Metric sex determination from the pelvis in modern Greeks

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Abstract

The ability to determine sex from unknown skeletal remains is vital, and methods to do this on the various bones of the human skeleton have been researched extensively. Many researchers have emphasized the need for population specific data for methods which are based on measurements, as there are vast differences in body size in various populations. The pelvis is known to be the most sexually dimorphic part of the human body, and no discriminant function formulae for this bone are available for Greek or other Mediterranean groups. The purpose of this study was therefore to develop discriminant functions which can be used for sex determination on measurements of the pelvis of modern Greeks. A sample of 97 male and 95 female pelves in a skeletal collection housed in Heraklion, Crete, was used. Measurements were taken from the articulated pelvis, single os coxae and the sacrum. Discriminant function formulae for all measurements and various combinations were used in order to assess the degree of sexual dimorphism in various parts of the pelvis, and to make the formulae usable on fragmented remains. For the single os coxae, average accuracies of 79.7 – 95.4% (79.1 – 93.5% on cross-validation) were found. However, it was found that measurements of the sciatic notch were unreliable and yielded poor results, and it is advisable that this characteristic must only be used as a last resort. Dimensions of the sacrum were not very dimorphic (average accuracy 60.9%), while measurements from the articulated pelvis yielded poorer results than that from single innominate bones. The diameter of the acetabulum was the single most dimorphic characteristic, providing on average 83.9% accuracy when used in isolation.

Keywords: pelvis, sacrum, sexual dimorphism, osteometric analysis, discriminant function analysis, os coxa, innominate

1. Introduction

The correct determination of sex is a key aspect in the analysis of a skeleton from forensic and archaeological contexts. For this purpose, the pelvis has always been the most commonly used bone, providing the most accurate results. According to Krogman and İşcan [1], 95% accuracy can be obtained if the pelvis is complete, although Bruzek [2] found that accuracies ranged from 59% to 96%. However, it has widely been recognized that skeletal characteristics vary among populations (e.g., [3-7]), and due to this regional variability that each population should have specific standards to optimize the accuracy of identification. Several studies using a variety of measurements and characteristics of the pelvis have therefore been conducted from all over the world, with varying degrees of accuracy (e.g., [8-11]).

It has also been shown that some of the traditional characteristics in various parts of the skeleton, e.g., the shape of the greater sciatic notch [12], or gonial eversion [13] may not be as accurate as is commonly believed. New methods are constantly being developed (eg, [14]) and existing standards tested (e.g, [15-17]). These include both metric and morphological methods of assessing sexual dimorphism.

Seen in the light of the exceptional time depth and wealth of archaeological skeletal material from Greece and the Mediterranean area in general (e.g, [18-22]), it is surprising that relatively little research has been done on sex determination from the skeleton in this part of the world. Ari [7] studied the morphology of the greater sciatic notch in male Byzantine skeletons from Turkey, while Rissech et al. [23] studied skeletons from various collections from Europe, but concentrated more on age determination and growth. Duric et al. [24] studied remains from mass graves in Serbia, and found that they were very sexually dimorphic, such that they could be sexed with 100% accuracy using morphology alone. Of interest is the research by Albanese [25] who studied samples from both the Terry and a Portuguese collection, using both the hipbone and the femur, in an attempt to create standards which can be used across populations. He also investigated the repeatability of a new method to measure pubis and ischial length, and used a logistic regression analysis for sex determination.

The aim of this study was to collect metric data from the skeletons of modern Greeks, living on Crete, in order to develop discriminant function formulae that can be used to determine the sex of unknown adults. In this study the traditional measurements from articulated pelves, single os coxae and sacra were used. Various combinations of measurements were used, in order to assess the sexual dimorphism of various parts of the pelvis, and to make the formulae usable in fragmentary and incomplete remains.

2. Materials and methods

The materials for this study are housed in Heraklion, Crete, and were collected by members of the Department of Forensic Science, Medical School, University of Crete. The remains belong to modern Greek people who had lived on Crete and died during the past 50 years. Due to lack of space in graveyards, individuals are buried for a short period of time. After about 4 years, the remains are excavated if full decomposition has taken place and are then kept in boxes in mausoleums. The remains of these individuals may be destroyed if all their relatives are dead, or insufficient funds are available to keep them in the mausoleum (Kranioti, pers comm.).

The skeletal collection is comprised of approximately 100 male and 100 female individuals, but due to the presence of soft tissue and damage to some of the bones, a total of 97 male and 95 female pelves could be measured. A full set of measurements could not be obtained from each of these individuals, mostly due to the presence of dried soft tissue, but sample size for each of the measurements ranged between 72 and 94 (Table 1). Using standard anthropometric techniques [1,11,26,27], the following 17 measurements were taken:

1. Pubic length: measured using a sliding caliper from the most medio-superior point of the pubis to the closest point on the acetabular rim.

2. Height of the pubic symphysis : measured from the most superior to the most inferior point on the pubic symphysis [8].
3. Ischial length: measured using a sliding caliper from the most distal point of the ischium to the closest point on the rim of the acetabulum.
4. Pubic tubercle-acetabulum length: measured with a sliding caliper from the highest point of the pubic tubercle to the nearest point on the acetabulum.
5. Total innominate height: the greatest distance from the most superior point on the iliac crest to the most inferior point of the ischial tuberosity [26].
6. Iliac width: the greatest distance from the anterior superior to the posterior superior iliac spines [26].
7. Greater sciatic notch breadth: measured from the base of the ischial spine to the posterior inferior iliac spine stopping at a point before the curvature of the spine angles to the posterior [11]. This was measured on a graph paper, so that the two points from which the measurements were taken were on the same horizontal line on the graph paper.
8. Greater sciatic notch depth: measured with the bone in the same position as for (9), but at the deepest edge of the notch perpendicular to the line between the two points mentioned in (9). This is in essence the same measurement as that of Patriquin et al, but just measured on graph paper rather than with a caliper in order to attempt to improve accuracy.
9. Acetabular diameter: maximum diameter of the acetabulum measured in a superior-inferior direction [28].
10. Anterior length of sacrum: measured with spreading caliper from the middle point of promontorium to the middle point of the inferior border of the sacrum.
11. Anterior straight breadth of sacrum: measured with sliding caliper as the distance between the left and right auricular surfaces.
12. Maximum breadth S1: maximum breadth of S1 on the superior surface of the sacrum, measured with a sliding caliper.
13. Bi-iliac diameter (articulated pelvis): maximum distance between the iliac crests measured with an osteometric board after the articulation of the pelvis [1].
14. Conjugate vera: antero-posterior diameter of the pelvic inlet measured with a sliding caliper in an articulated pelvis.
15. Transverse diameter: maximum distance between the arcuate lines measured in an articulated pelvis with a sliding caliper.

In order to test for intra-observer repeatability of the measurements, the pelves of 30 randomly selected individuals, including both males and females, were remeasured by MS after the completion of the collection of the original dataset. The two sets of values for these 30 individuals were compared by means of a paired Students' t-test.

	Male				Female				
	N	Mean	Std. Deviation	SE Mean	N	Mean	Std. Deviation	SE Mean	Sig
Publng	94	70.35	4.48	0.46	81	73.21	4.37	0.49	0.000
Pubsymph	93	40.86	3.38	0.35	77	37.10	4.14	0.47	0.000
Ischlng	95	56.74	3.29	0.34	92	51.55	4.57	0.48	0.000
Tubac	90	53.90	5.42	0.57	79	52.65	5.67	0.70	0.144*
Totalht	95	214.62	9.20	0.94	90	199.86	8.90	0.94	0.000
Iliacwth	94	159.26	7.52	0.78	91	154.51	7.27	0.76	0.000
Notchbr	93	43.37	3.94	0.41	84	50.96	5.89	0.64	0.000
Notchdpt	93	28.68	4.68	0.49	84	30.58	4.40	0.48	0.006
Acet	92	54.59	3.07	0.32	94	49.15	2.76	0.28	0.000
Sacrlngth	78	108.81	12.08	1.37	81	101.70	11.19	1.24	0.000
Sacrbr	83	116.57	6.06	0.67	91	115.61	6.33	0.66	0.308*
S1br	72	49.46	4.16	0.49	78	47.09	4.68	0.53	0.001
Bi-iliac	84	276.86	14.43	1.57	86	275.16	21.25	2.29	0.542*
Conjvera	85	103.21	8.54	0.93	83	113.33	9.27	1.02	0.000
Trdiam	85	124.66	7.79	0.84	86	130.69	7.51	0.81	0.000

* not significant

Table 1
Descriptive statistics for the pelvic measurements. (Publng = pubic length, Pubsymph = height of the pubic symphysis, Ischlng = ischial length, Tubac = pubic tubercle-acetabulum length, Totalht = total innominat height, Iliacwth = iliac width; Notchbr = greater sciatic notch breadth, Notchdpt = greater sciatic notch depth, Acet = acetabular diameter, Sacrlngth = anterior length of sacrum, Sacrbr = anterior straight breadth of sacrum, S1br = maximum breadth S1, Bi-iliac = bi-iliac diameter, Conjvera = conjugate vera, Trdiam = transverse diameter

Standard descriptive statistics, including means and standard deviations, were obtained for all measurements. Significance of differences between the sexes was assessed by means of a one-way ANOVA analysis. Data were then subjected to statistical analysis using the SPSS program.
Firstly, all dimensions on a single innominate bone (pubic length, height of the pubic symphysis, ischial length, pubic tubercle-acetabulum length, total innominate height, iliac width, greater sciatic notch width and depth and acetabular diameter) were entered into a stepwise discriminant function procedure using Wilks' lambda, to determine which variable provided the best

discrimination between the sexes (Function 1). F to enter was 3.84 and F = 2.71 to remove. Stepwise analysis incorporated all pelvic dimensions that were systematically added and removed from the list. Once the first variable is selected it is removed from the analysis and the remaining variables are reassessed and selected.

Step	Variables entered	Wilks' lamda	Degrees of freedom
1	Acetabular diameter	0.569	150
2	Sciatic notch breadth	0.430	149
3	Total height	0.360	148
4	Pubic length	0.292	147
5	Ischial length	0.275	146
6	Pubic tubercle-acetabular length	0.263	145

Table 2
Stepwise discriminant function analysis of pelvic dimensions, Function 1.

The same analysis was also performed on the measurements for various parts of the pelvis, but this time using a direct approach. These were grouped as all the measurements of the pubis and ischium (Function 2), the measurements of the complete innominate bone only (total innominate height and iliac width, Function 3), the sciatic notch width and depth (Function 4), the measurements of the sacrum (Function 5) and the three measurements for the articulated pelvis (Function 6). An additional function (Function 7), was also calculated using only the variable that was chosen first (thus the best discriminator) by the stepwise analysis.

To measure the effectiveness of the functions, a “leave one out” classification procedure was performed. This classifies each individual bone by the functions derived from all cases other than that case itself. This process continues for all individual bones, until all are tested. Through this process the accuracy of assignments to either male or female categories is thus crossvalidated.

Of the 192 individuals used in this study, the ages of only 122 were noted in the records. The sample comprised mostly of older individuals with a mean age of just above 70 years, and with so few younger individuals the effect of age on sex determination could not be assessed.

Functions and variables (mm)	Standard coefficients	Structure coefficients	Unstand coefficients	Centroids
Function 1 (complete bone)				
Acetabular diameter	0.436	0.519	0.146	M= 1.477
Sciatic notch breadth	-0.431	-0.443	-0.084	F= -1.874
Total height	0.474	0.491	0.052	
Pubic length	-0.752	-0.183	-0.171	
Ischial length	0.363	0.510	0.116	
Pubic tub-acetab length	0.276	-0.099	0.052	
Constant			-11.388	
Sectioning point			-0.199	
Function 2(pubis & ischium)				
Pubic length	-0.987	-0.272	-0.221	M=1.006
Height pubic symphysis	0.612	0.442	0.166	F=-1.288
Ischial length	0.749	0.526	0.185	
Pubic tub-acetab length	0.466	0.142	0.088	
Constant			-5.505	
Sectioning point			-0.141	
Function 3(complete bone)				
Total height	1.179	0.961	0.131	M=0.818
Iliac width	-0.353	0.377	-0.048	F=-0.864
Constant			-19.560	
Sectioning point			-0.023	
Function 4(sciatic notch)				
Sciatic notch width	0.994	1.000	0.200	M=-0.726
Sciatic notch depth	0.023	.273	0.005	F=0.804
Constant			-9.552	
Sectioning point			0.039	
Function 5 (sacrum)				
Sacrum length	0.669	0.739	0.059	M=0.418
Sacrum breadth	-0.283	0.186	-0.045	F=-0.376
S1 breadth	0.730	0.764	0.163	
Constant			-8.868	
Sectioning point			0.021	
Function 6 (articulated)				
Bi-iliac diameter	-0.659	-0.019	-0.039	M=-0.783
Conjugate vera	0.818	0.731	0.092	F=0.793
Transverse diameter	0.768	0.508	0.100	
Constant			-11.979	
Sectioning point			0.005	
Function 7 (acetabulum)				
Acetabular diameter	1.000	1.000	0.343	M=0.944
Constant			-17.782	F=-0.924
Sectioning point			0.01	
Demarking point			Female<51.87>Male	

Table 3

Canonical discriminant function coefficients for pelvic dimensions. Function 1 was derived by means of a stepwise analysis, all others by a direct analysis.

3. Results

All measurements yielded non-significant values between the two groups of 30 randomly selected specimens when tested for intra-observer repeatability, with the exception of sciatic notch depth ($p<0.01$). This showed that all measurements were repeatable and could be measured with a high degree of accuracy, excluding the measurement of sciatic notch depth.

The descriptive statistics are shown in Table 1. Most of the measurements show statistically significant differences between the two sexes, excluding three measurements namely pubic tubercle-acetabular length, width of the sacrum, and the bi-iliac width in the articulated pelves. As expected, the pubis is longer in females, although the symphyseal height is more in males. The ischium is larger in males, as is the acetabulum, the total height of the innominate, the iliac width and sacral length. The sciatic notch is wider and deeper in females, who also have longer pubic bones and larger pelvic inlets.

Table 2 displays the results of the stepwise analysis of pelvic dimensions. For function one, all dimensions on the unarticulated os coxa were entered and acetabular diameter was selected first, followed by sciatic notch breadth. Only six of the nine variables entered were selected, with sciatic notch depth, pubic symphysis height and iliac width not included. The degrees of freedom is less than the total number of individuals as displayed in Table 1, as all individuals without a complete set of variables for the included measurements were left out.

The standard, structure and unstandardized coefficients as well as the centroids and sectioning points are shown in Table 3 for all functions, including those that were derived from direct analyses (Functions 2-7). In order to use these formulae the value of the variable (measured in mm) should be multiplied by the unstandarized coefficient, and added/subtracted to each other. This value should then be added/subtracted to the constant. If the obtained value is less than the sectioning point in Functions 1, 2, 3, 5 and 7, the individual is a female, and larger a male. The opposite is true for Functions 4 and 6, where a value larger than the sectioning point indicates a female and vice versa. As the sample sizes for males and females are not equal, the sectioning points are not zero. For example, for Function 3 if Total Height is 216 mm and Iliac Width is 160 mm, the equation should be: $(0.131 \times 216) - (0.048 \times 160) - 19.560 = 1.056$. This is larger than the sectioning point of -0.023, indicating a male.

For Function 7 a demarcation point was included, which simply means that a value for the acetabular diameter of less than 51.87 mm would indicate a female, and more than that a male. Obviously if a value is close to this demarcation point, the possibility of error is larger, but if it is further it will be more accurate.

The accuracies for these functions, including the leave-one-out analysis, are shown in Table 4. Function 1, where all the variables on a single os coxa were included, showed the best results, being on average 95.4% accurate. Three females were lost during cross-validation, bringing the

Functions	Males		Females		Average accuracy
	Count	%	Count	%	
Function 1					
Original	82/85	96.5	64/68	94.1	95.4
Cross-validated	82/85	96.5	61/68	89.7	93.5
Function 2					
Original	78/87	89.7	60/68	88.2	89.0
Cross-validated	78/87	89.7	60/68	88.2	89.0
Function 3					
Original	80/94	85.1	72/89	80.9	83.1
Cross-validated	80/94	85.1	72/89	80.9	83.1
Function 4					
Original	81/93	87.1	60/84	71.4	79.7
Cross-validated	81/93	87.1	59/84	70.2	79.1
Function 5					
Original	34/63	54.0	47/70	67.1	60.9
Cross-validated	34/63	54.0	45/70	64.3	59.4
Function 6					
Original	66/84	78.6	64/83	77.1	77.8
Cross-validated	65/84	77.4	64/83	77.1	77.2
Function 7					
Original	80/92	87.0	76/94	80.9	83.9
Cross-validated	80/92	87.0	76/94	80.9	83.9

Table 4

Percentage accuracy and cross-validation for the derived formulae

accuracy down to 93.5%. The pubis and ischium measurements were also very accurate, with 89% of individuals correctly classified. This dropped to around 80% when only the sciatic notch measurements (Function 4) or measurements of the whole bone (Function 3) were used. It seems that it is hardly worthwhile to measure an articulated pelvis, because the results of measuring individual os coxae are much better (Function 6, 77.8% accuracy). The sacrum in this population is not very dimorphic at all, with accuracies that are hardly more than chance (54% for males and 67% for females). Measuring the acetabulum only provided fairly good results, with about 84% of individuals correctly classified.

4. Discussion

Forensic anthropologists are continually attempting to improve methods of skeletal identification through development of new methods of determining sex or fine-tuning of existing methods on various parts of the skeleton so that it can be admissible in court [e.g., 29,30]. The aim of this paper was to follow in this tradition, by developing population specific formulae that could be used on people living in Greece and the Mediterranean.

Some measurements in the pelvis may be very difficult to record accurately [31]. In this study it was found that all measurements were highly repeatable, with the exception of the sciatic notch depth. This fact, coupled with the low levels of accuracy obtained for sciatic notch measurements when used in isolation (Function 4; 79.1%), makes measurements and formulae based on sciatic notch dimensions less reliable. Some studies have shown that size of the greater sciatic notch may not be a very good characteristic to use in sex determination and that it may vary between populations (e.g., [11,12,32]. Rösing et al. [33] stated that outside of Europe this feature often does not permit reliable sex determination, but this may well be true of European populations as well (see also [24]). It thus seems that this characteristic is unreliable both when applied in a metric or morphological assessment, and that other features of the pelvis can provide more reliable results. Walker [32] found that sciatic notch shape is also influenced by age, and this may be something to take into account too.

It is interesting to note that three of the measurements (bi-iliac breadth, sacrum breadth and pubic-tubercle acetabular length) are not dimorphic at all. As far as the bi-iliac breadth is concerned, this is probably due to the fact that the relatively wider hips expected in females is being “obscured” by the larger body size of males, leading to very similar overall dimensions. It therefore seems that measuring the complete pelvis would not provide better results than measuring the disarticulated bones, as also comfirmed from the low accuracies of Function 6. It is also interesting to note that the dimension which is the most dimorphic (acetabular diameter) is one that is associated simply with robusticity, and has nothing to do with child bearing at all. This measurement was also found to be one of the best indicators of sexual dimorphism in similar studies [5,11,34].

Studies in the metric characteristics of male and female sacra seem to be less numerous than that for the rest of the pelvis. The reports concerning results and accuracies also seem to be quite different, with some authors finding it usable and others less so (e.g., [35-38]). In this study the accuracy of the discriminant function for the sacrum is particularly disappointing, with only about 60% of the study sample classified correctly. Females are classified with more accuracy than males. The male sacrum seems to be more variable, making it nearly impossible to use metric methods for sex determination.

The accuracies with which sex can be determined using discriminant function formulae in this population is on a par with that found in several other studies. The 95% accuracy when using all measurements (dropping to 93% after cross-validation) is similar to that found, for example, by Schulter-Ellis et al. [27] on an American sample (95 – 98%) and Patriquin et al. [11] on a South African sample (up to 91%). It seems that most of the differences in the pelves between the sexes are situated in the pubic and ischial parts. Absolute size (robusticity), however, also plays a significant role as can be seen by the fact that acetabular diameter was selected first in the stepwise analysis and total bone size also gave good results.

The accuracies found here are also similar to that of Albanese [28] who used logistic regression to determine sex (allocation accuracy of 90 – 95%). As this author suggested, a future avenue of research should now be to combine various datasets of populations across the continent, to see whether it is possible to employ more global standards. It would also be of interest to see whether results of logistic regression and discriminant functions are on a par as far as their accuracies are concerned.

In summary, this paper provides discriminant function formulae that can be used with high levels of accuracy on Greek populations. Single innominate bones provided better results than the sacrum or articulated pelvis. The sciatic notch depth measurement is difficult to repeat, and also does not seem to contribute much to the ability to distinguish between the sexes. This population is very dimorphic as far as pelvic dimensions are concerned, and the results are on a par with those on other populations. Factors such as secular trends, the influence of body size on pelvic dimensions [39], age at death [32] and nutrition were not taken into account, and may play a role which needs to be taken into account when using these formulae on other populations, specifically those from archaeological contexts.

Acknowledgements

M Steyn would like to thank Prof M Michalodimitrakis and Dr E Kranioti for their hospitality during the stay on Crete. Funding was provided by the University of Pretoria.

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