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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 Bruzek's Morphoscopic method (statistical version, SBMM), on a large archeological metasample, to provide the percentage of agreement between the two methods, and 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 are 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 are 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: biological profile; coxal bone; methodology; bioarcheology.

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, Gopher, Pinhasi, & Hershkovitz, 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 PACEA. 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, Brůžek, Houët, & Cunha, 2005), or by independent researchers (e.g. Jerković, Bašić, Kružić, & Anđelinović, 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; 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 2,000 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 details in several articles (Brůžek, Santos, Dutailly, Murail, & Cunha, 2017; Murail et al., 2005; Santos, Guyomarc’h, Cunha, & Brůžek, 2020). Description of each measurement is available in the DSP2 software freely available at <http://projets.pacea.u->

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3 bordeaux.fr/logiciel/DSP2/dsp2.html. This method calculates the individual probability of a specimen
4 being a male or a female from any combination of at least four variables, by comparing the os coxae
5 metrics of the individual with those from the reference sample. For reliable sex estimation, a posterior
6 probability equal or greater than 0.95 is considered by the authors to be the classification threshold
7 (Brůžek et al., 2017; Murail et al., 2005). The authors of the method reported an accuracy above 97%
8 (Brůžek et al., 2017; Murail et al., 2005; Santos et al., 2020), and several tests on skeletons with known
9 sex provided similar results, yet with one exception on a Brazilian-identified skeletal collection
10 (accuracy 88.34%) (Table 1). These tests often imply artificially created missing data (i.e. removal of a
11 various number of measurements to simulate sex estimation on partially preserved bones) in order to
12 illustrate the reliability of the method even for badly preserved coxal bones (e.g., Chapman et al., 2014;
13 de Almeida et al., 2020; Jerković et al., 2018; Kranioti, Štovićková, Karell, & Brůžek, 2019). Recently, a
14 software called DSP2 has been made available; the values of measurements can be entered manually
15 in DSP2 or simply pasted from an Excel or LibreOffice spreadsheet into this software (Brůžek et al.,
16 2017). The DSP2 software has been used in the present study.
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31 *2.2 The Brůžek's morphoscopic method and its statistical version (SBMM)*

32 The Brůžek's morphoscopic method for estimating sex from the os coxae was originally published in
33 2002, with 11 traits recorded on a trichotomic scheme ("f," "i" and "m", accounting for "female",
34 "intermediate" and "male" form respectively). These traits were originally related to five characters of
35 the hip bone: 1) aspects of the preauricular surface (3 traits), 2) aspects of the greater sciatic notch (3
36 traits), 3) the form of the composite arch (1 trait), 4) the morphology of the inferior pelvis (3 traits),
37 and 5) ischiopubic proportions (1 trait). The 2002's method follows the principle of majority, first at
38 the character level (when they include more than one trait), and then at the level of the five characters
39 in order to provide a final classification: female, male or indeterminate sex. Using the whole hip bone,
40 the method yields an accuracy rate close to 98% (i.e. 2% of misclassification) while 3% of the initial
41 sample is classified as indeterminate (Brůžek, 2002). More recently, a statistical approach of Brůžek's
42 morphoscopic method (SBMM), using logistic regression, was presented (Santos, Guyomarc'h,
43 Rmoutilova, & Brůžek, 2019). It derives a statistical sex estimate from the 11 original traits, thereby
44 providing a posterior probability for the classification through models based on a metapopulation of
45 more than a thousand individuals of known sex. The authors made an R package freely available online
46 called "PELVIS". Description of each trait is available in the online PELVIS app at [https://f-
47 santos.shinyapps.io/pelvis/](https://f-santos.shinyapps.io/pelvis/). One can enter the Brůžek's morphoscopic traits manually or pasted them
48 from a spreadsheet. A posterior probability is computed even if only one trait is provided. As for the
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3 DSP2, a posterior probability greater than 0.95 is considered by the authors as a minimal classification
4 threshold. The accuracy rates reported by the authors for SBMM are above 98% for complete bones,
5 the sacroiliac module, and the ischiopubic module, with an average rate of 13% indeterminate results
6 on complete bones and respectively 18% and 30% on each module (Santos et al., 2019). In the present
7 study, the SBMM has been applied using the “PELVIS” R-statistical software.
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10 The Brůžek’s morphoscopic method appears widely used, with or without its statistical version (more
11 than 1600 citations on google scholar in 2024), but interestingly enough it seems to have been much
12 less tested on independent identified samples. Most of the traits considered in the Brůžek’s
13 morphoscopic method have been recorded in identified skeletal collections (e.g., the greater sciatic
14 notch morphology and the preauricular sulcus morphology in Selliah et al., 2020) and are usually
15 considered as providing accurate sex estimations. We were, however, able to found only one study on
16 the reliability of the whole Brůžek’s morphoscopic method, namely the one done by Listi and Bassett
17 (2006). They reported a correct sex estimation with this method comprised between of 89% and 92%
18 in a large sample of left os coxae from three skeletal collections of modern Americans of known age,
19 sex, and ancestry. It should be noted that in their study “individuals scored as “Indeterminate” were
20 classified as “Incorrect” for sex classification” (Listi & Bassett, 2006, p. 250). Thus, the true percentage
21 of misclassification (i.e., the number of individuals assigned to the wrong sex divided by the number
22 of individuals for which a sex as been estimated) in these modern American collections is actually
23 unknown, but it is no more than 11% and likely lower than this value.
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36 2.3 *The metasample*

37 The metasample under study is composed of adult skeletons from several European collections
38 spanning from the Final Mesolithic to the Early Modern period (Table 2), analyzed during specific
39 studies carried out by each of us (Kacki, 2017, 2020; Thomas, 2014a, 2014b; Villotte & Knüsel, 2014;
40 Villotte, Stefanović, & Knüsel, 2014). It should be noted that we all have applied both methods on each
41 skeleton (both coxal bones) in a specific order, first the morphoscopic second the morphometric, so
42 that the recording of nonmetric traits was not influenced by the results based on metric traits. In order
43 to create this metasample, the first author merged individual skeletal data in one database, which
44 includes a unique identifying number, information about the site and, for each coxal bone, the raw
45 measurements used in the Diagnose Sexuelle Probabiliste and scores for the morphological characters
46 defined in the Brůžek’s morphoscopic method. All individuals with at least one coxal bone for which a
47 sex can be estimated with the DSP2 (at least 4 metric variables available) or the SBMM (at least one
48 morphological trait observable) were kept in the database. The final data set (available in SI) includes
49 1270 coxal bones belonging to 765 individuals: 125 subjects represented only by the left coxal bone,
50 135 represented only by the right one and 505 with both bones.
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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 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 odds ratios 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).

INSERT TABLE 2 HERE

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 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 4 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

The 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;
- with none of them for 78 bones (9.8%).

The SBMM thus significantly allow 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 4 cases (SK137, SV037, SK338, SV142) of discrepancy were encountered (Tables 3 and 4)

INSERT TABLES 3 and 4 HERE

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).

INSERT TABLES 5 and 6 HERE

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 estimation, 89.5% of the individuals from our sample was assigned a sex: 357 individuals are estimated as females (representing 46.7% of our sample), 320 individuals are estimated as male (41.8%), 80 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).

INSERT TABLE 7 HERE

4 Discussion

We demonstrated the applicability and congruency of two sex estimation methods based on coxal bone morphology: one that employs measurements (Diagnose Sexuelle Probabiliste, second version DSP2) and another that relies on visual assessment of phenotypic traits (Brůžek's morphoscopic method, statistical version). 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, Gómez-Valdés, Herrera, & Veleminsky, 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 the method section), 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 archaeological and forensic studies for two main reasons. Firstly, DSP2 appears less subjective than SBMM, ensuring greater reproducibility. The measurements used in the DSP2 are presented in details (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

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3 al., 2020). Moreover, the computation of the posterior probability allows for taking into account minor
4 taphonomical damage: when a measure can be estimated between a minimum and maximum values,
5 the user can compute a posterior probability twice (with each of the values) and if both probabilities
6 are similar and above 95% a sex can be safely estimated. Secondly, even if it has been possible to apply
7 the SBMM on much more specimens and if this method provides more sex estimations than the DSP2,
8 the DSP2 provides a sex estimate (male or female) for 84 coxal bones (6.6% of the sample) for which
9 the SBMM was not applicable or led to an indeterminate sex classification.

10
11 In our dataset of 765 individuals, we observed incongruities in sex estimates between the two methods
12 and/or coxal bones in eight instances. Details on preservation and biological profiles of these
13 individuals are outlined in Table 4. Notably, seven individuals were identified as females using DSP2
14 (the 8th one remaining indeterminate with this method), while SBMM yielded more diverse results.

15 For most of these individuals, the SBMM computed a probability of being a male or a female mostly
16 based on the morphology of the sacroiliac module (i.e., the preauricular surface, the greater sciatic
17 notch, and the presence or not of a composite arch). The authors of the SBMM have observed that
18 pronounced morphological asymmetries in the sacroiliac module are not uncommon, in contrast to
19 the ischiopubic module (Santos et al., 2019). In the Table 4, a noticeable discrepancy in the
20 probabilities of being female is evident between the left and right coxal bones as provided by SBMM
21 (i.e., the probabilities tend to be higher for the right side). Santos et al. (2019) reported in their meta-
22 sample that the asymmetry for morphological traits of the sacroiliac module tends to be directional.
23 For example, the retroversion of the posterior notch chord of the greater sciatic notch is highly
24 asymmetric in 12% of their sample, with most individuals exhibiting a female form on the right side
25 and a male form on the left side. This directional asymmetry, seen to a lesser extent for other traits,
26 could potentially influence the outcomes of our study in two ways: 1) unevenly impacting the results
27 of SBMM and DSP2, leading to incongruent sex estimation between the two methods, and/or 2)
28 generating contradictory results between sex estimates provided by SBMM for the left and right sides.
29 Another noteworthy aspect highlighted in Table 4 is the age distribution of the individuals: a majority
30 passed away before reaching their fifties. This relatively young age-at-death raises the question of
31 whether it may, in part, contribute to the disparities in their sex estimates. The association between
32 age-at-death and specific coxal morphologies has been sporadically discussed. Walker (2005)
33 demonstrated a robust positive correlation between sciatic notch scores and age-at-death for
34 individuals under 50, noting that both males and females who died at a younger age tended to have
35 wider, more 'feminine' sciatic notches. This trend does not align with our results, as most of the
36 individuals exhibit 'masculine' or 'intermediate' morphologies in this area (data in SI). Age-related
37 effects on the morphology of the preauricular surface have also been documented. While young adult
38 females may present a clear circumscribed sulcus ('hyperfeminine' morphology), true sulci are more
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3 prevalent in older females (Perréard Lopreno, Santos, & Brůžek, 2021; Pany-Kucera, Spannagl-Steiner,
4 Maurer-Gesek, Weninger, & Rebay-Salisbury, 2022). Perréard Lopreno and colleagues (2021)
5 suggested that the preauricular region, being a site of attachment for the joint capsule and anterior
6 sacroiliac ligament, undergoes lifelong evolution due to biomechanical stress and senescence.
7
8 Complementing this hypothesis, Pany-Kucera and collaborators (2022) and Igarashi and colleagues
9 (2020) propose that pregnancy and parturition also contribute to the development of a clearly
10 circumscribed sulcus. The absence of a preauricular sulcus in almost all coxal bones of the eight
11 individuals (see SI) may thus be linked to their young age-at-death, potentially leading to misleading
12 sex estimation for some of them.
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20 **5 Limitations of the study**

21 While our findings provide strong evidence of a high agreement between the results of the two
22 methods, it is important to acknowledge the presence of several limitations that may influence the
23 outcomes of our study. The first key limitation is that our research relied on archaeological material,
24 which precludes the possibility of confirming sex estimations with gonadic or chromosomal traits.
25 Despite this inherent constraint, the high level of consistency between the results obtained from both
26 methods across this extensive diachronic European metasample indicates robustness and reliability.
27 While it is true that some traits recorded in Brůžek's morphoscopic method correspond to
28 measurements or combinations used in DSP2, explaining much of the congruence (e.g., the relation
29 between pubis and ischium lengths), certain traits, such as the morphology of the composite arch and
30 preauricular surface, cannot be captured solely by measurements. Conversely, DSP2 measurements
31 (e.g., coxal length, breadth, cotylo-sciatic breadth, or vertical acetabular diameter) do not directly align
32 with specific morphological traits in Brůžek's morphoscopic method. Each method captures different
33 sexually dimorphic features, yet both yield highly congruent results.
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43 Second, although not the primary focus of this study, intra- and inter-observer variability remains a
44 potential limitation. Variations in how different observers record measurements or assessments could
45 influence the final sex estimation. The DSP2 utilizes metric variables with established intra-observer
46 and inter-observer reliability (Brůžek, Murail, Houët, & Cleuvenot, 1994; Vacca & Di Vella, 2012). While
47 Brůžek's morphoscopic method involves some inherent subjectivity due to its nonmetric nature, it
48 employs a trichotomy (binary scoring of 'm' or 'f' and an intermediate category 'i' for uncertain cases)
49 to reduce observer subjectivity compared to classical ordinal scoring (Santos et al., 2019). Future
50 research should aim to standardize and calibrate these observations, to minimize discrepancies and
51 enhance overall consistency.
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58 The state of preservation of the coxal bones also poses a limitation. Variations in preservation quality
59 among specimens can potentially affect the accuracy of the sex estimation methods. It is important to
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3 note that SBMM reliability has been primarily assessed for complete coxal bones or fully preserved
4 sacroiliac and ischiopubic regions. Further investigation is needed to evaluate its reliability when
5 considering a smaller set of morphological traits, as in our current study.
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8 Finally, age-at-death may impact the recording of morphoscopic traits used in the SBMM, potentially
9 affecting sex estimation. Younger individuals may display different morphological characteristics
10 compared to older individuals, which could influence the results. This effect warrants further
11 investigation, but it requires access to collections with well-documented ages-at-death to conduct a
12 detailed analysis.
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18 **6 Conclusion**

19 The two methods of sex estimation, Brůžek's morphoscopic method and Diagnose Sexuelle
20 Probabiliste, based respectively on nonmetric (Brůžek 2002) or metric traits (Murail et al 2005, Brůžek
21 et al. 2017) of the coxal bone, reach an accuracy rate above 98% according to the authors (i.e., the
22 percentage of correctly classified individuals among the total sample of classified and misclassified
23 individuals). The Diagnose Sexuelle Probabiliste (2005 or DSP2 2017) and the SBMM, statistical
24 application of Bruzek's nonmetric traits based on logistic regressions (Santos et al. 2019), deliver both
25 posterior probabilities for sex estimation, making these methods strongly recommendable in
26 archaeological contexts. For both methods, the classical value of 95% is considered as the posterior
27 probability threshold to reach for an individual to be classified "female" or "male". Below this
28 threshold, the individual remains "indeterminate".
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30 The joint application of the two methods on the same individuals, both on the right and left coxal
31 bones, in a diachronic European metasample leads to very high rates of sex estimations with high
32 congruency. Discrepancies between SBMM and DSP2 for a given coxal bone appear thus rare,
33 something we expected based on our experience, but that was, as far as we know, never demonstrated
34 before. The DSP2 leads to a lower rate of sex classification than SBMM but the metric traits likely have
35 better interobserver reproducibility. Above all, the joint application of two methods significantly
36 increases the total number of classified individuals, as the sample of "indeterminate"
37 individuals/individuals for which the method is not applicable is not strictly the same in both cases.
38

39 These results lead us to formulate some recommendations for sex assessment of skeletons of any
40 archaeological assemblage. The metric and nonmetric variables should be recorded together on both
41 coxal bones, right and left sides. In order to guarantee better objectivity of the observation the
42 recording of qualitative traits should be done before computing the DSP2 posterior probabilities. The
43 Bruzek's nonmetric traits should then be computed for posterior probabilities using "PELVIS" R-
44 statistical software. A final sex classification for a given individual 1) should be assigned (i.e., "female"
45 or "male" individual) if at least one coxal bone and at least one method leads to a sex classification; 2)
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3 should not be assigned (i.e. “indeterminate” individual) if discrepancy occurs between the two
4 methods or between right and left sides.
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9
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21 22 23 **Figure Legends**

24
25 **Figure 1.** Number of coxal bones in the meta-sample according to the number of recordable traits for
26
27 the Diagnose sexuelle probabiliste (PSD2) and Brůžek's morphoscopic method (SBMM).

28
29 **Figure 2.** Proportion of coxal bones for which the Diagnose sexuelle probabiliste (PSD2) and Brůžek's
30
31 Morphoscopic method (SBMM) provide a sex estimate (posterior probability equal to or greater than
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33 0.95) as a function of the number of recordable traits in each method. The relationship between the
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35 two parameters follows a linear trend for the DSP2, whereas it is better explained by a log-linear
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37 regression for the SBMM.
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Table 1. Inventory of studies that have tested the performance and accuracy of the DSP method on skeletons with known sex. DSP refers to the original version of the method (Murail et al. 2005), while DSP2 refers to its more recently released software-assisted version (Bruzek 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 (Chili)	2	100.0%	100.0%
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%

Table 2. Composition of the meta-sample 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 shellmidsens	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

Table 3. Confrontation between the sex estimates obtained using the Diagnose sexuelle probabiliste (DSP2) and the Brůžek's morphoscopic method (SBMM). F: female; I: indeterminate; M: male; NA: not applicable.

		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%

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 (DSP2) and Brůžek's Morphoscopic Method (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).

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

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 (DSP2). Only those skeletons for which the method was applicable at least on one side are included (n=565). F: female; I: indeterminate; M: male; NA: not applicable.

		Left coxal bone				Total
		F	I	M	NA	
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

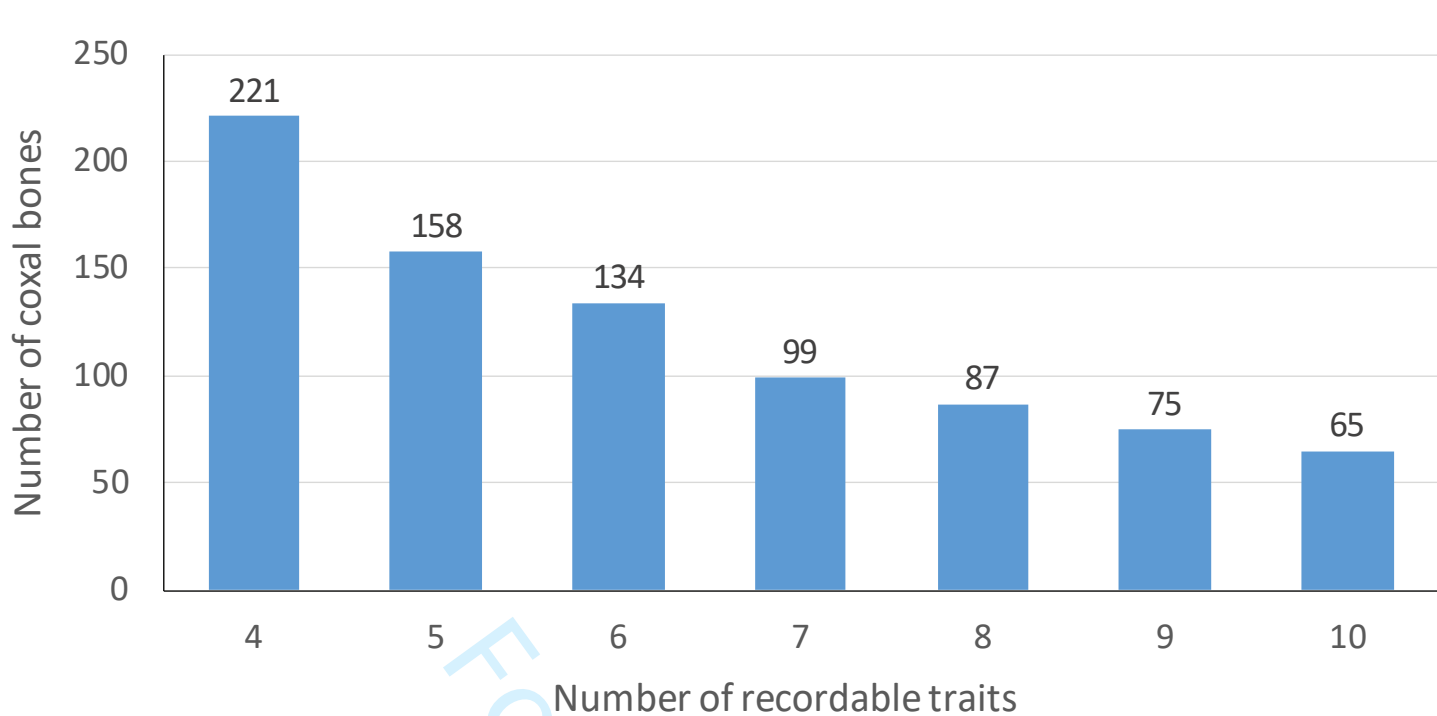
Table 6. Confrontation between the sex estimates obtained for the right coxal bone and the left coxal bone of the same skeletons, using the Brůžek's morphoscopic method (SBMM). Only those skeletons for which the method was applicable at least on one side are included (n=745). F: female; I: indeterminate; M: male; NA: not applicable.

		Left coxal bone				Total
		F	I	M	NA	
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

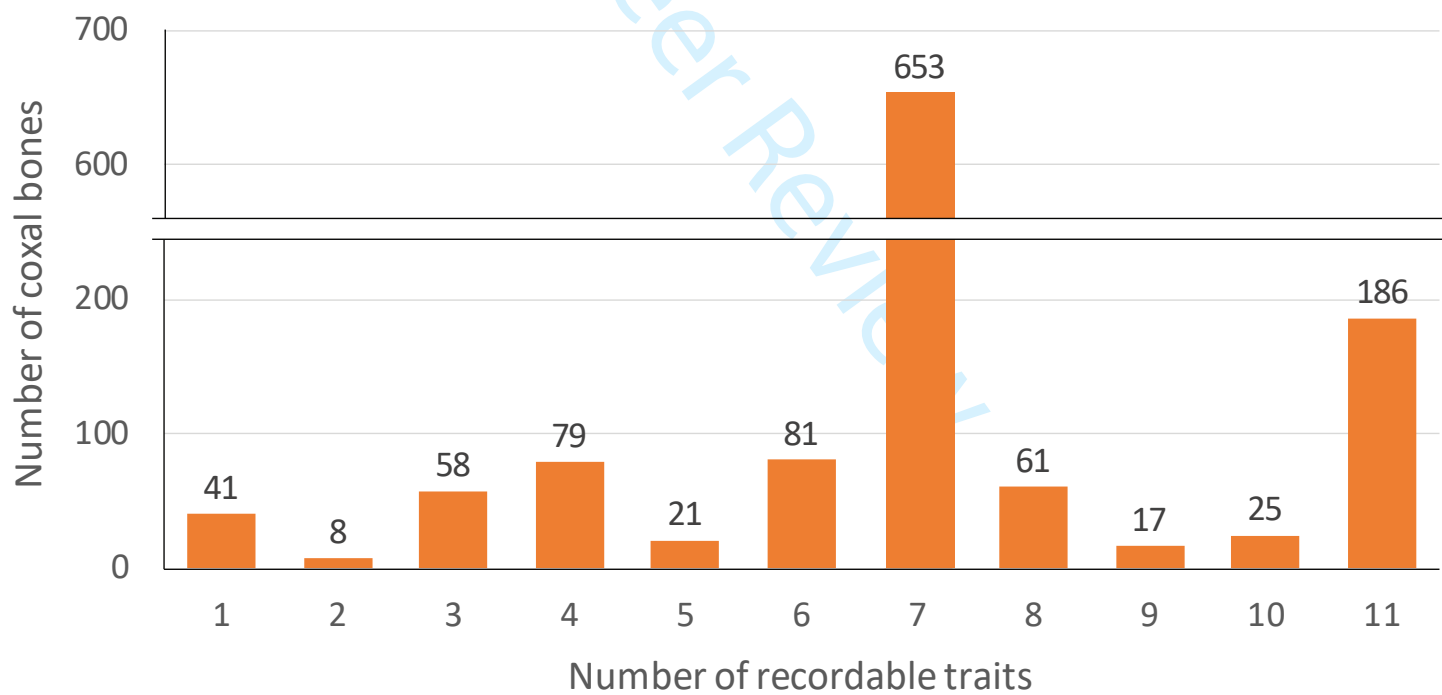
Table 7. Final sex estimation for the 765 individuals for which at least one method was applicable on one or both coxal bones.

Sex estimation	Side for which at least one method was applicable			Total
	Left+Right	Left only	Right only	
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

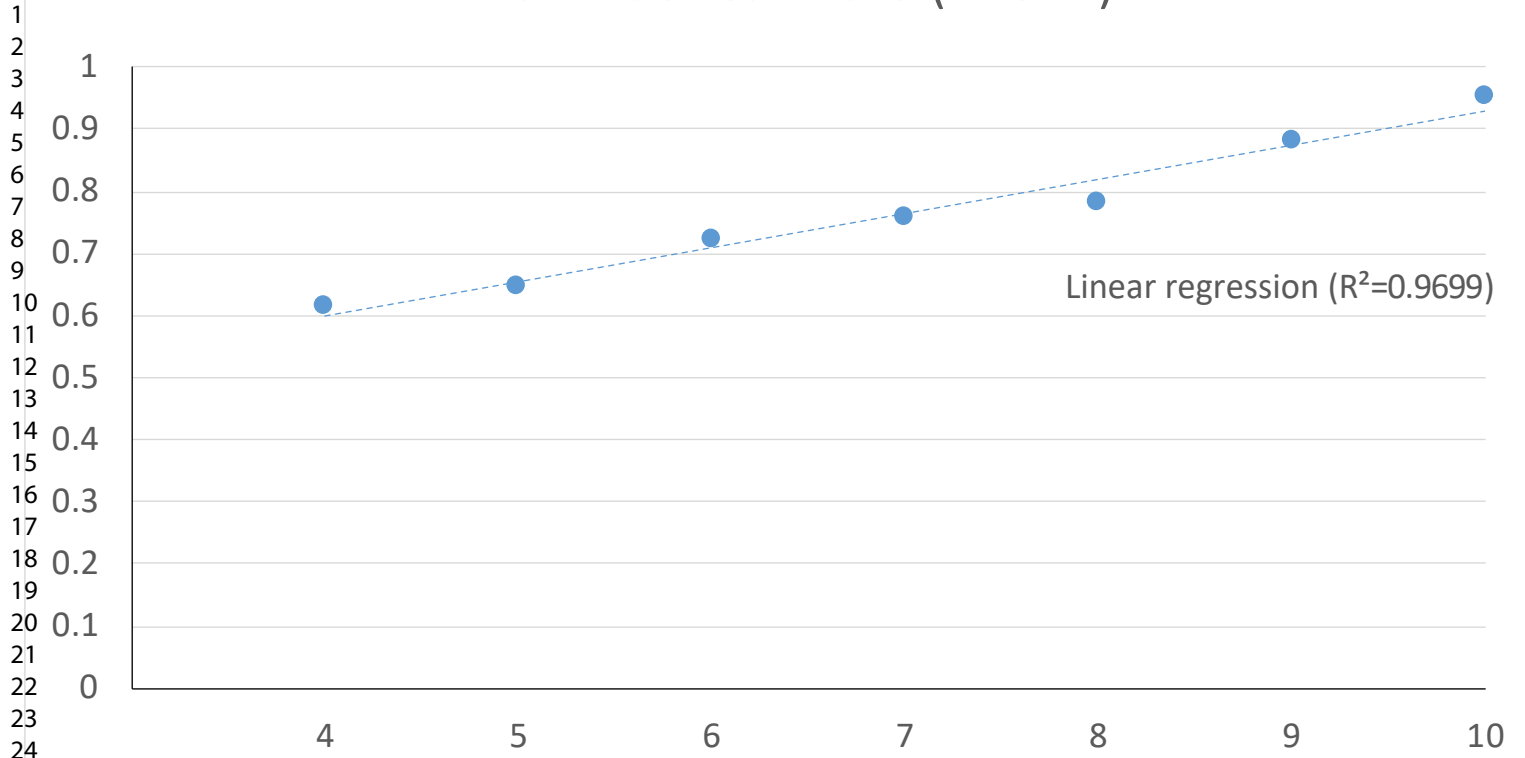
DSP2



SBMM



DSP2: Sex estimate (M or F)



SBMM: Sex estimate (M or F)

