present a certain advantage in terms of objectivity in data evaluation. In that respect the current study has resulted in the development of population-specific osteometric standards designed for sex assessment from the skulls of the Cretan population. Although the mandible is considered the most dimorphic part of the skull [26], it was excluded from the current study because of a large number of edentulous individuals and those with excessive alveolar resorption, which may affect the mandibular dimensions.

Among the published studies on cranial sex dimorphism, one should mention the one of Giles and Elliot [6] who studied 408 American Black and White crania of known sex and found cranial height, maximum bizygomatic diameter and mastoid length to be statistically significant. Classification accuracy was 85.5%.

Hanihara [10] worked on Japanese skulls and found 89.7% accuracy in diagnosing the sex correctly. In a more recent study, İşcan and co-workers [27] found accuracies of 84.1% (cranium and mandible) and 83.7% (cranium only) in a different Japanese population.

İşcan and Steyn [9] worked on 106 South African White crania and 90 South African Black crania, taking 13 standard cranial measurements. Correct group membership yielded from 86.7% up to 97.8% for males and from 81.1% to 95.8% for females. Interestingly, cranial length and breadth were not selected by stepwise procedure. In another study by the same authors, correct sexing in White South Africans was obtained with an accuracy rate of 85.7% for crania and 80.2% for bizygomatic breadth alone [8].

In general, the percentage accuracy for cranial measurements obtained in this study is comparable and sometimes higher when compared with other groups [6,8,26]. Furthermore, the jack knife technique gave almost the same classification as the original data. A significant remark comparing all mentioned studies is that cranial length is included in the cranial function only in the present sample, suggesting that sexual dimorphism seems to be better entrenched in Cretans. Interestingly, length was found of great discriminatory value in studies on long bones of the same population [28].

One can remark the comparison of the present data with those of Manolis's Middle and Late Helladic Cretans. In spite of all diverse discussions about significant secular changes in bones [17,29], such a conclusion is not supported in Manolis's study [18]. The Helladic population seems rather stable, suggesting that there was less contact with significantly different populations. This conclusion is in accordance with Coon's suggestion that Cretans represented a homogenous isolated racial element during Minoan civilization [30]. Therefore, we consider all individuals from the Middle and Late Helladic period as one group. Comparing the means of six dimensions in Table 4 there is an obvious increase in all but cranial length in the modern Cretan sample for both males and females. One can assume that brachycephalization may have occurred in Crete with the influence of other populations, probably deriving from the eastern part, that is, Turkey. Such a speculation is supported by recent studies that suggest that long-term secular changes are a result of genetic effect rather than environmental conditions [31,32]. Contrary to this is a theory based on a radiographic study, where it is concluded that craniofacial characteristics in Greeks remained unaltered for the past 4000 years [17,33,34]. Nevertheless, the classification accuracy of the archaeological sample gave poor results when standards of modern Cretans for bizygomatic breadth were used. Thus, it is questionable whether the formulae produced in this study can be applicable to archaeological populations. Obviously additional research is needed in order to express any reliable suggestion on such a complicated issue.

Sexual dimorphism in Cretans is well reflected in cranial dimensions, thus providing a very high accuracy rate of correct classification. From the forensic perspective this information is essential for the identification of skeletal remains. Hence, one should be very sceptical in expressing a definitive theory on the racial affinity of modern Cretans which exceed the main purpose of this study. A more detailed investigation of the shape and size components of sexual dimorphism must be carried out in order to define with better accuracy the special craniofacial characteristics of modern Cretans and the degree of isolation of the population compared with other groups in space and time. Further research may provide additional standards for Cretans and Greeks and hopefully will be applicable to other Mediterranean and Balkan populations.

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