

## Geometric morphometric approach to sex estimation of human pelvis

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### ABSTRACT

Sex estimation of skeletal remains is an important issue in both forensics and bioarchaeology. The chance of attaining a high level of accuracy regarding sex allocations is related to the skeletal component analyzed and the ability of the techniques employed to describe shape and size differences among the sexes. Current opinion regards the hip bone as the most reliable sex indicator because it is the most dimorphic bone, particularly in adult individuals. The aim of this study was therefore to analyze the greater sciatic notch and the ischiopubic complex morphology by employing geometric morphometric techniques, based on semilandmark and multivariate statistical methods, in order to develop a reliable and accurate technique for adult sex estimation. The sample analyzed consisted of 121 adult left hip bones randomly selected from the collection of documented skeletons housed at the Museu Antropologico de Coimbra. Morphometric analysis was based on coordinates of landmarks and semilandmarks of the ilium and ischiopubic regions that were digitized on 2D photographic images. Discriminant analysis with leave-one-out cross-validation and *k*-means clustering of shape and shape-size variables were used in order to classify individuals by sex. For the greater sciatic notch, average accuracy of 90.9% was achieved with both multivariate analyses based on shape variables. For the ischiopubic complex, the values obtained with shape variables were 93.4% and 90.1% for discriminant and *k*-means, respectively. Females were misclassified more frequently than males, especially for the ischiopubic complex. When multivariate statistical analyses were performed using shape-size variables, the percentages of correct classifications were lower than those obtained with shape variables. We conclude that the use of geometric morphometrics and multivariate statistics is a reliable method to quantify pelvic shape differences between the sexes and could be applied to discriminate between females and males.

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### 1. Introduction

Accurate sex estimation is an important issue in both forensics and bioarchaeology. The skeletal components often investigated for this purpose are the pelvis and skull, although current opinion regards the hip bone as the most reliable sex indicator because it has long been recognized as the most dimorphic bone, particularly in adult individuals [1,2]. Numerous techniques of sex estimation have been proposed, based either on visual assessment or recording of lineal metric variables of the hip bone [3–12].

Visual or morphoscopic techniques are based on the scoring of diverse traits, such as subpubic angle, shape of the sciatic notch or the preauricular sulcus, and final sex assignment is made according to a rating which separates males from females [6,10,13]. Such an approach has been largely criticized because it is highly subjective, requires an experienced observer and is even more unreliable

when the final score is close to the separating value [6,9,12,14,15]. Another problematic aspect of these techniques is the use of dichotomous or ordinal scoring that precludes an adequate description of continuous phenotypic traits, reducing the variation to a few discrete categories [16,17].

An alternative to sex estimation based on visual scoring is to quantify pelvis variation. Morphometric variables have some advantages over morphoscopic ones, such as higher levels of simplicity and consistency in their recording and the existence of powerful statistical methods for the analysis of continuous data [14]. These are frequently collected by using linear measurements (i.e., traditional morphometrics); however, quantification of size and shape of many pelvic traits, mostly curvilinear and with few conspicuous landmarks, is extremely difficult by means of these techniques. A reliable technique used to estimate the sex of individuals from morphology requires the selection of an adequate method for describing the differences between sexes, both in size and shape, and a suitable statistical approach for classifying the individuals. The application of semilandmark-based geometric morphometric techniques for detecting differences between the male and female pelvis was

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recently proposed [16,18]. Geometric morphometric methods quantify the shape of an object, employing 2D and 3D coordinates of anatomical landmarks and semilandmarks. These methods are preferable to linear distances because they retain the geometry of the objects throughout the analysis and allow for the description of subtle differences among structures [19–22]. Although this approach is a useful tool for the description of sexually dimorphic structures with few landmarks, it has not yet been extensively applied to the development of techniques for sex estimation.

The aim of this work is therefore to analyze the greater sciatic notch and the ischiopubic complex morphology by employing geometric morphometric techniques based on semilandmarks and multivariate statistical methods. This will develop a reliable and accurate procedure for adult sex estimation.

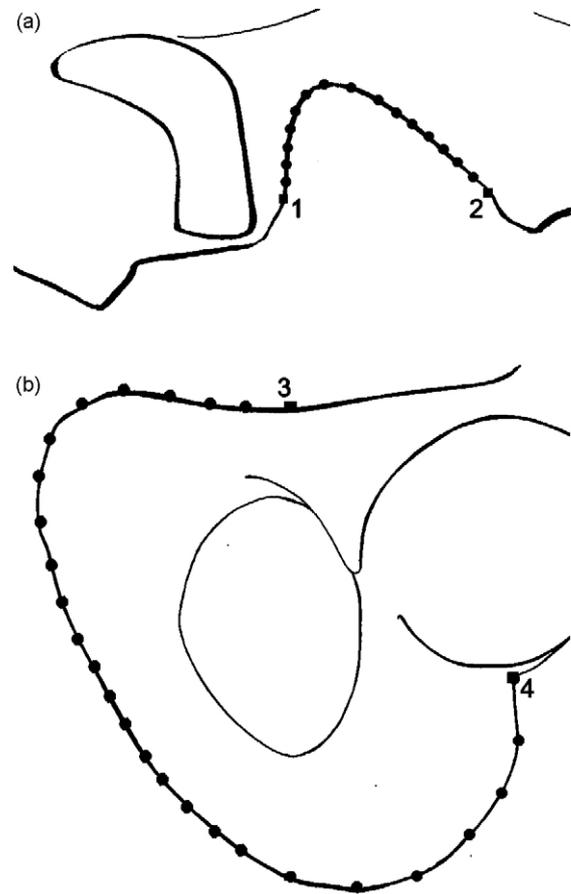
## 2. Materials and methods

The sample consisted of 121 adult left hip bones randomly selected from the collection of documented skeletons housed at the Museu Antropologico de Coimbra (University of Coimbra, Coimbra, Portugal). The individuals used in this study (Table 1) are of European ancestry and were buried during the 19th and 20th centuries [23].

For the morphometric analysis we took 2D photographic images of the greater sciatic notch and ischiopubic region of each left hip bone with a digital camera (Olympus Camedia C-3030). In this study we chose to utilize the description of these two structures based on configurations of landmarks and semilandmarks obtained from photographs because they principally vary in two dimensions. The right hip bone was used when the left one was not present or damaged. Each bone was placed with the auricular surface facing upwards. Sciatic notch photographs were taken with the camera lens 250 mm from the bone and parallel to the ilium surface. The ischiopubic region was placed 250 mm from the camera and parallel to the camera lens. All the hip bones were placed in exactly the same position for photography. Two landmarks, i.e., points placed on homologous morphological features [20], and 14 semilandmarks were digitized on the greater sciatic notch (Fig. 1a). Landmark 1 was placed at the base of the ischial spine, and landmark 2 at the tip of the piriform tubercle. When the tubercle was absent, the landmark was placed at the end of the sciatic notch just before the bone curves backward toward the auricular surface [24]. Two landmarks and 25 semilandmarks were digitized on the ischiopubic region (Fig. 1b). Landmark 3 was placed at the intersection of the upper edge of the pubis with the perpendicular line that reaches the uppermost point of the obturator groove, and landmark 4 on the intersection between the external margin of the ischium and the inferior border of the acetabulum. To digitize evenly distributed points along the contour line of the two analyzed structures guidelines named “fans” were placed onto the images using MakeFan6 software [25]. In both structures the lines were positioned in a semi-circular pattern, between the landmarks previously defined. Next, both landmarks and semilandmarks were digitized using software tpsDIG 1.40 [26].

Intra- and inter-observer errors associated with the placement of point coordinates in geometric morphometric analysis were evaluated previously [18]. The analysis showed that the use of geometric morphometrics results in high intra- and inter-observer agreement.

Within geometric morphometrics the shape is defined as the information remaining after the effects of position, orientation and scale have been held constant [27]. In this study, the Generalized Procrustes analysis [27,28] was used to remove these effects in landmark and semilandmark configurations, and centroid size was employed as the size measurement [21]. To convert the evenly distributed points along contours into semilandmarks, they were aligned by means of the



**Fig. 1.** (a) Allocated landmarks (1 and 2) and semilandmarks (circles) on sciatic notch; (b) allocated landmarks (3 and 4) and semilandmarks (circles) on ischiopubic complex.

perpendicular projection or minimum Procrustes distance criteria [29,30]. This operation extends the Generalized Procrustes analysis [27,28] by sliding the semilandmarks until they match the positions of corresponding points along an outline in a reference specimen as closely as possible, thereby minimizing the Procrustes distance [30]. This results in an alignment of the semilandmarks along the curve so that the semilandmarks on the target form lie along the lines perpendicularly to a curve passing through the corresponding semilandmarks on the reference form [30,31].

To describe major trends in shape variation within the sample, we performed a principal component analysis of the uniform components plus partial warps variables, which were obtained from thin plate spline analysis [32]. Within geometric morphometrics this analysis is known as Relative Warps [RW; 20, 33]. The alpha parameter, which determines the relative weight of the principal warps on different scales, was fixed at 0 (zero) value, as suggested by Rohlf [33]. In order to visualize sexual dimorphism, graphical representations of shape differences were generated as deformation grids of female and male individuals relative to the reference configuration (i.e., consensus configuration).

Likewise, a principal component analysis based on a matrix that includes shape coordinates and an additional column with log centroid size was performed in order to describe the differences in the shape-size space [34]. The value of centroid size represents a measurement of overall bone size and was obtained as the sum of the values corresponding to the ischiopubic complex and ilium [18]. We analyzed the size because sexual dimorphism in this variable is reported by previous studies [35].

To estimate the sex of individuals, we used two statistical methods, discriminant analysis with leave-one-out cross-validation and *k*-means clustering. Their performance was examined by comparing the percentage of cases in which the estimated sex of individuals correctly matched their true sex (i.e., the percent of correct classification). These methods were applied to the greater sciatic notch, the ischiopubic complex and both structures simultaneously.

Discriminant analysis is a method used to find a set of axes that possesses the greatest possible ability to discriminate between two or more groups [36]. A major purpose of discriminant analysis is to achieve a predictive classification of individuals. The first step is to estimate the discriminant functions that best differentiate between groups, computing the classification scores for the individuals. The next step is to classify the individuals according to the group

**Table 1**  
Composition by age and sex of the sample used to analyze ischiopubic complex (IPC) and greater sciatic notch (SN).

Age (years)	Female	Male
15–19.9	4	7
20–24.9	6	4
25–29.9	12	13
30–34.9	7	11
35–39.9	10	11
40–44.9	3	12
45–49.9	4	6
>50	6	5
Total	52	69

for which they have the highest classification score. Finally, the accuracy of the classifications is evaluated using a cross-validation analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case. Therefore, the analysis is performed several times, excluding one individual at a time, as a way to establish whether or not it is well classified. This provides an unbiased estimate of the percentage of individuals that were wrongly classified. Because discriminant analysis requires more individuals than variables per group, the use of outline methods poses difficulties due to the large number of semilandmarks needed per individual to describe outlines and due to the representation of semilandmark points by two coordinates ( $x$ - and  $y$ -) when there is only one degree of freedom per point [37]. Therefore, principal components analysis is used to reduce the dimensionality of the data by analyzing a limited number of scores instead of the original data. In this study, the discriminant analysis was based on the score of individuals along the first two axes of the principal component analysis, and was obtained to examine shape and shape-size variables of the greater sciatic notch and the ischiopubic complex. The scores along the first axis of each analysis were also employed for the estimation based on both structures.

In  $k$ -means clustering analysis, a set of specimens are divided into  $k$ -groups fixed a priori in such a way that the specimens within the  $k$ -groups are more similar to one another than specimens in the other clusters, thereby minimizing within-group variation [38]. The first step in this analysis is to define  $k$  centroids, one for each cluster. The next step is to take each specimen and associate it with the nearest centroid. Then, the  $k$  new centroids are re-calculated and the specimens are associated with the nearest new centroid. Consequently, a loop is generated, where  $k$  centroids will change their location by step until no more changes occur. The  $k$ -means clustering is different from discriminant analysis because no information about the specimens is required, so the clusters are generated based only on the morphological similarity among specimens. In this study, we classified the individuals into two groups representing both sexes. Then, we assessed grouping accuracy for the individuals in comparison with their real sex.

Geometric morphometric analyses were performed using tpsRelw 1.44 [26] and Semiland6 software [25]. All statistical analyses were performed using R 1.9.1 [39].

### 3. Results

Fig. 2 is a plot of the first two relative warps calculated from the landmarks and semilandmarks of the greater sciatic notch, which account for 92.06% of the explained variance. The first relative warp explains 58.18% of the variance, and the morphologies at its most positive values corresponding to males are narrower and deeper than those located at the most negative values, which correspond to females (Fig. 2a and b). Moreover, those morphologies with extreme positive values in the first

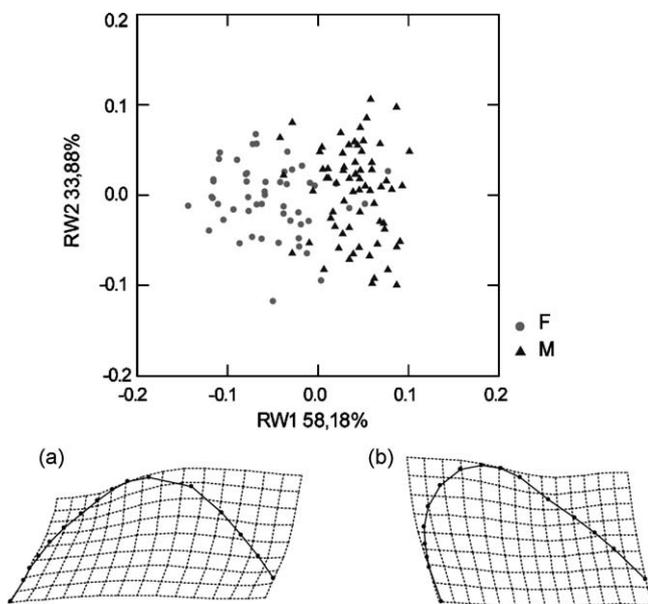


Fig. 2. Relative warps analysis of the greater sciatic notch. The deformation grids represent the variation along the first relative warps axis, showing typically female (a) and male morphology (b). F, female; M, male.

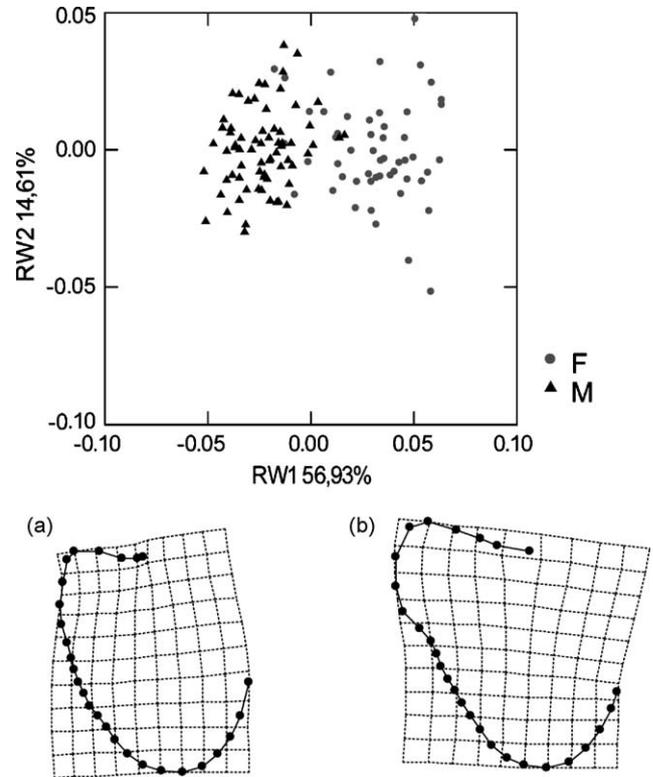


Fig. 3. Relative warps analysis of the ischiopubic complex. The deformation grids represent the variation along the first relative warps axis, showing typically male (a) and female morphology (b). F, female; M, male.

relative warp present their deepest point at the posterior side of the sciatic notch. In contrast, the specimens located at negative values are characterized by more symmetrical greater sciatic notches.

The relative warp analysis of the ischiopubic complex, which accounts for 71.94% of the explained variation, is shown in Fig. 3. The first relative warp, accounting for 56.93% of the total sample variance, comprises variations in the subpubic concavity and pubis projection. The females are represented by the positive values of this axis and present a greater pubis projection than the males located at the negative values (Fig. 3a and b). In addition, the former are characterized by a subpubic concavity that is not found in the latter. The second component explains a negligible percentage of total variation (14.61%). At its positive values the specimens have a more marked subpubic concavity than those located at the negative values.

The discriminant and  $k$ -means clustering analyses based on shape variables yield similar results (Table 2). The percentage of correct allocations by discriminant analysis is comparable for both structures, being 90.9% for the greater sciatic notch and 93.4% for the ischiopubic complex. Females were misclassified more frequently than males, especially for the ischiopubic complex. When the age of the misclassified individuals is considered, the results indicate that three females who were classified as male according to their ischiopubic morphology are less than 20 years old and the two misclassified males are 30 years. In contrast, the ages of the individuals misclassified according their greater sciatic notches range from 19 to 53 years. The percentage of correct allocations by  $k$ -means clustering is higher for the greater sciatic notch than for the ischiopubic complex, being 90.9% and 90.1%, respectively (Table 2). These results are similar to those obtained by means of discriminant analysis. Moreover, subjects incorrectly assigned

**Table 2**

Percentages of correct estimations obtained with discriminant analysis and *k*-mean clustering for greater sciatic notch (SN) and ischiopubic complex (IPC) based on shape variables.

	Discriminant analysis			<i>k</i> -means clustering		
	Correctly assigned	Incorrectly assigned	% correctly assigned	Correctly assigned	Incorrectly assigned	% correctly assigned
SN						
F	47	5	90.4	46	6	88.5
M	63	6	91.4	64	5	92.75
Total	110	11	90.9	110	11	90.9
IPC						
F	46	6	88.46	45	7	86.53
M	67	2	97.1	67	2	97.1
Total	113	8	93.4	112	9	90.1
SN + IPC						
F	49	3	94.2	46	6	88.5
M	65	4	94.2	65	5	94.2
Total	114	7	94.2	111	11	91.7

F, female; M, male.

**Table 3**

Percentages of correct estimations obtained with discriminant analysis and *k*-mean clustering for greater sciatic notch (SN) and ischiopubic complex (IPC) based on shape-size variables.

	Discriminant analysis			<i>k</i> -means clustering		
	Correctly assigned	Incorrectly assigned	% correctly assigned	Correctly assigned	Incorrectly assigned	% correctly assigned
SN						
F	46	6	88.46	45	7	86.54
M	63	6	91.30	64	5	92.75
Total	109	12	90.08	109	12	90.08
IPC						
F	39	13	75	49	3	94.23
M	53	16	76.81	67	2	97.1
Total	92	29	76.03	116	5	95.86
SN + IPC						
F	47	5	90.38	45	7	86.53
M	63	6	91.30	61	8	88.40
Total	110	11	90.09	106	15	87.60

F, female; M, male.

by discriminant analysis were also misclassified by *k*-means clustering. When the individuals were classified by employing the first relative warps of both the sciatic notch and the ischiopubic complex, the number of correct estimations increased, but only slightly (Table 2).

When the discriminant analysis was performed in base to shape-size variables, the results were worse than those obtained with shape variables (Table 3). For the ischiopubic complex the allocation accuracy was only 76.03%, whereas for the greater sciatic notch accuracy was 90.08% (Table 3). This percentage increases when analyzing both structures, although it is still lower than the results achieved by means of shape analysis. The percentage of correct allocation by *k*-means clustering of shape-size variables ranges from 87.60% to 95.86% according to the structure analyzed (Table 3), meaning that it is inferior to the percentage of correct allocation found with shape variables. The results of the shape-size analysis also indicate a slightly higher accuracy for males.

## 4. Discussion

This study shows that multivariate analysis of landmarks and semilandmarks of the ischiopubic region allow for differentiation between males and females with a high degree of accuracy. In particular, the highest values of correct assignment were found using shape variables (93.4% and 90.1% with discriminant and *k*-means clustering analysis, respectively), indicating that this structure displays marked sex differences in morphology, independent of size. The main differences among the sexes, as displayed by deformation grids, are due to the greater pubis projection in females than in males and to the presence of a subpubic concavity in the former (Fig. 3a and b). The differential elongation of the pubic bone in females relative to males has the effect of increasing the size of the pelvic aperture in females compared to males, which is related to the specialization of the female pelvis to parturition [40].

The fact that the pubic bone is relatively longer in adult females than males while the male ischium is longer than that of the female allowed to propose a method for determining the sex of the skeletons based on the ischio-pubic index, which is commonly higher in females [41,42]. According to Washburn [42] the sex of over 90% of skeletons can be determined by this index alone. However, the problems of quantifying this structure have been acknowledged for as long as it has been measured. Length of pubis and ischium are taken from the point in the acetabulum where the three elements of coxal bone meet, but this point cannot be accurately located in the adult because these elements are completely fused. The problems associated with the definition and location of the acetabular landmark were recently summarized by Albanese [3]. Taking these difficulties into account, in the present paper the contour of the ischiopubic region was described by two alternative landmarks (3 and 4) and a set of semilandmarks. In a previous study it was shown that the coordinates of the points employed here can be obtained with a very low intra- and inter-observer error, and then can be consistently located in an adult pelvis [16]. Consequently, the technique applied in this paper is a valuable alternative used to quantify sexual dimorphism in the shape of the ischiopubic region.

The high allocation accuracy obtained in this study agrees with the results reported by Phenice [10] based on a method for visually scoring sex differences (96%). However, others' studies have failed to achieve such high values using Phenice's method. In this way, percentages ranging from 60% to 90% have been found using different European samples [6,9], a sample from British Columbia [43] and a sample from Ontario [44]. Likewise, Bruzek [6] has documented relatively low percentages (70–92%) of sex assignment by the visual inspection of ischiopubic proportions in two European samples. These differences in accuracy could be attributed to either population variation or degree of experience of the observers [9,45]. Ubelaker and Volk [45] suggest that experience likely contributes to the accuracy of Phenice's method and that for inexperienced investigators, consultation of all pelvic indicators offers an advantage over using just the three variables in that method [45]. In contrast, the coordinates of landmarks and semilandmarks can be consistently digitized even by observers with little experience in the analysis of pelvic sexual dimorphism, and no previous knowledge about the expression of such traits in the population being examined is required [16]. Our results show that females were misclassified more frequently than males in base to shape variables of the ischiopubic complex (Table 2). These percentages are age biased since the females between 15 and 19.9 years of age were misclassified in a greater proportion than those 20 years of age and older. Such results could be due to the prolongation of pubic growth in females during early adulthood, which was documented both in past and living populations

[18,46–49]. Longitudinal growth studies show that between the ages of 8 or 9 and 18, growth at all points on the pubis is greater in females than males; these pelvic measurements show significant growth extending beyond that of stature [46,47]. This fact highlights the relevance of considering the age of individuals for sex estimation in forensic studies, as well as in the analysis of demographic profiles of archaeological samples. The main problems could be found in adolescents and young adults showing complete fusion of the ilium, ischium and pubis because their sex is estimated with the same criteria applied to adults, but adult female morphology emerges some years after that pelvis is fused.

The extended growth of the pubic bone in females also affects the analysis of independent traits. For instance, pubic length is positively and significantly correlated with lateral placement of the ventral arc [50], and it is also related to the development of subpubic concavity. Therefore, they should not be considered as independent criteria in sexing an adult pelvis. The alternative technique suggested in this study describes the shape of the ischiopubic region using landmarks and semilandmarks which are treated as a single variable representing the whole contour of this structure.

Although the pubic bone is recognized as one of the most dimorphic structures in the skeleton, it is also one of the worst preserved parts of the skeleton in inhumation contexts. In contrast, the central region of the coxal bone has a greater rate of preservation. Because of that, many studies rely on sex estimations based on visual or metric analysis of the greater sciatic notch [4,6,24]. This study shows that a semilandmark-based analysis of the sciatic notch provides a high accuracy of sex prediction, around 90% (Tables 2 and 3). The percentages of correct estimations found here are similar to those found by Pretorius et al. [24] for South African black individuals using geometric morphometrics based on landmarks (87.1% of females and 93.1% of males correctly placed).

These results contrast other studies based on visual sexing. For instance, Bruzek [6] visually registered the shape of the sciatic notch and found that misclassifications occurred in around of 6–8% of the men and in 16–21% of the women of two European samples (one of which is the same sample from Coimbra used here). Patriquin et al. [51] found that 84% of South African black females had a wide sciatic notch and 91% of South African black males a narrow configuration by simple visual assessment. In the same way, DiBennardo and Taylor [7] achieved only 79–81% accuracy based on the shape of the sciatic notch. This is because sexual characteristics of the sciatic notch are difficult to assess by visual examination. As is noted by Bruzek [6], not only is the observer influenced by the size of the pelvis, but by the development of marginal structures. Therefore, this kind of analysis would be very subjective.

The studies employing metric approaches based on linear measurements have obtained low accuracies as well. Using measurements of the sciatic notch depth and width, Patriquin et al. [51] found that 77% of males and 73% of females could be correctly classified, thus providing lower accuracies than were found by geometric morphometric analysis of the same sample [24]. More recently, Steyn and İscan [35] noted that measurements of the sciatic notch are not highly repeatable. Furthermore, these authors obtained low levels of accuracy for sciatic notch measurements when used in isolation (79.1%) and then concluded that this characteristic is unreliable when using either a metric or a morphological approach.

Regarding shape variation between sexes, our findings demonstrate that the male sciatic notch is not only deeper and narrower than the female notch, but it is more asymmetric due to the posterior location of the deepest point (Fig. 2). Dimorphism in the modern human sciatic notch has functional significance for success in parturition, which is dependent upon a maternal pelvis

adequate for delivery of the neonate. Therefore, the shape of the human female sciatic notch, with its large posterior chord, ensures that the sacrum is located toward the back and out of the birth canal, thereby increasing the anteroposterior dimensions of the midpelvis and pelvic outlet [52]. The large posterior component accounts for the broad and symmetric notch in females. Such differences in the relative proportions of the anterior and posterior chords between the sexes had been previously demonstrated by Genoves [1] by the sciatic notch index. This index documents the fact that the line representing the maximum height (i.e., a line projected from the deepest point to the maximum width) divides the notch into two almost equal portions in females, whereas in males the posterior portion is wider than the anterior portion.

An issue that one must be taken into account is the influence of the overlapping region, where are located morphologically similar individuals, on the accuracy of sex estimation [53]. In this paper, sex estimation was performed in consideration of the way discriminant scores of individuals deviate from the sectioning point. This is the common procedure to follow for pelvic [3,7,54] and non-pelvic structures [55–58]. However, some problems could arise when two similar individuals deviating slightly from the sectioning point are classified on opposite sides even if they represent the same sex [59]. One way to solve this problem is to take into account the posterior probability, choosing a threshold according to the objectives of the research and the distribution of posterior probabilities [59–61]. We calculated the percentages of correct allocation using a 0.85 threshold in the discriminant analyses of shape variables. This value was estimated considering the distribution of probabilities and agrees with the threshold suggested by Murail et al. [59]. The cases below said threshold were considered indeterminate. The results obtained indicate that the percentage of indeterminate individuals is greater for the sciatic notch (23%) than for ischiopubic traits (8%). The error rate of using this threshold was 4% for both structures. The main advantage is that posterior probability provides information about the likelihood of each individual being male or female, which implies a statistical decision making process when determining sex [15]. The higher the posterior probability, the greater the likelihood of an individual's correct placement in the reference population [60]. Therefore, one can increase the posterior probability threshold to increase accuracy, which is recommended for forensic applications, or reduce it to increase the number of classified individuals, whilst the global accuracy decreases.

Finally, the results of *k*-means clustering show that individuals can be grouped according to their morphological affinity without previous information about their sex. This is particularly relevant because the pattern of sexual dimorphism varies among populations [16,62]. Therefore, specific standards for each population should be developed in order to optimize the accuracy of identification. For that reason, several authors have called attention to the applicability of discriminant functions derived from one sample to others [7,54]. Unfortunately, the pattern of sexual dimorphism of many populations is unknown, and the access to reference samples from prehistoric times is restricted to some exceptional cases [63–65]. The results obtained here show that similar levels of accuracy are obtained either with multivariate methods, such as *k*-means clustering, which does not require a reference sample of known sex, or with discriminant analysis (Tables 2 and 3). This suggests that when suitable references are not available, techniques based on the internal variation of the samples, as proposed in this study, could be used for sexing undocumented skeletal material. Nevertheless, this approach requires more detailed study and comparison using more than one identified sample of skeletons, since its accuracy could vary with the degree of sexual dimorphism represented within each population. Therefore, the high percentage of correctly

allocated individuals found in this study does not warrant future sexing of archaeological or forensic samples.

## 5. Conclusion

A reliable technique for sex estimation should maximize both precision and accuracy in order to achieve consistent results among observers as well as high levels of correct assignments. In this study we prove that the use of landmarks and semilandmarks with multivariate statistics is a highly reliable technique to estimate sex based on pelvic traits. The average percentage of accuracy obtained was between 90.1 and 93.4%, and the levels of intra- and inter-observer error were very low. This technique, contrary to visual assessment, is highly replicable and can be applied by observers with different levels of experience in the estimation of sex. In addition, it allows the quantification of the shape of curved structures, such as the sciatic notch and pubic bone, which is extremely difficult by linear measurements. The results obtained here indicate that the shape of the sciatic notch described in this way identifies females and males, achieving high values of accuracy. Thus, low accuracies reported by previous studies are probably result from the techniques used for objectively assessing this trait.

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