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Sex determination using the DSP (probabilistic sex diagnosis) method on the coxal bone: Efficiency of method according to number of available variables

Gérald Quatrehomme [a,b,*], Irina Radoman [a], Luísa Nogueira [a], Philippe du Jardin [c], Véronique Alunni [a,b]

[a] Laboratoire de Médecine Légale et d'Anthropologie médico-légale, Université de Nice Côte d'Azur, avenue de Valombrose, 06107 Nice Cedex 2, France
[b] CEPAM, (UMR CNRS) n° 7264, 24 avenue des Diables Bleus, 06357 Nice cedex 4 , France
[c] Edhec Business School, 393 Promenade des Anglais, BP 3116, 06202 Nice Cedex 3, France

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A B S T R A C T

The DSP method (probabilistic sex diagnosis) was applied to100 contemporary coxal bones from elderly individuals of the South of France. Ten variables with a posterior probability greater or equal to a 0.95 threshold were used. There was no statistical difference between right side and left side measurements. There was no mistake for sex assignment but the level of indetermination varied a great deal. It was higher in females than in males. The best combinations were obtained when using all 10 variables, some combination of 9 variables (all except SS or SIS or VEAC) or the first 8 variables. We conclude that the DSP method is of great interest in forensic anthropology, thanks to a very weak possibility of mistake when using the software for sex determination of the coxal bone. The main drawback is the level of indetermination that can be high depending on the available variables.

1. Introduction

The coxal bone is considered to be the most dimorphic bone, a feature that is easily explained by the requirements of parturition in females. Various methods of sex assessment have been described: (i) qualitative, i.e., morphological methods dependent on the observation of various features (careful examination of features such as the subpubic angle, the great ischiatic notch, the subpubic concavity, the ventral arc, the composite arch, the pre-auricular and post-auricular sulcus, the pyramidal tubercle, the acetabulum, the iliac crest and the dorsal pittings, among others allows for 90–95% of correct sex classification); (ii) semi-quantitative methods, i.e., scoring and (iii) quantitative methods. In 1969, Phenice [1] proposed a qualitative method based on the observation of the ventral arc, the subpubic concavity and the medial area of the pubis ramus. Various methods combining several morphological features have been described [2–11]. Ferembach et al. [2,3] created a score based on 11 criteria enabling a classification into 5 groups (supra-males, males, indeterminate, female, supra-female) and Bruzek [12] created a score to classify hip bones as "female", "male", or "intermediate" based on the sacro-iliac complex (pre-auricular surface, great sciatic notch and the presence of a composite arch), and the ischio-pubis complex (inferior margin of the coxal bone and ischium-pubis proportions). These visual methods are time-efficient but are still potentially subjective. Quantitative methods, using single measurements, indices (ratio of two measurements) or combined measurements (discriminant analysis, logistic regression) are proposed (e.g., [13,14]). Each method has advantages and drawbacks. Morphological and scoring methods require a certain amount of expertise on the part of the observer, are population dependent and may be ambiguous if the features are similar between males and females. Quantitative methods are easy to learn and implement, and more objective. Nevertheless they are not always superior to the morphological methods in terms of correct sex determination.

To estimate the sexual dimorphism of the skeleton and its magnitude we used a method called probabilistic sex diagnosis method (named DSP method or "diagnostic sexuel probabiliste" in

* Corresponding author at: Laboratoire de Médecine Légale et d'Anthropologie médico-légale, Université de Nice Côte d'Azur, avenue de Valombrose, 06107 Nice Cedex 2, France.
E-mail address: gquatreh@unice.fr (G. Quatrehomme).

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French) devised by Murail et al. [15]. Murail et al.'s study was based on the measurements of 2040 coxal bones from Europe, Africa, North America and Asia, dating from the 18th to the mid-20th centuries. This method is very original in that it is based on the Bayes theorem with posterior probabilities greater or equal to a 0.95 threshold. Ten anthropological distances are measured on the coxal bone. Free software is available describing the measurements with photographs and short explanations. The 10 variables are classified in decreasing order of interest. At least 4 of the first 8 variables are required. When it is impossible to obtain 4 of the first 8 variables, the last two variables may be added up. The software then indicates if the coxal bone belongs to the male or female category and calculates the probability associated with the result. The software also indicates when the coxal bone cannot be classified using the DSP method. The software returns an answer of male, female, or indeterminate. The authors state that all of the coxal bones are correctly classified using the DSP method, that there is a percentage of indetermination, and that the method is not dependent of bio geographical origin. Steyn and Patriquin [16] also claimed that "population-specific formulae may not be necessary for coxal bones data coming from widely differing populations".

Nevertheless there are few confirmatory studies of the results of this method on other bone collections. Chapman et al. [17] focused on a comparison between actual bones and virtual (CT Scan) bones and stated that 100% of the coxal bones of their collection were correctly classified, after ruling out the indeterminates, except for the worst combination of 4 variables (SIS, SA, SS, and VEAC) where one observer failed to correctly classify 2 out of 21 specimens, and another observer failed to correctly classify the same two specimens out of 11. The percentage of indetermination ranged from 2.56% to 46.15%, according to the combination of variables used. Mestekova et al. [18] reported a rate of 100% correct classification and an indetermination level of 2.8 to 73.1%, according to the combination of variables applied to CT scans of virtual coxal bones.

Therefore the aim of this study was to use the DSP method on a contemporary collection of coxal bones of the south of France in order to observe the percentage of coxal bones that would be correctly classified using this method, to state the percentage of indeterminate bones within this collection and to find the most important variables to avoid sex indetermination.

2. Material and methods

The coxal bones were collected from people who "had donated their body to science", through a specific French legislation allowing for teaching and research. This collection (called the Nice Bone Collection) is made of skulls, long bones, coxae and some whole skeletons. The sex of all of the bones is perfectly documented. The bones come from elderly individuals born after 1920 and having died between 1998 and 2016. 100 right and left coxal bones from 51 individuals were studied. Two individuals provided just one coxal bone.

The 10 variables described by Murail et al. [15] were measured as recommended by these authors by an observer blind to the sex of the coxal bones. The measurements, in decreasing order of interest, are defined by Murail et al. [15] as:

- PUM (acetabulo-symphyseal pubic length): Minimum distance from the superior and medial point of the pubic symphysis to the nearest point on the acetabular rim at the level of the lunate surface.
- SPU (cotylo-pubic breadth): Pubic breadth between the most lateral acetabular point and the medial aspect of the pubis.
- DCOX (maximum pelvis height): Maximum height of the coxal bone measured from the inferior border to the most superior portion of the iliac crest.
- IIMT (depth of the great sciatic notch): Distance from the postero-inferior iliac spine to the anterior border of the great sciatic notch.
- ISMM (post-acetabular ischium length): Distance from the most anterior and inferior point of the ischial tuberosity to the furthest point of the acetabular border.
- SCOX (iliac breadth): Distance between the antero-superior iliac spine and the postero-superior iliac spine.
- SS (spino-sciatic length): Minimum distance between the antero-inferior iliac spine and the deepest point in the greater sciatic notch.
- SA (spino-auricular length): Distance between the antero-inferior iliac spine and the auricular point (intersection of the arcuate line with the auricular surface)
- SIS (cotylo-sciatic breadth): Distance between the lateral border of the acetabulum and the midpoint of the anterior portion of the great sciatic notch.
- VEAC (vertical acetabular diameter): Maximum vertical diameter of the acetabulum, measured on the acetabular rim, as the prolongation of the longitudinal axis of the ischium.

A comparison between the measurements of the right and left coxal bones was achieved (ANOVA). No intra or inter-observer trial was achieved because the technical error of measurement is low [18] and excellent inter-observer agreement of the measurements has already been demonstrated [17].

3. Results and discussion

In this study we sought to confirm the results of the DSP method in terms of correct classification and number of undetermined coxal bones, according to the number of variables. Our sample contained 100 coxal bones from 51 individuals (two individuals provided just one coxal bone).

Measurements of the right and left coxal bones were comparable and did not display any significant difference (ANOVA with 1 factor, $p = 0.32–0.95$, depending on the variable). Therefore some measurements may be substituted by those obtained on the other side when all variables are not available.

The basic descriptive statistics are displayed in Table 1. As expected only the PUM and IIMT variables were larger in females than in males, but there was no significant differences between males and females for PUM, SCOX and SA.

Various combinations of measures are easy to learn and to implement on bones and usually yield 85-95% of correct classification. In the current study, no matter what combination of variables was used, our main finding was that 100% of the 100

Table 1
Descriptive statistics and comparison of males vs females (average of right and left coxal bones) (wilcoxon.test).

Variables	Males Mean (Sd, *N*)	Females Mean (Sd, *N*)	*p*
PUM	72.15 (4.92,41)	72.92 (4.93,24)	NS
SPU	33.00 (2.33,41)	27.61 (1.71,24)	<0.0000
DCOX	225.25 (10.35,41)	205.47 (9.49,24)	<0.0000
IIMT	41.76 (5.17,41)	46.11 (3.18,24)	<0.001
ISMM	118.77 (5.24,23)	103.51 (4.27,22)	<0.0000
SCOX	162.53 (9.98,21)	159.51 (8.54,22)	NS
SS	79.35 (5.68,23)	71.82 (4.93,24)	<0.0000
SA	80.94 (5.64,23)	80.70 (5.87,24)	NS
SIS	43.68 (3.32,23)	39.65 (3.73,22)	<0.001
VEAC	57.93 (3.33,23)	50.48 (2.55,22)	<0.0000