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Secondary sex estimation using morphological traits from the cranium and mandible: application to two Merovingian populations from Belgium

La diagnose sexuelle secondaire sur base de traits morphologiques du bloc crânio-facial et de la mandibule : application sur deux populations mérovingiennes de Belgique

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Abstract – It is generally accepted that the coxal bone is the most reliable bone for estimating the sex of adult subjects. When the coxal bone is not usable, researchers generally turn to methods based on the skull (cranium and mandible). However, these methods are less reliable, because they are largely based on an estimate of the robusticity, which can be influenced by characteristics independent of the sex of the subject. In the context of primary sex estimation, skull-based methods should therefore be avoided. However, by using morphological traits of the cranium and the mandible as part of a secondary sex estimation, we were able to estimate the sex of a relatively large number of individuals with a minimum reliability of 95%. Our study thus illustrates the value of using morphological characteristics of the skull for a secondary sex estimation conducted with a reliable statistical method.

Keywords – sex estimation, secondary sex estimation, coxal bone, morphological traits, cranium, mandible

Résumé – Il est généralement admis que l'os coxal est l'os le plus fiable pour l'estimation du sexe chez les sujets adultes. Lorsque ce dernier n'est pas exploitable, les chercheurs se tournent généralement vers des méthodes basées sur le crâne (le bloc crânio-facial et la mandibule). Or, ces méthodes sont moins fiables, car elles reposent en grande partie sur une estimation de la robustesse, qui peut être influencée par des caractéristiques indépendantes du sexe du sujet. Dans le contexte de la diagnose sexuelle primaire, les estimations basées sur le crâne devraient ainsi être évitées. Toutefois, l'utilisation de traits morphologiques du bloc crânio-facial et de la mandibule dans le cadre d'une diagnose sexuelle secondaire nous a permis d'estimer le sexe

d'un nombre relativement important d'individus avec une fiabilité minimum de 95 %. Notre étude illustre ainsi l'intérêt d'utiliser des caractéristiques morphologiques du crâne lors d'une diagnose secondaire réalisée avec une méthode statistique fiable.

Mots clés – estimation du sexe, diagnose sexuelle secondaire, os coxal, traits morphologiques, bloc crânio-facial, mandibule

Introduction

Producing a reliable estimate of sex is essential for anthropologists studying past human populations. The degree of reliability of sex estimates for adult subjects is influenced primarily by their degree of expression of sexual dimorphism and by the methods used. Many skeletal elements have been used to develop sex estimation methods, with varying degrees of success (Klales, 2020).

It is now accepted that the best indicator of sex among skeletal remains is the coxal bone (also called the innominate) (Ferembach et al., 1980; Brůžek, 1992; Murail et al., 1999; Klales, 2020). Moreover, this bone presents broadly similar patterns of sexual dimorphism across the different regions of the world (Murail et al., 2005; Brůžek and Murail, 2006). Consequently, the methods based on the coxal bone are not population-specific, unlike those based on other parts of the skeleton (Brůžek, 1992; Murail et al., 2005). In archaeological contexts, the coxal bone, and the pubis in particular, is often fragmented or in a poorer state of preservation than other skeletal remains (e.g. Waldron, 1987), so that extra-pelvic methods tend to be used for individuals whose pelvis is in poor condition or absent.

However, methods based on extra-pelvic measurements and, among other things, cranial morphology, are less reliable. Furthermore, extra-pelvic sexual dimorphism is population-specific and can therefore vary. In 1999, to avoid this problem, P. Murail and collaborators developed a two-step approach to estimate sex when the coxal bone cannot be used for all individuals in the study: “the secondary sex diagnosis” (Murail et al., 1999). This approach requires a reliable sex estimation method (i.e., based on the morphology of the coxal bone) to have been applied to part of the archaeological sample studied, with some individuals remaining indeterminate because their coxal bone is damaged, missing or does not present a sufficiently distinctive morphology. The individuals whose sex could be estimated during the first step make up the reference sample for the second step. Extra-pelvic measurements from this sample are then used to build up statistical models, which are then applied to the indeterminate individuals (Murail et al., 1999). The approach is thus specific to the population studied.

The extra-pelvic data used for secondary sex estimation in anthropological research are mainly metric (e.g. Villotte et al., 2011; Schmitt and Saliba-Serre, 2014; Rolland et al., 2018); to our knowledge, qualitatively-based secondary estimation approaches are less commonly used. According to the literature, an approach close to a secondary estimation with qualitative data has occasionally been used, but without any appropriate statistical tools (e.g. Allières, 2016; Ruff, 2018). We have developed such a statistical method for secondary sex estimations based on qualitative data, which this article illustrates as applied to anthropological collections from two Merovingian necropolises, Cibly and Braives, located in present-day Belgium.

We based the secondary sex estimation on the morphological traits of the skull (i.e. the cranium and the mandible) described by D. Ferembach, I. Schwidetzky and M. Stloukal

in 1980. We decided to do so for several reasons. First, the skull is considered, after the pelvis and the long bones, as the most sexually dimorphic part of the skeleton, in many if not all populations, and when it is not possible to use the coxal bone, researchers usually turn first to the skull (Klales, 2020). Secondly, skull bones are robust and thus less sensitive to taphonomic alterations than other bones. The third reason is directly related to the aim of our ongoing study of these archaeological samples, which is to discuss gender roles in Merovingian times. Given that one of our objectives is to study appendicular sexual dimorphism, using the robusticity of long bones for a secondary estimation would have led to a circular argument (i.e., robust individuals are males and males are robust).

Materials and methods

Sample

What we define today as medieval culture emerged in Western Europe in the 5th century, as a form of a syncretism between the Gallo-Roman and Germanic cultures (Effros, 2002). The Merovingian dynasty reigned for 270 years (481-751) over an area that broadly corresponds to present-day France, Belgium, Luxembourg, the Netherlands and western Germany (Effros and Moreira, 2020).

The anthropological material is from two Merovingian cemeteries which were in use in the 6th and 7th centuries. The first necropolis, Cibly (figure 1) is located a few kilometres south of Mons, in the province of Hainaut, while the necropolis of Braives (figure 1) is in the province of Liège.

The Cibly cemetery would have contained between 1,200 to 2,000 graves, given the minimum number of 290 individuals collected (recent inventory by C. Polet and M. Demelenne); making it one of the largest in Belgium

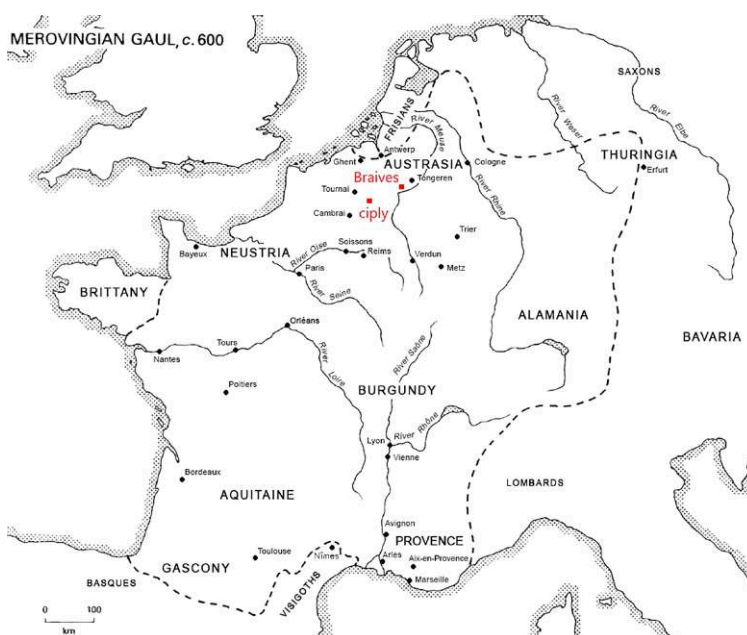


Figure 1. Map of Merovingian Gaul, c. 600 showing its approximate extent and the location of the two populations studied (Cibly and Braives), modified from T.S. Brown, 1997 / *Carte de la Gaule mérovingienne, vers 600, montrant son étendue approximative et l'emplacement des deux populations étudiées (Cibly et Braives), modifiée d'après T.S. Brown, 1997*

(Faider-Feytmans, 1970). The collection belongs to the Royal Museum of Mariemont, but the anthropological material is mainly kept at the Royal Belgian Institute of Natural Sciences and the Royal Museums of Art and History.

At the Braives site, the archaeological excavations revealed 112 tombs within the cemetery (Brulet and Moureau, 1979) with a minimum number of 118 individuals (Humbel, 2014). The osteological material is also curated at the Royal Belgian Institute of Natural Sciences.

We worked with a total sample of 249 “individuals” (182 from Cibly and 67 from Braives). The research sample consisted of subjects for which at least one measurement could be taken on the coxal bone or at least one characteristic could be observed on the skull or the coxal bone. Of the 118 individuals identified in the Braives collection, 67 presented at least one measurement or observation allowing us to conduct our research. Of the 290 individuals identified at Cibly, 182 presented at least one such measurement or observation. However, due to the fact that the Cibly collection comes from early excavations, inconsistencies in the numbering of the bones appeared during the study. The demographic profile is therefore not entirely accurate, because bones not bearing the same number may in fact have belonged to the same individual, which artificially increases the “Minimum Number of Individuals” (MNI).

Primary sex estimation

For the primary sex estimation, only procedures based on the coxal bone were selected. We applied the *Diagnose Sexuelle Probabiliste* (DSP) based on quantitative data and developed by P. Murail and collaborators in 2005 and used the DSP2 software created by J. Brůžek and collaborators in 2017 to calculate probabilities and estimate sex. We also applied a second method, established from qualitative data by J. Brůžek in 2002. Both sex estimation and probabilities were obtained with the “PELVIS” R package, developed in 2019 by F. Santos and collaborators. We applied these two procedures in parallel to all the coxal bones in order to increase the reliability of the estimate as well as the number of individuals whose sex could be estimated. We selected a 95% reliability threshold for both methods.

Secondary sex estimation

In order to estimate the sex of individuals whose coxal bone was damaged, missing or did not present a sufficiently distinctive morphology, we used the approach proposed by Murail and collaborators in 1999: “the secondary sex diagnosis”. With this approach, the extra-pelvic sexual dimorphism of the subjects sexed during the primary sex estimation is used as a reference, and is considered to be representative of the dimorphism of the entire sample (Murail et al., 1999). Thus, using discriminating functions specific to the sample, we used the individuals whose sex could be estimated on the basis of the coxal bone in order to estimate the sex of the rest of the individuals based on extra-pelvic data (e.g. Villotte et al., 2011; Thomas, 2011; Salesse et al., 2013).

The secondary sex estimation can be based on cranial or extra-cranial bones; in both cases it is usually done with metric values. Contrary to what is classically done with skull bones (Brůžek and Velemínský, 2008; Seguin et al., 2011; Schmitt and Saliba-Serre, 2014; Thèves et al., 2016), instead of cranial metric data we used morphological traits, taking those of the cranium and the mandible proposed by D. Ferembach and collaborators in 1980 as the “extra-pelvic data” required for the approach, for which fourteen traits are to be observed, ten on the cranium and four on the mandible. The observer assigns a score to each criterion, ranging from -2 (hyper feminine) to 2 (hyper masculine) with 0 being intermediate (Ferembach et al., 1980). For a description of the criteria, see table II in Ferembach et al. (1979).

Two machine learning algorithms were used to produce sex estimations from the cranial traits, considered as ordinal variables. First, we built random forests (Breiman, 2001) composed of 1,000 trees, where the prior probabilities for female and male outputs were both set to 0.5. Second, neural network models of a simple type (namely, single-hidden-layer neural networks) were computed; the size and decay parameters were optimized using a leave-one-out cross-validation procedure. We considered an individual to be sexed when at least one of the two models assigned a posterior probability and an accuracy of the model of 95% or more. All the statistical analyses were performed using R (R Core Team, 2022), and the R packages caret (Kuhn, 2022), nnet (Venables and Ripley, 2002), randomForest (Liaw and Wiener, 2002) and rdss (Santos, 2021).

We then carried out a “tertiary sex estimation”, by incorporating the individuals who were reliably sexed with the secondary estimation (those with a probability of being male or female of 95% or more and an accuracy of the statistical model of 95% or more) into the reference sample and then repeating the secondary sex estimation process. We therefore used the same cranial traits for the tertiary estimation as for the secondary estimation.

Observer repeatability

In order to test the reliability of our measurements within the DSP2 framework and our assessment of morphological traits using the Brůžek method, a second person (SV), applied both methods to 21 individuals randomly selected from those we had previously studied. The results showed that there were no contradictions between our respective sex estimations, and that both ended up with the same number of sexed individuals.

Results

Primary sex estimation

There were altogether 111 individuals from the two Merovingian populations for which at least one measurement could be taken or at least one character was observable on the coxal bone. The other 138 individuals did not have coxal bones (or not sufficiently well preserved) and were

therefore not included in the primary estimation. Of these 111 individuals, 98 were sexed during the primary estimation, 61 as males and 37 as females. Our results show no contradiction between the two methods and no sex discrepancy between the left and right coxal bones of the same individual.

With regard to the Cibly collection, all 51 individuals for whom pelvic variables could be recorded were sexed, 32 as males and 19 as females (table 1). In the case of the Braives necropolis, of the 60 subjects from whom measurements could be taken, we were able to estimate the sex of 47 individuals, 29 as males and 18 as females (table 1).

Secondary sex estimation

We were able to observe at least one cranial character for 212 individuals altogether. The other 37 individuals did not have a skull (or not sufficiently well preserved) and were therefore not included in the secondary estimation. We based the secondary estimation on a reference sample composed of 34 males and 29 females from Cibly and

Braives, whose sex we had previously estimated from the coxal bone and for which we had been able to score criteria for the cranium and the mandible. We then applied the model developed on the basis of the reference sample to 149 still undetermined individuals (131 from Cibly and 18 from Braives) for whom we had been able to score at least one criterion on the skull. By the end of the procedure, we had estimated the sex of 18 additional individuals, 11 as females and 7 as males (tables 2-3).

Tertiary sex estimation

We reinjected the 18 additional individuals sexed with the secondary estimation into the reference sample, which therefore included 41 males and 40 females at the time of the tertiary estimation. We applied the approach to the 131 individuals who were still undetermined (116 from Cibly and 15 from Braives). By the end of this procedure, we had obtained 17 additional sexed individuals, 8 females and 9 males (tables 4-5).

Sex	Cibly	Braives	Total
Male	32	29	61
Female	19	18	37
Indeterminate	0	13	13
Total with pelvic data	51	60	111
Individuals with no pelvic data recorded	131	7	138
Total	182	67	249

Table 1. Results of the primary sex estimation for the individuals from Cibly and Braives / *Résultats de la diagnose sexuelle primaire pour les individus de Cibly et Braives*

Sex	Cibly	Braives	Total
Male	4	3	7
Female	11	0	11
Indeterminate	116	15	131
Total	131	18	149

Table 2. Results of the secondary sex estimation for the individuals from Cibly and Braives / *Résultats de la diagnose sexuelle secondaire pour les individus de Cibly et Braives*

ID	Site	ProbM RF	PercAccu RF	ProbM NN	PercAccu NN	Sex
2A	Cibly	0.96	100.0	0.88	77.6	Male
27		0.04	95.5	0.07	100.0	Female
35		0.01	84.2	0.04	95.0	Female
170		0.97	100.0	1.00	81.8	Male
215		0.00	100.0	0.08	88.9	Female
308		0.01	100.0	0.10	87.5	Female
329		0.96	96.0	0.92	94.4	Male
375		0.01	100.0	0.02	95.2	Female
377		0.03	100.0	0.00	81.5	Female
425		0.00	95.0	0.00	82.5	Female
442		0.00	95.5	0.00	87.5	Female
499		0.04	93.3	0.02	95.8	Female
500		0.02	100.0	0.01	96.3	Female
552		0.98	95.0	0.83	93.8	Male
787		0.08	93.8	0.05	95.5	Female
T.55		Braives	0.97	100.0	0.97	73.3
T.92	0.97		95.0	1.00	76.8	Male
T.111	1.00		100.0	0.93	100.0	Male

Table 3. Results of the secondary sex estimation with the posterior probability of being male (ProbM), the accuracy of the model (PerAccu) for the random forest (RF) and the neural network (NN) models for the subjects from Cibly and Braives whose sex was estimated during the secondary estimation / *Résultats de la diagnose sexuelle secondaire avec la probabilité à posteriori d'être de sexe masculin (ProbM) et la précision du modèle (PerAccu) pour les modèles de forêt aléatoire (RF) et de réseau neuronal (NN) pour les sujets de Cibly et Braives dont le sexe a été estimé lors de la diagnose secondaire*

Sex	Ciply	Braives	Total
Male	7	2	9
Female	7	1	8
Indeterminate	102	12	114
Total	116	15	131

Table 4. Results of the tertiary sex estimation for the individuals from Ciply and Braives / *Résultats de la diagnose sexuelle tertiaire pour les individus de Ciply et Braives*

ID	Site	ProbM RF	PercAccu RF	ProbM NN	PercAccu NN	Sex	
10A	Ciply	0.00	96.9	0.03	95.5	Female	
11A		0.03	96.6	0.14	95.5	Female	
31		0.98	97.1	0.94	96.8	Male	
101A		0.01	96.1	0.25	96.0	Female	
104A		0.00	95.9	0.13	100.0	Female	
119		0.98	95.9	0.84	100.0	Male	
121		0.99	96.0	0.97	98.0	Male	
396		0.00	97.1	0.05	93.3	Female	
515		0.97	96.6	0.90	85.7	Male	
571		0.96	95.8	0.86	92.9	Male	
576		1.00	96.2	1.00	92.6	Male	
605			95.7	0.83	100.0	Male	
638		0.05	97.1	0.10	86.4	Female	
797		0.01	97.1	0.02	92.0	Female	
T.6		Braives	0.95	100.0	0.87	96.4	Male
T.30			0.02	97.4	0.04	93.9	Female
T.74	1.00		97.2	0.91	95.2	Male	

Table 5. Results of the tertiary sex estimation with the posterior probability of being male (ProbM), the accuracy of the model (PerAccu) for the random forest (RF) and the neural network (NN) models for the subjects from Ciply and Braives whose sex was estimated during the tertiary estimation / *Résultats de la diagnose sexuelle tertiaire avec la probabilité à postériori d'être de sexe masculin (ProbM) et la précision du modèle (PerAccu) pour les modèles de forêt aléatoire (RF) et de réseau neuronal (NN) pour les sujets de Ciply et Braives dont le sexe a été estimé lors de la diagnose tertiaire*

Overall results

By the end of the primary, secondary and tertiary sexual estimations, we had estimated the sex of 133 individuals altogether, as 77 males and 56 females (table 6). For Ciply, out of the minimum of 181 individuals that had been identified, 80 individuals (44%) were sexed, as 43 males and 37 females (table 6). In the case of the Braives collection, out of the minimum of 118 individuals, we were able to estimate the sex of 53 individuals (45%), as 34 males and 19 females (table 6).

Sex	Ciply	Braives	Total
Male	43	34	77
Female	37	19	56
Total	80	53	133

Table 6. Results of the sex estimation for the individuals from Ciply and Braives / *Résultats de l'estimation du sexe pour les individus de Ciply et Braives*

Discussion

Comparison with other studies performed on Ciply and Braives material

We compared the results concerning the sex estimation of the Ciply individuals with the study published in 1970 by G. Faider-Feytmans (Faider-Feytmans, 1970) (table 7). In her work, the author specifies that 73 female individuals and 70 males were identified on the basis of anthropological material, and that according to the funerary material,

Research	Sexed ind.	% of males	% of females
Faider-Feytmans (1970)	334	52%	48%
Our study (2023)	80	54%	46%

Table 7. Results of the sex estimation for Ciply as part of our own research as well as in the study published by G. Faider-Feytmans (1970) / *Résultats de l'estimation du sexe pour Ciply dans le cadre de notre recherche ainsi que dans l'étude publiée par G. Faider-Feytmans (1970)*

88 additional female graves and 103 additional male graves were present. The total number of sexed individuals in the 1970 study therefore includes graves that yielded no anthropological material. Unfortunately, in this inventory, we did not find any information specifying whether the sex for each individual was obtained from the anthropological data or from the study of the archaeological material. When we compared the sexes for each individual obtained in our research with those published by G. Faider-Feytmans, we found that a sex was estimated in both studies for only 44 subjects. Among them, only one sex was reversed, for individual 1025, sexed as female in the study published in 1970 and as male during the primary estimation in our study.

As regards the Braives necropolis, we compared our results with those from M.A. Delsaux (Brulet and Moureau, 1979), and from F. Limbourg's Master's thesis (2014) (table 8). M.A. Delsaux attributed a sex based on funerary material and F. Limbourg applied the DSP.

Research	Sexed ind.	Sexed ind.*	Males	Females
Delsaux (1979)	13	11%	77%	23%
Limbourg (2014)	21	18%	71%	29%
Our study (2023)	53	45%	64%	36%

Table 8. Results of the sex estimation for the subjects from Braives as part of our own research as well as in the studies carried out by M.A. Delsaux and F. Limbourg. * Compared to the minimum number of individuals (MNI = 118) / *Résultats de l'estimation du sexe pour les sujets de Braives dans le cadre de notre recherche ainsi que dans les études menées par M.A. Delsaux et F. Limbourg.* * Par rapport au nombre minimum d'individus (NMI = 118)

We compared the sexes obtained, individual by individual, in our research with those of F. Limbourg and M.A. Delsaux. Four individuals are common to our research and that of M.A. Delsaux; no reversal in sex assignment was observed. Twenty individuals were sexed both during our study and that of F. Limbourg, with three reversals (table 9). The result of the measurement comparison is available in the Supplementary Information section (SI). Most of the discrepancies are probably due to measurement issues in the previous study (see SI for a comprehensive discussion).

Tomb	Sex DSP (2014)	Sex DSP2 (2023)	Sex Brůžek (2023)
T.3	Male	Female	Female
T.57	Male	Undetermined	Female
T.110	Male	Undetermined	Female

Table 9. Comparison between the results of our study and those of F. Limbourg (2014) for the three individuals where the sex was reversed / *Comparaison entre les résultats de notre étude et ceux de F. Limbourg (2014) pour les trois individus dont le sexe est inversé*

General discussion

The secondary sexual estimation approach based on the morphological characteristics of the cranium and the

mandible enabled us to estimate the sex of 35 additional subjects out of the 133 individuals sexed altogether, with a minimum reliability of 95%.

Morphological and metric sex estimation methods based on the skull achieve 80% reliability on average (Steyn and İşcan, 1998; Deshmukh and Devershi, 2006; Walker, 2008). It is generally accepted that sex estimation methods using the skull are less reliable than with the pelvis, as they are based largely on an estimate of the robusticity of observed traits, which can be influenced by characteristics independent of the sex of the subject (Brůžek, 1992; Stock, 2006). Nevertheless, the cranium and the mandible still allow a relatively reliable estimation of sex and above all can be useful to obtain the extra-pelvic data necessary for a secondary estimation. Indeed, as illustrated by our study, if the method of Ferembach and collaborators applied as a primary sexual estimation is generally less than 95% reliable, applying it on the basis of these discriminating models created especially for the Cibly and Braives populations made it possible to achieve a higher reliability. For collections which include skulls and a certain number of associated coxal bones, the approach illustrated here therefore appears to be particularly useful to increase the number of individuals that the researcher can reliably sex. This approach then makes it possible to study the infracranial robusticity of individuals without falling into a circular argument.

Conclusion

In the context of primary sexual estimation, morphology or morphometry of the skull should be avoided. However, using morphological criteria from the cranium and the mandible for a secondary sex estimation allowed us to assign a sex to a relatively large number of additional individuals with a reliability of 95% or more. This study thus highlights the value of using the skull for secondary estimations carried out with a reliable statistical method. The use of the skull also allowed us to study the robusticity of long bones and avoid circular arguments such as: "we attributed a male sex to robust individuals and then deduced that men have more robust long bones than women".

During the secondary estimation, the probability of being male and the accuracy of the models generated were sometimes quite variable for the same individual¹. However, no contradictions were observed between the sex estimations of the two statistical tools used, and the models developed made it possible to sex 35 additional individuals with a high degree of reliability; the approach is therefore relevant. Nevertheless, one solution to improve the model would be to enrich the reference sample with other subjects for better stability.

¹ Although a slight variation is to be expected, since some of the characteristics are chosen randomly.

The method has other limitations, such as the fact that it still requires a sample with individuals possessing at least one coxal bone allowing sex estimation and their associated skull, which is not always the case in archaeological collections. Other problems can arise when the sample is relatively small or when one of the two sexes is much more represented than the other, which can make the sex estimations less reliable (see Santos, 2021). Finally, since rds offers a “semi-automated” approach, we had to run the program manually, individual by individual, which could be time-consuming.

Following our study, several future research directions can be considered. First, as part of the project entitled “*Des hommes et des femmes, individualités plurielles au Haut Moyen Âge. Analyse croisée des données matérielles et archéométriques de la nécropole mérovingienne de Cibly (B., Hainaut, Mons)*”, supported by the Fondation Roi Baudouin (Fonds J.-J. Comhaire)², DNA tests will be carried out on individuals from the Cibly collection, making it possible to compare the results of our research with the genetic sexing. Secondly, we will be able to test our approach with an identified collection (e.g. Schoten, Belgium, 19th-20th centuries). Finally, again with an identified collection, we will be able to conduct a primary sex estimation with the method of Ferembach and collaborators for comparison with our results.

Supplementary information

The supplementary information is available in .pdf from the BMSAP website (<https://journals.openedition.org/bmsap/14049?file=1>).

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