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RESEARCH ARTICLE

Sex estimation of the human os coxae in archeological contexts: An advocacy of using both *Diagnose Sexuelle Probabiliste* and Brůžek's morphoscopic method

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Abstract

The aims of this article are (1) to present the applicability of two methods of sex estimation of the coxal bone—the *Diagnose Sexuelle Probabiliste* (second version, DSP2) and the Brůžek's morphoscopic method (statistical version, SBMM)—on a large archeological metasample; (2) to provide the percentage of agreement between the two methods; and (3) to illustrate the interest to use both methods together. The metasample under study is composed of adult skeletons from several European collections spanning from the Final Mesolithic to the Early Modern period. It includes 1270 coxal bones belonging to 765 individuals. Final sex estimation provided by each method is compared for each coxal bone and for each individual. A sex estimate (female or male) has been obtained by at least one method for 1066 coxal bones, and for 685 of the individuals (83.9% and 89.5% of our sample, respectively). Incongruity between methods and/or left and right coxal bones is extremely rare. The combined use of SBMM and DSP2 yields high rates of congruent sex estimations. While DSP2 results in a lower rate of sex estimation compared to SBMM, it likely offers better interobserver reproducibility, and their joint application significantly increases the total number of classified individuals. It is recommended to record both metric and nonmetric variables from DSP2 and SBMM on both coxal bones to increase the number of sex estimations while maintaining high reliability.

KEYWORDS

bioarcheology, biological profile, coxal bone, methodology

1 | INTRODUCTION

A reliable sex estimation is a prerequisite for most archeoanthropological studies, whether the focus is on funerary practices, gendered divisions of tasks, or health status in the past, for instance. However, surprisingly enough, in articles discussing such aspects of past behaviors, the methods used for sex estimation are most of the time only very briefly presented. These methods are often referred to as "standard anthropological methods" (e.g., Eshed et al., 2010; Manzon & Gualdi-Russo, 2016; Varalli et al., 2016), but one has to recognize that there is no clear standardization and that the choice for a given method is mostly related to the place (i.e., university or country) where the scholars were trained.

The three authors of this article received their formation as biological anthropologists at Bordeaux University in the Department of Anthropology and Prehistory now known as UMR 5199 PACEA (de la Préhistoire à l'Actuel: Culture, Environnement et Anthropologie). We were mainly trained to two methods of sex estimation focusing on the coxal bone developed by researchers from this department, namely, the *Diagnose Sexuelle Probabiliste* by Murail and collaborators and the

Brůžek's morphoscopic method. These two methods are considered as highly reliable as they both exhibit >95% correct sex classification in tests on identified skeletal collections run by their creators (Brůžek, 2002; Murail et al., 2005), or by independent researchers (e.g., Jerković et al., 2018; Listi & Bassett, 2006).

All along our career as biological anthropologists, we applied both methods together on coxal bones from various archeological contexts. Empirically, we did not frequently find discrepancies between sides or between methods for individual sex estimates. However, we never attempted until now to quantify and qualify this apparent agreement, and this appears to have never been done previously by other scholars. Based on the study of a large dataset of coxal bones (1270, belonging to 765 individuals), the aims of this article are to present and discuss (1) their applicability on archeological material; (2) the percentage of agreement between the two methods; and (3) the interest to use both methods together.

2 | MATERIAL AND METHODS

2.1 | The *Diagnose Sexuelle Probabiliste* method

This method was developed on the basis of over 2000 adult individuals of known sex from 12 population samples from four continents (Europe, North America, Africa, and Asia), using 10 measurements on the coxal bone (Murail et al., 2005). The measuring procedure has been explained, illustrated, and discussed in detail in several articles (Brůžek et al., 2017; Murail et al., 2005; Santos et al., 2020). Description of each measurement is available in the *Diagnose Sexuelle Probabiliste* (second version) (DSP2) software freely available at http://projets.pacea.u-bordeaux.fr/logiciel/DSP2/dsp2.html. This method calculates the individual probability of a specimen being a male or a female from any combination of at least four variables, by comparing the os coxae metrics of the individual with those from the reference sample. For reliable sex estimation, a posterior probability equal or greater than 0.95 is considered by the authors to be the classification threshold (Brůžek et al., 2017; Murail et al., 2005). The authors of the method reported an accuracy above 97% (Brůžek et al., 2017; Murail et al., 2005; Santos et al., 2020), and several tests on skeletons with known sex provided similar results, yet with one exception on a Brazilian-identified skeletal collection (accuracy 88.34%) (Table 1). These tests often imply artificially created missing data (i.e., removal of a various number of measurements to simulate sex estimation on partially preserved bones) in order to illustrate the reliability of the method even for badly preserved coxal bones (e.g., Chapman et al., 2014; de Almeida et al., 2020; Jerković et al., 2018; Kranioti et al., 2019). Recently, a software called DSP2 has been made available; the values of measurements can be entered manually in DSP2 or simply pasted from an Excel or LibreOffice spreadsheet into this software (Brůžek et al., 2017). The DSP2 software has been used in the present study.

2.2 | The Brůžek's morphoscopic method (statistical version) (SBMM)

The Brůžek's morphoscopic method for estimating sex from the os coxae was originally published in 2002, with 11 traits recorded on a

TABLE 1 Inventory of studies that have tested the performance and accuracy of the *Diagnose Sexuelle Probabiliste* (DSP) method on skeletons with known sex. DSP refers to the original version of the method (Murail et al., 2005), while *Diagnose Sexuelle Probabiliste* (second version) (DSP2) refers to its more recently released software-assisted version (Brůžek et al., 2017).

Study	Method	Material	*N*	% sex estimation	% accuracy
Sánchez-Mejorada et al. (2011)	DSP	Identified skeletal collection (Mexico)	250	89.2%	100.0%
Chapman et al. (2014) obs 1	DSP	Virtual pelvic girdles from full cadavers with known sex (Belgium)	39	97.4%	100.0%
Chapman et al. (2014) obs 2	DSP	Virtual pelvic girdles from full cadavers with known sex (Belgium)	20	95.0%	100.0%
Mestekova et al. (2015)	DSP	Virtual pelvic girdles from patients (France)	106	94.3%	100.0%
Quatrehomme et al. (2017)	DSP	Identified skeletal collection (France)	100	94.3%	100.0%
Jerković et al. (2018)	DSP	Medieval skeletal collection, sex determined using aDNA analysis (Eastern Adriatic coast)	42	85.7%	97.2%
Machado et al. (2018)	DSP2	Brazilian-identified skeletal collection (Brazil)	103	85.4%	88.3%
Kranioti et al. (2019)	DSP2	Identified skeletal collection (Greece)	133	88.0%	97.4%
Chapman et al. (2020)	DSP	Virtual pelvic girdles from mummies with visible secondary sexual characteristics (Chile)	2	100.0%	100.0%
de Almeida et al. (2020)	DSP2	Identified skeletal collection (Brazil)	301	83.7%	99.6%
Kuchař et al. (2021)	DSP2	Virtual ossa coxae from routine examinations in hospital (Czech Republic)	199	93.0%	99.5%

Abbreviation: aDNA, ancient DNA.

trichotomic scheme ("f," "i," and "m" accounting for "female," "intermediate," and "male" form, respectively). These traits were originally related to five characters of the hip bone: (1) aspects of the preauricular surface (three traits), (2) aspects of the greater sciatic notch (three traits), (3) the form of the composite arch (one trait), (4) the morphology of the inferior pelvis (three traits), and (5) ischiopubic proportions (one trait). The 2002's method follows the principle of majority, first at the character level (when they include more than one trait), and then at the level of the five characters in order to provide a final classification: female, male, or indeterminate sex. Using the whole hip bone, the method yields an accuracy rate close to 98% (i.e., 2% of misclassification), while 3% of the initial sample is classified as indeterminate (Brůžek, 2002). More recently, a statistical approach of Brůžek's morphoscopic method (SBMM), using logistic regression, was presented (Santos et al., 2019). It derives a statistical sex estimate from the 11 original traits, thereby providing a posterior probability for the classification through models based on a metapopulation of more than a thousand individuals of known sex. The authors made an R package freely available online called "PELVIS." Description of each trait is available in the online PELVIS app at https://f-santos.shinyapps.io/pelvis/. One can enter the Brůžek's morphoscopic traits manually or pasted them from a spreadsheet. A posterior probability is computed even if only one trait is provided. As for the DSP2, a posterior probability greater than 0.95 is considered by the authors as a minimal classification threshold. The accuracy rates reported by the authors for SBMM are above 98% for complete bones, the sacroiliac module, and the ischiopubic module, with an average rate of 13% indeterminate results on complete bones and, respectively, 18% and 30% on each module (Santos et al., 2019). In the present study, the SBMM has been applied using the "PELVIS" R-statistical software.

The Brůžek's morphoscopic method appears widely used, with or without its statistical version (more than 1600 citations on google scholar in 2024), but interestingly enough, it seems to have been much less tested on independent identified samples. Most of the traits considered in the Brůžek's morphoscopic method have been recorded in identified skeletal collections (e.g., the greater sciatic notch morphology and the preauricular sulcus morphology in Selliah et al., 2020) and are usually considered as providing accurate sex estimations. We were, however, able to found only one study on the reliability of the whole Brůžek's morphoscopic method, namely, the one done by Listi and Bassett (2006). They reported a correct sex estimation with this method comprised between of 89% and 92% in a large sample of left os coxae from three skeletal collections of modern Americans of known age, sex, and ancestry. It should be noted that in their study, "individuals scored as 'Indeterminate' were classified as 'Incorrect' for sex classification" (Listi & Bassett, 2006, p. 250). Thus, the true percentage of misclassification (i.e., the number of individuals assigned to the wrong sex divided by the number of individuals for which a sex as been estimated) in these modern American collections is actually unknown, but it is no more than 11% and likely lower than this value.

2.3 | The metasample

The metasample under study is composed of adult skeletons from several European collections spanning from the Final Mesolithic to the Early Modern period (Table 2), analyzed during specific studies carried out by each of us (Kacki, 2017, 2020; Thomas, 2014a, 2014b; Villotte et al., 2014; Villotte & Knüsel, 2014). It should be noted that we all have applied both methods on each skeleton (both coxal bones) in a specific order, first the morphoscopic and second the morphometric, so that the recording of nonmetric traits was not influenced by the results based on metric traits. In order to create this metasample, the first author merged individual skeletal data in one database, which includes a unique identifying number, information about the site, and, for each coxal bone, the raw measurements used in the *Diagnose*

TABLE 2 Composition of the metasample under study (for a presentation of the sites, see references in the text).

Period	Country	Sites	Obs	*N* individuals	*N* left coxal bone	*N* right coxal bone
Final Mesolithic	Portugal	Sado and Muge shellmidens	SV	84	59	58
Final Mesolithic	France	Hoëdic and Téviec	SV	12	11	9
Mesolithic and Neolithic	Serbia and Romania	Sites from the Iron Gates	SV	67	50	47
Early Neolithic	Germany	Stuttgart-Mülhausen	SV	78	67	69
Middle Neolithic	Switzerland	Sites from Valais and Vaud cantons	SV	74	52	65
Middle Neolithic	France	Sites from the Paris Basin	AT	56	49	48
Middle Ages	France	Sites from different regions	SK	211	176	177
Middle Ages	Spain	Basilica San Just i Pastor	SK	14	10	10
Middle Ages	UK	Hereford Cathedral	SK	72	66	65
Early Modern period	France	Les Fédons	SK	60	56	59
Early Modern period	Belgium	Maria Troon	SK	37	34	33
Total				765	630	640

Abbreviations: AT, Aline Thomas; Obs, Observer; SK, Sacha Kacki; SV, Sébastien Villotte.

Sexuelle Probabiliste and scores for the morphological characters defined in the Brůžek's morphoscopic method. All individuals with at least one coxal bone for which a sex can be estimated with the DSP2 (at least four metric variables available) *or* the SBMM (at least one morphological trait observable) were kept in the database. The final dataset (available in Data S1) includes 1270 coxal bones belonging to 765 individuals: 125 subjects represented only by the left coxal bone, 135 represented only by the right one, and 505 with both bones.

2.4 | Final sex estimation

For both methods, a posterior probability equal or greater than 0.95 was used as a classification threshold. In other words, a posterior probability of being a male or a female equal or superior to 95% was required to estimate the sex. Below this threshold, the individual is indeterminate.

Concerning the final sex estimation at the individual level, when both methods are applied to each coxal bone, there are five possible outcomes: not applicable, indeterminate, female, male, or incongruent results (between sides and/or between methods). The "not applicable" result is solely related to preservation issues, while "indeterminate" is more complex and may involve both preservation and potential biological characteristics at the individual and population levels. An indeterminate classification for a given individual with both methods may suggest an intermediate pelvis morphology or poorly preserved sexually dimorphic parts.

2.5 | Statistical analyses

In order to illustrate our results, classical odds ratios (ORs) were computed when independent variables were under studies (i.e., the percentage of possible sex estimations for historical and prehistorical periods), whereas we used matched pairs ORs in the case of comparison of sex estimations provided by both methods for a given coxal bone. Statistical analyses were performed using R-statistical software (v4.3.2; R Core Team, 2022) with the packages BioProbability (Saavedra-Nieves & Saavedra-Nieves, 2020) and catfun (Williams, 2019).

3 | RESULTS

3.1 | Applicability of the DSP2 and SBMM

Due to preservation issues, the DSP2 was applicable on 839 coxal bones (66.1%) in our sample of 1270 bones: 276 from prehistorical

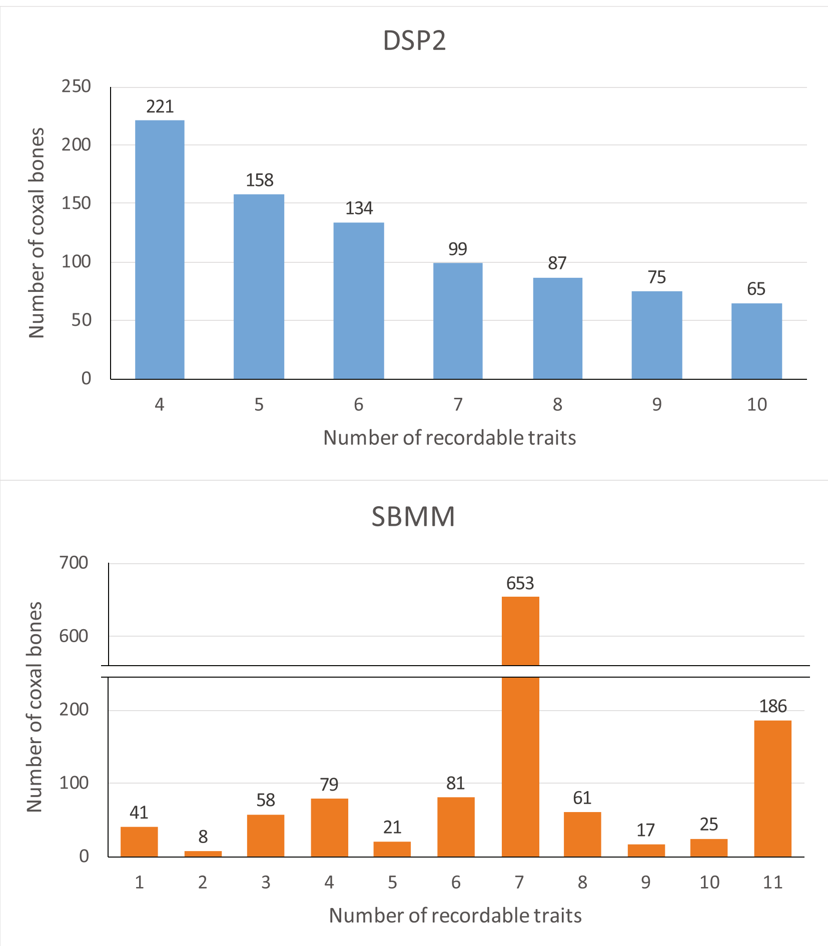

FIGURE 1 Number of coxal bones in the metasample according to the number of recordable traits for the *Diagnose Sexuelle Probabiliste* (second version) (DSP2) and Brůžek's morphoscopic method (statistical version) (SBMM). [Colour figure can be viewed at wileyonlinelibrary.com]

periods (out of 584) and 563 from historical periods (out of 686). This difference between both periods is significant (OR = 0.20; 95% CI: 0.15–0.25). The SBMM was applicable on much more coxal bones: 1230 specimens, representing 96.9% of the whole sample. It was possible to apply the method for 95.2% of the prehistorical coxal bones and 98.3% of the historical ones.

In our sample, the number of coxal bones decreases as the number of measurements increases, with 221 coxal bones having four measurements and gradually declining to 65 specimens having 10 measurements (Figure 1). The situation becomes more complex when considering the traits evaluated by the Brůžek's morphoscopic method. The number of observable traits varies significantly across our sample, with a notable peak in the number of bones for which seven traits could be recorded (53.1% of our sample, Figure 1). This phenomenon can be attributed to the differential preservation of the coxal bone, as these seven traits are all located on the sacroiliac module, which tends to be preserved much more frequently than the ischiopubic module.

3.2 | Sex estimation with both methods, per bone

Figure 2 represents the percentage of sex estimations (male or female) for the DSP2 and the SBMM (using the 95% posterior probability classification threshold) according to the number of measurements (DSP2) or traits (SBMM) recorded. In both cases, there is a positive correlation between the number of variables used and the percentage of sex estimates. However, the relation appears much more regular for the DSP2, and the SBMM tends to provide more sex estimates than the DSP2, especially when the bones are not well preserved. A sex estimate (female or male) has been obtained by at least one method for 1066 coxal bones (83.9% of our sample, Table 3).

The application of both methods together was possible for 799 coxal bones (Table 3). A male or female sex has been estimated

- for 522 bones (65.3%) with both methods;
- for 58 bones (7.3%) with the DSP2 only;
- for 141 bones (17.6%) with SBMM only; and
- with none of them for 78 bones (9.8%).

The SBMM thus significantly allows more sex estimation than the DSP2 (matched pairs OR = 2.43; 95% CI: 1.79–3.30) in our sample. The percentage of agreement between both methods is particularly high (99.2%): For the 522 coxal bones for which a male or a female sex has been estimated with both methods, only four cases (SK137, SV037, SK338, SV142) of discrepancy were encountered (Tables 3 and 4).

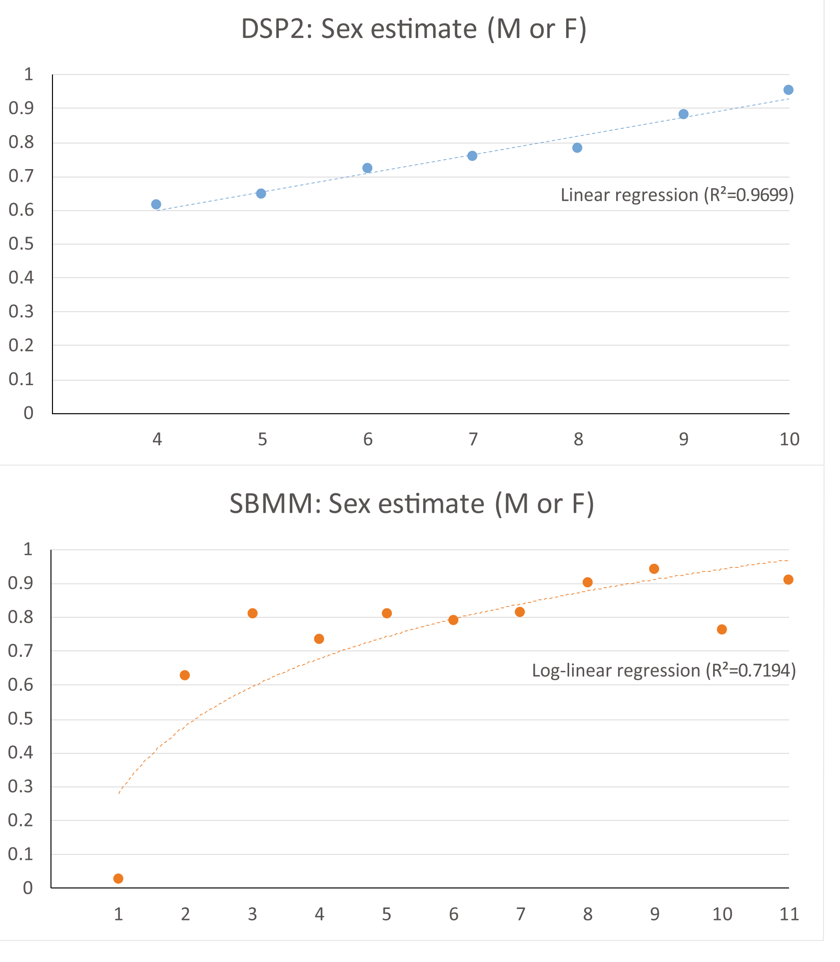

FIGURE 2 Proportion of coxal bones for which the *Diagnose Sexuelle Probabiliste* (second version) (DSP2) and Brůžek's morphoscopic method (statistical version) (SBMM) provide a sex estimate (posterior probability equal to or greater than 0.95) as a function of the number of recordable traits in each method. The relationship between the two parameters follows a linear trend for the DSP2, whereas it is better explained by a log-linear regression for the SBMM. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Confrontation between the sex estimates obtained using the *Diagnose Sexuelle Probabiliste* (second version) (DSP2) and the Brůžek's morphoscopic method (statistical version) (SBMM).

			DSP2 Estimates					Applicability	
			F	I	M	NA	Total	*n* (F + I + M)	*n*/Total
SBMM	Estimates	F	264	49	0	187	500	313	62.6%
		I	37	78	21	112	248	136	54.8%
		M	4	92	254	132	482	350	72.6%
		NA	15	14	11	0	40	40	100.0%
		Total	320	233	286	431	1270	839	66.1%
	Applicability	*n* (F + I + M)	305	219	275	431	1230	799	-
		n/Total	95.3%	94.0%	96.2%	100.0%	96.9%	-	62.9%

Abbreviations: F, female; I, indeterminate; M, male; NA, not applicable.

TABLE 4 Inventory of individuals showing discrepancies in sex estimates (between methods and/or between the left and right coxal bones). The associated posterior probabilities of being female according to the *Diagnose Sexuelle Probabiliste* (second version) (DSP2) and Brůžek's morphoscopic method (statistical version) (SBMM) are reported. This table includes discrepancies between right and left sides using SBMM (SK137 and SV011), discrepancies between SBMM and DSP2 on the same coxal bone (SV037, SK338, SV142), and discrepancies between SBMM on one coxal bone and DSP2 on the other side (SV018, SV182, AT038).

		Left coxal			Right coxal			
			Probability F			Probability F		
Individual	Age-at-death	Preservation	DSP2	SBMM	Preservation	DSP2	SBMM	Discrepancies
AT038	20–39	Sacroiliac module	/	0.005	Part of sacroiliac module	0.991	0.937	SBMM versus DSP2 (opposite sides)
SK137	30–59	Sacroiliac module	0.955	0.005	Part of sacroiliac module	0.831	0.987	SBMM left versus right side/SBMM versus DSP2 (left side)
SK338	40+	Sacroiliac module	0.966	0.005	Sacroiliac module	0.345	0.005	SBMM versus DSP2 (left side and opposite sides)
SV011	20–29	Sacroiliac and ischiopubic modules	0.284	0.996	Sacroiliac module	0.341	0.032	SBMM left versus right side
SV018	20–29	Part of sacroiliac and ischiopubic modules	0.561	0.005	Part of sacroiliac module	0.961	0.091	SBMM versus DSP2 (opposite sides)
SV037	20–39	Part of sacroiliac module	0.975	0.048	Sacroiliac module	0.522	0.722	SBMM versus DSP2 (left side)
SV142	20–49	Sacroiliac module	0.984	0.005	Part of sacroiliac module	/	0.414	SBMM versus DSP2 (left side)
SV182	20–39	Part of sacroiliac module	0.969	0.414	Part of sacroiliac module	/	0.016	SBMM versus DSP2 (opposite sides)

3.3 | Sex estimation per individual and per method

The DSP2 was applicable for at least one coxal bone for 565 subjects (Table 5) out of the 745 composing the metasample (75.8%). A sex (male or female) was estimated for both sides for 163 individuals, and no discrepancies were recorded between left and right sides.

The SBMM was applicable for at least one coxal bone for all 745 individuals of the metasample (Table 6). When a sex (male or female) was estimated for both sides, two individuals out of 349 (0.6%) display discrepancies (SK137 and SV011, see Table 4).

3.4 | Final sex estimation

When results of both methods are combined (Table 7), and considering that at least one method applied on one side is enough for a sex

TABLE 5 Confrontation between the sex estimates obtained for the right coxal bone and the left coxal bone of the same skeletons, using the *Diagnose Sexuelle Probabiliste* (second version) (DSP2). Only those skeletons for which the method was applicable at least on one side are included ($n = 565$).

		Left coxal bone				
		F	I	M	NA	Total
Right coxal bone	F	86	11	0	61	158
	I	18	46	18	30	112
	M	0	18	77	59	154
	NA	58	46	37	0	141
	Total	162	121	132	150	565

Abbreviations: F, female; I, indeterminate; M, male; NA, not applicable.

TABLE 6 Confrontation between the sex estimates obtained for the right coxal bone and the left coxal bone of the same skeletons, using the Brůžek's morphoscopic method (statistical version) (SBMM). Only those skeletons for which the method was applicable at least on one side are included ($n = 745$).

		Left coxal bone				
		F	I	M	NA	Total
Right coxal bone	F	168	22	1	65	256
	I	18	57	17	27	119
	M	1	22	179	49	251
	NA	57	28	34	0	119
	Total	244	129	231	141	745

Abbreviations: F, female; I, indeterminate; M, male; NA, not applicable.

TABLE 7 Final sex estimation for the 765 individuals for which at least one method was applicable on one or both coxal bones.

	Side for which at least one method was applicable			
Sex estimation	Left + right	Left only	Right only	Total
F	190	78	89	357
M	185	57	78	320
F/M	6	2	0	8
I	40	23	17	80
Total	421	160	184	765

Abbreviations: F, female; I, indeterminate; M, male.

estimation, 89.5% of the individuals from our sample were assigned a sex: 357 individuals are estimated as females (representing 46.7% of our sample), 320 individuals are estimated as male (41.8%), 80 individuals are classified as indeterminate sex (10.5%), and 8 individuals display incongruous results (1.0%). These subjects (presented in the Table 4) are the two individuals that display discrepancies between right and left sides with SBMM (SK137 and SV011), the three other cases of discrepancies between SBMM and DSP2 on the same (left side) coxal bone (SV037, SK338, SV142), and three last cases that display discrepancies between SBMM on one coxal bone and DSP2 on the other side (SV018, SV182, AT038).

4 | DISCUSSION

We demonstrated the applicability and congruency of two sex estimation methods based on coxal bone morphology: one that employs measurements (DSP2) and another that relies on visual assessment of phenotypic traits (SBMM). The accuracy of the DSP2, validated on known-sex skeletal collections, exceeds 95% in both modern and pre-modern contexts (Chapman et al., 2014; Jerković et al., 2018; Sánchez-Mejorada et al., 2011), while the SBMM also consistently provides reliable results, with over 98% accuracy in sex estimation (Santos et al., 2019). Both methods adhere to high-quality standards, ensuring reproducibility, repeatability, and reliable sex estimation.

In our analysis, when both methods offered sex estimations (male or female) for a given coxal bone, these estimates were congruent in nearly all cases (99.2%). This suggests that the estimate from one method can reliably predict the outcome of the other.

In our sample, SBMM is more frequently applicable than DSP2, likely due to inclusion criteria for coxal bones (see Section 2), and the SBMM's ability to provide a posterior probability for sex estimation even with only one recorded trait out of 11. Considering this point and the very high congruence between SBMM and DSP2 results, the question arises whether it is necessary to apply both methods, or just to favor the use of SBMM. We advocate for utilizing both SBMM and DSP2 in archeological and forensic studies for two main reasons. First, DSP2 appears less subjective than SBMM, ensuring greater reproducibility. The measurements used in the DSP2 are presented in detail (Brůžek et al., 2017; Murail et al., 2005; Santos et al., 2020), and it has been shown that minor variations (more or less 5%) in the measures does not alter the reliability of the estimation (Santos et al., 2020). Moreover, the computation of the posterior probability allows for taking into account minor taphonomical damage: When a measure can be estimated between a minimum and maximum values, the user can compute a posterior probability twice (with each of the values) and, if both probabilities are similar and above 95%, a sex can be safely estimated. Second, even if it has been possible to apply the SBMM on much more specimens and if this method provides more sex estimations than the DSP2, the DSP2 provides a sex estimate (male or female) for 84 coxal bones (6.6% of the sample) for which the SBMM was not applicable or leaded to an indeterminate sex classification.

In our dataset of 765 individuals, we observed incongruities in sex estimates between the two methods and/or coxal bones in eight instances. Details on preservation and biological profiles of these individuals are outlined in Table 4. Notably, seven individuals were identified as females using DSP2 (the 8th one remaining indeterminate with this method), while SBMM yielded more diverse results.

For most of these individuals, the SBMM computed a probability of being a male or a female mostly based on the morphology of the sacroiliac module (i.e., the preauricular surface, the greater sciatic notch, and the presence or not of a composite arch). The authors of the SBMM have observed that pronounced morphological asymmetries in the sacroiliac module are not uncommon, in contrast to the ischiopubic module (Santos et al., 2019). In Table 4, a noticeable discrepancy in the probabilities of being female is evident between the left and right coxal bones as provided by SBMM (i.e., the probabilities tend to be higher for the right side). Santos et al. (2019) reported in their metasample that the asymmetry for morphological traits of the sacroiliac module tends to be directional. For example, the retroversion of the posterior notch chord of the greater sciatic notch is highly asymmetric in 12% of their sample, with most individuals exhibiting a female form on the right side and a male form on the left side. This directional asymmetry, seen to a lesser extent for other traits, could potentially influence the outcomes of our study in two ways: (1) unevenly impacting the results of SBMM and DSP2, leading to incongruent sex estimation between the two methods, and/or (2) generating contradictory results between sex estimates provided by SBMM for the left and right sides.

Another noteworthy aspect highlighted in Table 4 is the age distribution of the individuals: A majority passed away before reaching their fifties. This relatively young age-at-death raises the question of whether it may, in part, contribute to the disparities in their sex estimates. The association between age-at-death and specific coxal morphologies has been sporadically discussed. Walker (2005) demonstrated a robust positive correlation between sciatic notch scores and age-at-death for individuals under 50, noting that both males and females who died at a younger age tended to have wider, more 'feminine' sciatic notches. This trend does not align with our results, as most of the individuals exhibit 'masculine' or 'intermediate' morphologies in this area (Data S1). Age-related effects on the morphology of the preauricular surface have also been documented. While young adult females may present a clear circumscribed sulcus ('hyperfeminine' morphology), true sulci are more prevalent in older females (Pany-Kucera et al., 2022; Perréard Lopreno et al., 2022). Perréard Lopreno et al. (2022) suggested that the preauricular region, being a site of attachment for the joint capsule and anterior sacroiliac ligament, undergoes lifelong evolution due to biomechanical stress and senescence. Complementing this hypothesis, Pany-Kucera et al. (2022) and Igarashi et al. (2020) propose that pregnancy and parturition also contribute to the development of a clearly circumscribed sulcus. The absence of a preauricular sulcus in almost all coxal bones of the eight individuals (see Data S1) may thus be linked to their young age-at-death, potentially leading to misleading sex estimation for some of them.

5 | LIMITATIONS OF THE STUDY

While our findings provide strong evidence of a high agreement between the results of the two methods, it is important to acknowledge the presence of several limitations that may influence the outcomes of our study. The first key limitation is that our research relied on archeological material, which precludes the possibility of confirming sex estimations with gonadic or chromosomal traits. Despite this inherent constraint, the high level of consistency between the results obtained from both methods across this extensive diachronic European metasample indicates robustness and reliability. While it is true that some traits recorded in Brůžek's morphoscopic method correspond to measurements or combinations used in DSP2, explaining much of the congruence (e.g., the relation between pubis and ischium lengths), certain traits, such as the morphology of the composite arch and preauricular surface, cannot be captured solely by measurements. Conversely, DSP2 measurements (e.g., coxal length, breadth, cotylo-sciatic breadth, or vertical acetabular diameter) do not directly align with specific morphological traits in Brůžek's morphoscopic method. Each method captures different sexually dimorphic features, yet both yield highly congruent results.

Second, although not the primary focus of this study, intra- and inter-observer variability remains a potential limitation. Variations in how different observers record measurements or assessments could influence the final sex estimation. The DSP2 utilizes metric variables with established intra-observer and inter-observer reliability (Brůžek et al., 1994; Vacca & Di Vella, 2012). While Brůžek's morphoscopic method involves some inherent subjectivity due to its nonmetric nature, it employs a trichotomy (binary scoring of "m" or "f" and an intermediate category "i" for uncertain cases) to reduce observer subjectivity compared to classical ordinal scoring (Santos et al., 2019). Future research should aim to standardize and calibrate these observations to minimize discrepancies and enhance overall consistency.

The state of preservation of the coxal bones also poses a limitation. Variations in preservation quality among specimens can potentially affect the accuracy of the sex estimation methods. It is important to note that SBMM reliability has been primarily assessed for complete coxal bones or fully preserved sacroiliac and ischiopubic regions. Further investigation is needed to evaluate its reliability when considering a smaller set of morphological traits, as in our current study.

Finally, age-at-death may impact the recording of morphoscopic traits used in the SBMM, potentially affecting sex estimation. Younger individuals may display different morphological characteristics compared to older individuals, which could influence the results. This effect warrants further investigation, but it requires access to collections with well-documented ages-at-death to conduct a detailed analysis.

6 | CONCLUSION

The two methods of sex estimation, Brůžek's morphoscopic method and *Diagnose Sexuelle Probabiliste*, based respectively on nonmetric (Brůžek, 2002) or metric traits (Brůžek et al., 2017; Murail et al., 2005) of the coxal bone, reach an accuracy rate above 98% according to the authors (i.e., the percentage of correctly classified individuals among the total sample of classified and misclassified individuals). The *Diagnose Sexuelle Probabiliste* (2005 or DSP2 2017) and the SBMM, statistical application of Brůžek's nonmetric traits based on logistic regressions (Santos et al., 2019), deliver both posterior probabilities for sex estimation, making these methods strongly recommendable in archeological contexts. For both methods, the classical value of 95% is considered as the posterior probability threshold to reach for an individual to be classified "female" or "male." Below this threshold, the individual remains "indeterminate."

The joint application of the two methods on the same individuals, both on the right and left coxal bones, in a diachronic European meta-sample leads to very high rates of sex estimations with high congruency. Discrepancies between SBMM and DSP2 for a given coxal bone appear thus rare, something we expected based on our experience, but that was, as far as we know, never demonstrated before. The DSP2 leads to a lower rate of sex classification than SBMM, but the metric traits likely have better inter-observer reproducibility. Above all, the joint application of two methods significantly increases the total number of classified individuals, as the sample of "indeterminate" individuals/individuals for which the method is not applicable is not strictly the same in both cases.

These results lead us to formulate some recommendations for sex assessment of skeletons of any archeological assemblage. The metric and nonmetric variables should be recorded together on both coxal bones, right and left sides. In order to guarantee better objectivity of the observation, the recording of qualitative traits should be done before computing the DSP2 posterior probabilities. The Brůžek's nonmetric traits should then be computed for posterior probabilities using "PELVIS" R-statistical software. A final sex classification for a given individual (1) should be assigned (i.e., "female" or "male" individual) if at least one coxal bone and at least one method lead to a sex classification and (2) should not be assigned (i.e., "indeterminate" individual) if discrepancy occurs between the two methods or between right and left sides.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest regarding the publication of this paper.

DATA AVAILABILITY STATEMENT

The raw data are available in Supporting information (S1).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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