New Method for Sex Prediction Using the Human Non-Adult Auricular Surface of the Ilium in the Collection of Identified Skeletons of the University of Coimbra

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ABSTRACT

Sex estimation in non-adult skeletons is crucial in bioarchaeology and forensic anthropology. It was not extensively considered in the past, mainly because it was stated that the dimorphic osteological features were difficult to identify before adulthood. Over the past few years, this statement was disproved, and the study of numerous dimorphic non-adult skeletal traits was approached. This paper presents a new methodology that evaluates the auricular surface of the non-adult ilia. Several morphological and continuous variables were recorded for 34 individuals (21 females and 13 males) aged between 7 and 18 from the Coimbra Identified Skeletons Collection (University of Coimbra, Portugal).

The results show low intra and inter-observer errors for all the variables, which renders the methodology replicable. Two ratios related to the shape of the anterior area of the auricular surface offer the most dimorphic data (proportions of cases correctly assigned: 0.82 and 0.88; sexual allocation probabilities: 0.85 for both variables). A discriminant function and a logistic regression were developed, which correctly classified the 82.35 and the 88.23% of the individuals, respectively. Moreover, two qualitative variables, referred to as the *overall morphology* and the *apex morphology*, also show statistically significant differences between males and females (proportions of correct assignation: 0.82 and 0.76; sexual allocation probabilities: 0.79 and 0.76).

These variables can be incorporated in a multifactorial approach together with other indicators already available in the specialised literature in order to help improve the accuracy of the results obtained. This methodological procedure has to be applied with other identified samples, including younger individuals, so as to test whether the trends presented in this context are maintained and are useful in populations from a different geographical provenience.

INTRODUCTION

Sex and age-at-death estimations are the first and most important aspects of any bioarchaeological analysis because the generation of adequate and representative mortality profiles depends on the reliability of the results for both variables (Bocquet-Appel and Masset, 1977; Chamberlain, 2000, 2006; Hoppa and Vaupel, 2002; Bocquet-Appel, 2008). These features are considered useful for the purpose of corpse identification in forensic cases and for analysing selective mortality between non-adult males and females in past populations, considering issues such as parental care, infanticide, the influence of genetic factors in mortality, etc. (e.g., Harris and Ross, 1987; Wood et al., 1992; Barnes, 1994; Caldwell and Caldwell, 2003; Spinelli, 2005; Lewis, 2007; Luna, 2008).

A set of systematic procedures for the sex estimation in adults (see e.g. Buikstra and Ubelaker, 1994; Brickley and McKinley, 2004) offers the possibility of obtaining reliable information when the preservation of the human remains is good enough and a multifactorial estimation is performed (e.g. Acsádi and Nemeskéri, 1970; Buikstra and Mielke, 1985; Lovejoy et al., 1985; Isçan, 1989; Bedford et al., 1993; Krishan et al., 2016). The pelvic girdle includes the most dimorphic features of the adult skeleton (Lovell, 1989; Bruzek, 2002; Walker, 2005). With reference to non-adults, high percentages of skeletons are usually recovered at archaeological sites from different cultural, geographical and chronological contexts, due to the high mortality rates during the first years of life; however, in most of the cases, the research did not focus on sex estimation because it has been assumed that the estimation is fallible before the development of the secondary sexual characteristics. This paper offers a new methodology for non-adult sex estimation considering morphological and metric variables of the auricular surface, to be incorporated into a multifactorial approach along with previously known techniques.

Sexual dimorphism is mainly a result of differences in the hormone secretion between males and females (Gassler et al., 2000; Mays and Cox, 2000; Quigley, 2002). Nevertheless, socio-environmental variables may also play a key role in the final phenotypic expression (Bogin and Smith, 2000; Stinson, 2000). Non-adult sex differences tend to be higher in foetuses and children under one year after birth, as the levels of testosterone production are higher than at a later stage in life (Saunders, 1992; Mays and Cox, 2000; Loth and Henneberg, 2001), although skeletal phenotypic differences prior puberty are usually much lower than in adulthood (Winter et al., 1976; Saunders, 1992; Holcomb and Konigsberg, 1995). The period from 7 to 10-12 years of age is characterised by the lowest rate of growth since birth, while the major peak of growth occurs between 10-12 and 18-20 years of age (Bogin and Smith, 2000; Crews and Bogin, 2010). In accordance with these statements, for the Portuguese population, Rocha et al. (1998) stated that the average age of menarche was between 13.43 and 14.7 years of age for the females born in the period 1910-1940, while Cardoso (2008a) concluded that the highest increments in the stature of males occurred at 14-15 years of age between 1899 and 1966. After puberty, it is possible to obtain satisfactory results recording the same features observed in adults (Ferembach et al., 1980; Buikstra and Ubelaker, 1994; Vlak et al., 2008; Wilson et al., 2008; Rogers, 2009).

It has usually been stated that, even though there are morphological differences in the skeleton between the sexes from early ages, dimorphism is difficult to evaluate in a reliable manner prior to the changes in morphology, size and robustness that take place during puberty (Ferembach et al., 1980; Pickering and Bachman, 1997; Scheuer and Black, 2000a and b; Sutter, 2003; Bruzek and Murail, 2006). Numerous studies attempted to offer solutions and proposed important tools for non-adult sex estimation through the metric and morphological analyses of the skeleton and the dentition, especially in the last years (e.g., Schutkowski, 1993; Rösing et al., 2007; Cardoso and Saunders, 2008; Stull and Godde, 2013; Irurita Olivares and Alemán Aguilera, 2016; Klales and Burns, 2017; Stull et al., 2017, among others). In general, these methodological proposals include similar approaches to those that offered satisfactory results in adults (e.g., Molleson et al., 1998; Mays and Cox, 2000; Loth and Henneberg, 2001; Stull et al., 2017) and record anatomical portions of the ilium (e.g., angle, index, depth and location of the maximum depth of the greater sciatic notch, arch criterion, curvature of the iliac crest, elevation of the auricular surface and subpubic concavity; Boucher, 1957; Fazekas and Kòsa, 1978; Hunt, 1990; Mittler and Sheridan, 1992; Schutkowski, 1993; Holcomb and Konigsberg, 1995; Sutter, 2003; Cardoso and Saunders, 2008; García Mancuso, 2009; Klales and Burns, 2017), the orbit (Molleson et al., 1998), the internal auditory canal (Gonçalves et al., 2011), the mandible (Schutkowski, 1993; Molleson et al., 1998; Loth and Henneberg, 2001; Ridley, 2002; Scheuer, 2002; Sutter, 2003) and teeth (buccolingual and mesodistal diameters of crown and neck; e.g., Black, 1978; Rösing, 1983; De Vito and Saunders, 1990; Isçan and Kedici, 2003; Żądzińska et al., 2008; Mitsea et al., 2014; Viciano et al., 2015). Recently, the measurements of long bones added new important insights for the non-adult sex estimation (e.g., Stull and Godde, 2013; Stull et al., 2017). As it is usually a much more difficult task than in the case of adults, the development of new methods to be included in a comparative approach, is welcomed.

Important research has been conducted during the last decade concerning the sexual dimorphism of the auricular surface. For example, Wilson et al. (2008) studied several variables, including the outline of the non-adult auricular surface morphology, in a sample of 25 individuals of known sex and age (younger than 8 years of age) from Christ Church, Spitalfields, London, using a geometric morphometric approach. The authors generated a discriminant function that enabled 84% of the individuals to be allocated to the correct sex group. Posteriorly, Wilson et al. (2011) recorded different areas of the non-adult ilia in a larger sample (82 individuals of known sex and age from the Lisbon, St. Brides and Spitalfields collections) and showed that the inter-observer error was relatively high for the identification of some of the landmarks of the outline of the auricular surface, with poor levels of accuracy (65.2% on average). They concluded that the applicability of this criterion is questionable and of limited interest in other samples. This may point to population-specific patterns of growth and dimorphism. The authors also suggested that the age-at-death is in part responsible for the variability observed, introducing a variation that affects sexual dimorphism; differences in male and female maturity rates contribute to confounding the sexual discrimination and the trajectories of the development of the auricular surface diverge prior to adolescence (Wilson et al., 2015).

As some authors (e.g., Holcomb and Konigsberg, 1995; Vlak et al., 2008; Wilson et al., 2008; see discussion in Scheuer and Black, 2000a; Cardoso and Saunders, 2008) suggested, shape changes are evident in the non-adult pelvis since early childhood, especially in the area of the greater sciatic notch (e.g., Phenice, 1969; Patriquin et al., 2003; Correia et al., 2005; Irurita Olivares and Alemán Aguilera, 2016). The auricular surface may also be a good non-adult sex predictor since it is located immediately adjacent to the greater sciatic notch and may be influenced by similar biological, hormonal and biomechanical constraints. Considering the need to develop new methodological criteria for non-adult sex determination, a simple approach that studies the discrete and continuous variables of the auricular surface is proposed in this paper, focusing on specific areas and not on the complete outline of the feature.

SAMPLE AND METHODS

Thirty-four individuals (21 females and 13 males) aged between 7 and 18 years of age (Table 1; Fig. 1), who lived and died between the 1887 and 1934, were recorded. They belong to the Identified Skeletons Collection, housed in the University of Coimbra, Portugal, and were exhumed from the *Cemitério Municipal da Conchada* of Coimbra (Santos, 2000). The sample includes all the non-adult individuals of the collection, which means that skeletons younger than 7 years of age were not available. Each skeleton is associated with reliable information, including the full name, sex, age-at-death, place of birth, date, place and cause of death, and work activity (Rocha, 1995; Santos, 2000). Given the age range of the individuals studied, it is considered that this research contributes to the problem of sex estimation in non-adults (Bogin and Smith, 2000; Crews and Bogin, 2010).

[Table 1 and Figure 1 here]

Two different approaches seeking to analyse the articular surface were developed, one morphological and the other metric, with the aim of identifying features that facilitate the discrimination between males and females at a percentage higher than 75% (following Saunders, 1992). In both cases, the proportions of correctly allocated cases for the whole sample and for each sex were calculated. Moreover, considering the different rates of growth and development mentioned above for the non-adult period, these proportions were also obtained dividing the whole sample in two age-at-death groups: 7-12 years (14 females and 5 males) and 13-18 years (7 females and 8 males). It is expected that assignation results in the older age group should be better, considering the higher hormonal secretion rates (Gassler et al., 2000).

Metric variables

This methodological approach is original to this paper. Orthogonal digital images of the posterior area of the left ilia were taken with a standardised distance of 20 cm between the camera and the bone. The auricular surface was positioned with the inferior border vertically and a measuring grid was electronically developed. The first step was to identify the most inferior point of the border (α), where a vertical line along the inferior border was drawn; this area usually has a straight morphology. Secondly, two parallel lines were delineated; one should touch a point in the central area of the surface coincident with the angle of the auricular edge (*ß*), and the other, the most superior point of the anterior area of the joint (γ). As a second step, three parallel segments, orthogonal to the previous, were drawn. The first included the most anterior point of the auricular surface (δ); the second, the most posterior point (ε), and the third should touch *ß*. The vertices of the four rectangles obtained were labelled with capital letters (A to I; Fig. 2), which allow recording a series of measurements and calculating seven ratios in order to eliminate the variance due to size. These ratios

(AC/CI, FI/CF, AB/BC, HI/EH, EF/CF, DE/AD and DE/EH; see Figs. 2 and 3) provide basic information about the shape of the areas of the auricular surface and the entire joint, and allow a comparative analysis in order to identify significant sex differences.

[Figures 2 and 3 here]

Morphological variables

Three morphological variables were considered for the auricular surface: the *overall morphology* of the joint, the *apex morphology* and the *inflection*. The first two were previously defined and analysed in the ilia of 102 autopsied foetuses and newborns by Pizani Palacios (1996) in order to identify their potential as sexual discriminators. The author states that for males, the *overall morphology* of the auricular surface usually has a lying V-shape, the anterior and inferior edges are similar in length and the angle *εβγ* is obtuse (Figs. 3A, B and C). On the contrary, the feature has an inverted L-shape among females, with the inferior margin considerably longer than the anterior one and a perpendicular alignment between them. In consequence, the angle *εβγ* is approximately right (Figs. 3D, E and F). Furthermore, the *apex morphology* is a feature located in the upper area of the anterior portion of the auricular surface; it tends to be angular in males (Figs. 3A, B and C) and rounded in females (Figs. 3D, E and F).

During the survey of the aforementioned variables, it was observed that some auricular surfaces had a clear *inflection* in the area of the angle *εβγ* (Fig. 1; see Figs. 3A, C, E and F). In others, the contour was almost straight or with an obtuse angle (Figs. 3B and D). Thus, this feature, not considered in previous studies, was evaluated in order to identify whether the differences were sex-related. It is proposed that males show an attenuated or absent inflection, whereas females exhibit a clearly defined inflection.

Statistical analysis

The reproducibility of a method is an important condition to verify in a new approach. In order to know the degree of accuracy in the recording of each variable, intra and interobserver errors were evaluated using the Cohen Kappa Coefficient (κ) for morphological variables and the Intraclass Correlation Coefficient (*ICC*) for quantitative variables (Bland and Altman, 1986). The first two authors, who have extensive experience in osteological research, recorded each variable twice, without previous knowledge of the sex and age of the individuals. Each group of observations was performed at least one week apart; in the second set of observations, the ilia were randomly ordered to avoid conditionings from the previous survey data. Grids were also drawn twice from the same digital images in order to evaluate the accuracy of the identification of each of the points previously described.

After a section point (average of the closest values for each sex) was obtained for each ratio, the percentages of the correct discrimination for males, females and the whole sample -*P* (A|B)- were calculated; this is the proportion between the quantity of correctly assigned cases and the total observed. These values show the overall success rate for the sample. In turn, the likelihoods of a correct allocation -*P* (B|A)- were obtained (Koch, 2007), which is much more suitable for the identification of isolated individuals with no reliable sexual information. As Mittler and Sheridan (1992) state, this approximation offers information about the probability that an individual is correctly sexed considering a single category of the given variable. It evaluates the proportion between the number of cases with a particular trait by sex and those with that feature for the whole sample, and gives information about the likelihood of a new individual being included in the analysis, be of that sex (see Hoppa and Vaupel, 2002; Irurita Olivares and Alemán Aguilera, 2016).

The significance of the observed differences between sexes, the magnitude of the association between the sex and the values obtained, and the incidence of the age-at-death for each variable were evaluated using different statistical approaches. Nonparametric Mann Whitney (U) and Kolmogorov Smirnov (Z) test, and the Pearson correlation coefficient (r), were used for continuous variables, whereas the Coefficient of Cramer (V) was employed for qualitative variables. The statistic *eta* (η) measures the association between sex and the values for each ratio and was considered for both sets of variables (Gibbons, 1993; Zar, 2010). As shown in the introduction, the rates of secretion of sex hormones do not increase in correlation with age, but during two constrained periods within non-adulthood. Based on this, high positive correlations should not be expected with age. However, taking into account that the sample only includes individuals between 7 and 18 years of age, during that period the rates of hormone production tend to increase with age, so the application of the r and η statistics is adequate. Finally, a PCA was conducted in order to observe the distribution of the individuals from a multivariate perspective and both a discriminant function score equation and a binary logistic regression were derived, including the standardised data of the dimorphic variables. SPSS 16.0 and PAST 3.09 programmes were used to carry out the statistical procedures.

RESULTS

Intra and interobserver errors

The results of the intra and interobserver errors are given in Table 2. All *ICC* and κ values are higher than 0.823, which indicate that the associations between the observations of the variables are high. This means that the recording procedure is replicable.

[Table 2 here]

Characterisation of the variables by the sex and age-at-death of the individuals

Table 3 shows the descriptive statistical data obtained for each quantitative variable. Almost all the ratios show very similar minimum, maximum, mean and standard deviation values for each sex, with the exception two of them, namely FI/CF and DE/AD. When analysing the section points and the correctly assigned cases -*P* (A|B)-, only these two ratios are equal or higher than 0.75 for the entire sample; the values of the correctly assigned cases by sex range between 0.81 and 0.92. It is remarkable to note the high values of the whole positive allocation (0.82 and 0.88 respectively).

When the age ranges (7-12 and 13-18 years) are compared, the same general trend is observed. For the other ratios (*e.g.* AB/BC) the percentages are higher in older individuals, but mostly in the case of females; the sex of the males is not well predicted.

For the qualitative variables, the *overall morphology* and the *apex morphology* present good global results (0.82 and 0.76 respectively). The same trend is observed (≥0.75) when males and females are grouped separately. On the contrary, the *inflection* does not seem to be sex-related, because the percentages of the correct assignation are close to 50%. For the first two variables, males are once more better positioned than females, and 13-18 year-old individuals do not show better percentages of correct assignation than younger individuals (Table 3).

[Table 3 here]

The probabilities of sex allocation indicate the likelihood of correct assignation for unknown individuals -*P* (B|A)-. The probabilities for the FI/CF and DE/AD ratios are higher than 0.75 for males (FI/CF=0.83; DE/AD=0.83), females (FI/CF=0.86; DE/AD=0.86) and both sexes (FI/CF=0.85; DE/AD=0.85) (Table 4). When comparing the age-at-death categories, the same trend is observed: non-adults older than 12 years do not show better probabilities than younger ones, with the exception of DE/AD for males. Most of the probabilities of the other ratios are much lower, mainly in males. Table 5 shows this data for each sex in 0.1 increments.

[Tables 4 and 5 here]

The U and Z values show significant statistical differences for the FI/CF and DE/AD ratios between males and females. Moreover, the statistical *eta* (η), which measures the association between sex and the values for each ratio, shows high results only for FI/CF and DE/AD. Low Pearson correlation coefficient r values indicate that the metric data is not affected by the age-at-death; in consequence, the shape of the auricular surface is not significantly influenced by the process of growth and development (Table 6).

[Table 6 here]

The first two components of a PCA (98.63% of the variability explained) that include the data for the variables DE, AD, FI and CF show clear sex discrimination (Fig. 4). In the first component, that includes 73.69% of the variability, most female individuals are grouped on the negative scores, and the males on the positive values. This distribution means that the four variables are good sex predictors when considered altogether.

[Figure 4 here]

A discriminant function and a binary logistic regression were developed using the data of the two ratios that offered univariate dimorphic results (DE/AD and FI/CF). The Kolmogorov-Smirnov test was first conducted to test the normal distribution of both variables (DE/AD: Z=0.535; p=0.937; FI/CF: Z=0.644; p=0.801). The results of the stepwise method used to obtain the discriminant scores are shown in Table 7. The discriminant function score equation is

$$X = -3{,}470 + 0{,}865\ (DE/AD) + 2{,}739\ (FI/CF)$$

and the section point is 0,078. The correctly classified percentage is 79.41% and the value obtained from the cross-validation method, applied to check the predictive capacity of the function, is 82.35%. On the other hand, the data for the logistic regression is shown in Table

8. The formula obtained is

$P_{(sex)}$=1/1+$e^{-(-25,819+37,723*(DE/AD)+[-2,320*(FI/CF)])}$

In this case, 84.61% of males and 90.47% of females were correctly classified (88.23% for both sexes). The Nagelkerke R^2 coefficient of determination was calculated in order to evaluate the goodness of fit of the regression (i.e., the power of explanation of the model). The value obtained is 0.811, which means that 81.1% of the variation of the dependent variable is explained by the ratios included in the formula.

[Tables 7 and 8 here]

Considering the morphological variables, the probability of an individual with an inverted L-shaped auricular surface to be female is 0.81, and 0.77 for those with a lying V-shaped surface to be males; the general probability of correct sex estimation is 0.79. Males younger than 13 years and females older than 12 years have lower likelihoods of an adequate allocation than expected and do not reach the threshold of 0.75, but when both sexes are grouped, the likelihood reaches 0.85 and 0.76 respectively. The *apex morphology* shows a similar general pattern for the whole sample (0.76), and is a better predictor for females (0.78) than for males (0.72). The probabilities for males over 13 years old (0.86) are better than for females in the same age range (0.79), and are lower (0.50) for males than for females (0.78) under 13 years of age. The likelihoods are much better for older individuals only for this variable. Finally, the probabilities for the *inflection* are much lower, which indicates that most of the individuals are successfully sexed only slightly better than chance (with the exception of females between 7 and 12 years of age, which are all correctly sexed) (Table 4). The coefficients of Cramer *V* indicate high associations between the results and sex for the *overall morphology* and the *apex morphology*, while the *inflection* is not related to sex, as shown before; conversely, the relation between the results and the age-at-death is weak for the three variables, mainly the *overall morphology* and the *apex morphology*, considering the η values (Table 9).

[Table 9 here]

DISCUSSION

As the scoring of morphological methods may be related to the subjectivity of the observer when identifying each category, it is usually stated that metric methods may provide a more objective approach (Rösing, 1983; De Vito and Saunders, 1990; Mayhall, 2000; Pietrusewsky, 2000; Isçan and Kedici, 2003; Cardoso, 2008b; Kieser, 2008; Black and Ferguson, 2011). In this research, all the variables, morphological and continuous, show high values of replicability, which is promising considering that the identification of certain points of the grid (for example *ß* in Fig. 2) was initially expected to be quite inaccurate. In consequence, the procedure for recording the quantitative variables proposed in this paper is supposed to be reliable, although it must be tested in other documented skeletal samples, especially for individuals younger than 7 years of age.

The authors are aware that some sex bias may be influencing the results because males are less represented than females (38.24 and 61.76%, respectively; Table 1) (see Albanese et al., 2005; Milner and Boldsen, 2012). However, these values only deviate about 11 percent from the sample balance by sex, so biases in the results should be low. Moreover, Albanese et al. (2005) affirm that high allocation accuracies are expected when the sex ratios are less than 1.5:1, while in the present sample this ratio is 1.07. In any case, this initial research only attempts to offer preliminary results that have to be compared with other results obtained from bigger samples with equal sex distributions.

The analysis of the features of non-adult human skeletons that can offer reliable data for sex estimation is closely related to the search of variables not strongly influenced by growth and development (Mittler and Sheridan, 1992). The results show that this is the case for the variables considered. However, only some of them were useful for sex estimation, which indicates that other biological processes, such as the genetic input (see Stinson, 2000; Guattelli Steinberg et al., 2008) may influence the patterns identified. It is also observed that the percentages and probabilities of correct estimation, considering both metric and morphological variables, are not systematically better for individuals older than 12 years of age, as would be expected considering the sex variation in the levels of hormone secretion after that age (Tables 3 and 4) and the results obtained in previous research (e.g., Cardoso and Saunders, 2008). This situation introduces good perspectives for sex estimation in individuals younger than 7 years of age.

In the present study, the only ratios that offer reliable information about sex are FI/CF and DE/AD, with high percentage and probabilities of correct assignations, regardless of the age-at-death for both males and females. The remaining must therefore be dismissed as good sex predictors. Considering the information for the FI/CF ratio, the anterior half of the female auricular surface tends to be proportionately more elongated between the superior and inferior areas than the posterior, and shorter in the cases of males; for the DE/AD ratio, the superior-anterior area is more rectangular among females, while for males it usually shows a quadrangular shape (Fig. 3). The differences observed between sexes for both ratios could be partially associated with the fact that the female greater sciatic notch is wider and more symmetrical (see Bruzek, 2002), which pre-announces a more effective space for the birth canal in women. In fact, a wider greater sciatic notch is a feature typical of non-adult female ilia, as previously stated by authors such as Fazekas and Kòsa (1978), Schutkowski (1993), Luna and Aranda (2005) and Wilson et al. (2008). Moreover, in females (Fig. 3D) the anterior portion of the auricular surface usually comprises a much larger area as opposed of that of males (Fig. 3A).

For the three qualitative variables studied, the overall morphology and the apex morphology turned out to be dimorphic. Pizani Palacios (1996) identified 73.3% of the cases correctly assigned for both variables, although the apex morphology was classified better for males than females (80.0% vs. 66.7% respectively) (Table 10). This trend is maintained in the current study, with an angular apex and a lying V-shaped morphology for males, and a rounded apex and an inverted L-shape morphology for females (Figs. 2 and 3). On the contrary, the inflection did not show a dimorphic morphology pattern.Most of the variables offered higher percentages and probabilities for males, a trend previously identified by Weaver (1980), Mittler and Sheridan (1992), Schutkowski (1993) and Wilson et al. (2008), and the contrary by Sutter (2003) considering other variables for non-adult sex estimation. This trend may be likely due to genetic control and environmental differences among the sample studies (Stinson, 2000; Sutter, 2003), but also to variations in the dimorphic expression of different areas of the non-adult skeleton. It is also noteworthy that for the discriminant function generated, the percentage of correct assignations shown by the cross-validation is similar to those obtained from the analysis of the isolated variables, which means that the mathematical evaluation of the two ratios in the formula do not improve the accuracy or the results. Logistic regressions are more adequate when sex distributions are unequal. In this case, the formula obtained does improve the accuracy of the allocations, both for each sex separately and for the whole sample, so it is an important tool for non-adult sex estimation.

CONCLUSIONS

Two ratios (FI/CF and DE/AD) and two morphological traits (the *overall* and the *apex morphology*) of the eleven variables analysed (eight continuous and three qualitative), are suitable for the sex estimation in both age-at-death samples (7-12 and 13-18 years of age). One important conclusion of this paper is that this technique offer tools for sex estimations in individuals who died before the puberty growth spurt. It is suggested that they can be incorporated into the multifactorial approach of recording in order to improve the accuracy of the results obtained together with the other indicators already available (mainly the arch criterion and the angle, the index and the position of the maximum depth of the sciatic notch). However, previous studies have shown that the results obtained in samples not related to those used to generate the procedure may not improve the overall accuracy for the estimation of sex estimation (e.g., Hunt, 1990; Sutter, 2003; Luna and Aranda, 2005; Cardoso and Saunders, 2008; Wilson et al., 2008 for the elevation of the auricular surface, the iliac crest and the arch criterion). In consequence, the most important aspect of this research is the identification and testing of new variables as sex predictors for archaeological and forensic cases. The data obtained show that the auricular surface of non-adult ilia is useful for that task, so this initial approximation should be tested in other documented samples from different geographical origins, with the aim of analysing the biological variability of different human populations and identifying whether the trends observed in this paper are maintained or not and whether the suggested techniques are replicable. This multi-step analytical strategy will clarify if the observed differences can contribute to both the palaeodemographic research and the identification of missing persons in the forensic field. Moreover, the information obtained from the auricular surface has to be furthermore compared with the results from other variables proposed in previous papers (Boucher, 1957; Fazekas and Kòsa, 1978; Hunt, 1990; Mittler and Sheridan, 1992; Schutkowski, 1993; Holcomb and Konigsberg, 1995; Sutter, 2003; Cardoso and Saunders, 2008; Wilson et al. 2008) considering a multifactorial approach, in order to increase the accuracy of the estimation. Finally, this method may also be tested in adult coxae to assist in sex estimation when the pubic symphysis and the greater sciatic notch are not well preserved.

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Tables

Table 1. Age-at-death and sex recorded for the individuals analyzed.

Age range (years)	F				M				Total			
	N	%	Mean	SD	N	%	Mean	SD	N	%	Mean	SD
7-12	14	66.67	9.85	1.75	5	38.46	9.00	1.58	19	55.88	9.63	1.74
13-18	7	33.33	16.71	1.25	8	61.54	16.25	0.88	15	44.12	16.47	1.06
Total	21	100	12.14	3.67	13	100	13.46	3.84	34	100	12.64	3.74

Table 2. Intraobserver and interobserver error results for each variable considered. References: Obs.: Observer; *ICC*: Intraclass Coefficient of Correlation; *κ*: Cohen Kappa Coefficient.

Ratio	Obs 1 *vs*. Obs. 1	Obs. 2 *vs*. Obs. 2	Obs. 1 *vs*. Obs. 2
	ICC		
AC/CI	0.967	0.949	0.901
FI/CF	0.988	0.990	0.991
AB/BC	0.921	0.934	0.956
HI/EH	0.887	0.823	0.859
EF/CF	0.967	0.899	0.903
DE/AD	0.988	0.976	0.982
DE/EH	0.898	0.847	0.899
Variable	*κ*		
Overall morphology	0.878	0.897	0.889
Apex morphology	0.967	0.892	0.909
Inflection	0.878	0.889	0.880

Table 3. Extreme values, standard deviations (SD) and section points (SP) for the ratios considered in this paper, and frequencies of cases correctly assigned -*P* (A|B)- for all the variables. The highest values (≥0.75) are in bold. *Overall morphology*: F (female): inverted L-shaped; M (male): lying V-shaped. *Apex morphology*: F: rounded; M: angular. *Inflection*: M: attenuated or absent; F: clearly defined.

Variable	Sex	Min.	Max.	Mean	SD	All sample	Age groups (years) (n/N)	
						(n/N)	7-12	13-18
AC/CI	F	0.56	1.12	0.77	0.13	0.57 (12/21)	0.57 (8/14)	0.57 (4/7)
	M	0.48	1.04	0.77	0.13	0.23 (3/13)	0.40 (2/5)	0.13 (1/8)
	F + M	0.48	1.12	0.77	0.13	0.44 (15/34)	0.53 (10/19)	0.33 (5/15)
	SP	0.80						
FI/CF	F	0.50	1.52	0.75	0.24	**0.81** (17/21)	**0.79** (11/14)	**0.86** (6/7)
	M	0.91	1.45	1.16	0.18	**0.85** (11/13)	**1** (5/5)	**0.75** (6/8)
	F + M	0.50	1.52	0.91	0.21	**0.82** (28/34)	**0.84** (16/19)	**0.80** (12/15)
	SP	0.99						
AB/BC	F	0.37	1.80	0.90	0.38	**0.81** (17/21)	**0.79** (11/14)	**0.86** (6/7)
	M	0.55	1.40	0.93	0.24	0.23 (3/13)	0.20 (1/5)	0.25 (2/8)
	F + M	0.37	1.80	0.91	0.33	0.59 (20/34)	0.63 (12/19)	0.53 (8/15)
	SP	1.15						
HI/EH	F	0.49	1.69	0.84	0.26	0.33 (7/21)	0.36 (5/14)	0.29 (2/7)
	M	0.46	1.42	0.82	0.22	**0.77** (10/13)	**0.80** (4/5)	**0.75** (6/8)
	F + M	0.46	1.69	0.83	0.23	0.50 (17/34)	0.47 (9/19)	0.53 (8/15)
	SP	0.95						
EF/CF	F	0.45	1.28	0.85	0.25	0.62 (13/21)	0.64 (9/14)	0.57 (4/7)
	M	0.49	1.31	0.87	0.23	0.54 (7/13)	**0.80** (4/5)	0.38 (3/8)
	F + M	0.45	1.31	0.86	0.24	0.59 (20/34)	0.68 (13/19)	0.47 (7/15)
	SP	0.88						
DE/AD	F	0.36	0.80	0.60	0.11	**0.86** (18/21)	**0.86** (12/14)	**0.86** (6/7)
	M	0.73	1.03	0.84	0.10	**0.92** (12/13)	**0.80** (4/5)	**1** (8/8)
	F + M	0.36	1.03	0.69	0.11	**0.88** (30/34)	**0.84** (16/19)	**0.93** (14/15)
	SP	0.76						
DE/EH	F	0.31	1.38	0.71	0.30	0.67 (14/21)	0.64 (9/14)	0.71 (5/7)
	M	0.37	2.00	0.77	0.40	0.31 (4/13)	0.40 (2/5)	0.25 (2/8)
	F + M	0.31	2.00	0.74	0.36	0.53 (18/34)	0.58 (11/19)	0.47 (7/15)
	SP	0.87						
Overall morphology	F					**0.81** (17/21)	**0.79** (11/14)	**0.86** (6/7)
	M					**0.85** (11/13)	**1** (5/5)	**0.75** (6/8)
	F + M					**0.82** (28/34)	**0.84** (16/19)	**0.80** (12/15)
Apex morphology	F					**0.76** (16/21)	**0.78** (11/14)	0.71 (5/7)
	M					**0.77** (10/13)	**0.80** (4/5)	0.75 (6/8)
	F + M					**0.76** (26/34)	**0.79** (15/19)	0.73 (11/15)
Inflection	F					0.43 (9/21)	0.38 (5/14)	0.57 (4/7)
	M					**0.77** (10/13)	**1** (5/5)	0.62 (5/8)
	F + M					0.56 (19/34)	0.53 (10/19)	0.60 (9/15)

Table 4. Probabilities of sexual allocation -*P* (B|A)- for each sex and for the whole sample. Highest values (≥0.75) are in bold. *Overall morphology*: F (female): inverted L-shaped; M (male): lying V-shaped. *Apex morphology*: F: rounded; M: angular. *Inflection*: M: attenuated or absent; F: clearly defined.

Variable	Sex	All sample	7-12 years	13-18 years
AC/CI	F	0.67 (8/12)	0.5 (3/6)	**0.83** (5/6)
	M	0.50 (11/22)	0.43 (3/7)	0.53 (8/15)
	F + M	0.56 (19/34)	0.46 (6/13)	0.62 (13/21)
FI/CF	F	**0.86** (19/22)	**0.90** (9/10)	**0.83** (10/12)
	M	**0.83** (10/12)	**1** (3/3)	**0.78** (7/9)
	F + M	**0.85** (29/34)	**0.92** (12/13)	**0.81** (17/21)
AB/BC	F	0.60 (15/25)	0.67 (6/9)	0.56 (9/16)
	M	0.33 (3/9)	0.25 (1/4)	0.40 (2/5)
	F + M	0.53 (18/34)	0.54 (7/13)	0.52 (11/21)
HI/EH	F	0.60 (3/5)	0.50 (1/2)	0.67 (2/3)
	M	0.38 (11/29)	0.27 (3/11)	0.44 (8/18)
	F + M	0.41 (14/34)	0.31 (4/13)	0.48 (10/21)
EF/CF	F	0.68 (13/19)	**0.89** (7/8)	0.55 (6/11)
	M	0.46 (6/13)	0.60 (3/5)	0.38 (3/8)
	F + M	0.56(19/34)	**0.77** (10/13)	0.47 (9/19)
DE/AD	F	**0.86** (19/22)	**0.89** (8/9)	**0.85** (11/13)
	M	**0.83** (10/12)	**0.75** (3/4)	**0.88** (7/8)
	F + M	**0.85** (29/34)	**0.85** (11/13)	**0.86** (18/21)
DE/EH	F	0.58 (15/26)	0.67 (6/9)	0.53 (9/17)
	M	0.25 (2/8)	0.25 (1/4)	0.25 (1/4)
	F + M	0.50 (17/34)	0.54 (7/13)	0.48 (10/21)
Overall morphology	F	**0.81** (17/21)	**1** (7/7)	0.71 (10/14)
	M	**0.77** (10/13)	0.67 (4/6)	**0.85** (6/7)
	F + M	**0.79** (27/34)	**0.85** (11/13)	**0.76** (16/21)
Apex morphology	F	**0.78** (18/23)	**0.78** (7/9)	**0.79** (11/14)
	M	0.72 (8/11)	0.50 (2/4)	**0.86** (6/7)
	F + M	**0.76** (26/34)	0.69 (9/13)	**0.81** (17/21)
Inflection	F	0.66 (12/18)	**1** (4/4)	0.57 (8/14)
	M	0.50 (8/16)	0.44 (4/9)	0.57 (4/7)
	F + M	0.59 (20/34)	0.62 (8/13)	0.57 (12/21)

Table 5. Probabilities of the ratios DE/AD and FI/CF in 0.1 increments, for each sex (p_m=1-p_f).

	F	M
DE/AD		
<0.70	1	0
0.71-0.80	0.33	0.67
>0.81	0	1
FI/CF		
<0.90	1	0
0.91-1.00	0.50	0.50
1.01-1.10	0.50	0.50
>1.11	0	1

Table 6. Results of the statistical tests applied to continuous variables to evaluate the significance of the observed differences between sexes (Mann Whitney *U* and Kolmogorov Smirnov *Z*), the magnitude of the association between sex and the ratios (eta, η) and the influence of age of death for each variable (Pearson *r*). Statistical significant *p* values are in bold.

Variable	*U*	*p*	*Z*	*p*	η	*R*	*P*
AC/CI	127,00	0,73	0,644	0,80	0,008	-0,023	0,89
FI/CF	11,00	**0,00**	2,263	**0,00**	0,765	0,224	0,20
AB/BC	113,50	0,81	0,913	0,37	0,049	0,148	0,40
HI/EH	127,00	0,73	0,446	0,98	0,045	-0,109	0,53
EF/CF	129,00	0,79	0,446	0,98	0,055	0,029	0,87
DE/AD	9,50	**0,00**	2,564	**0,00**	0,757	0,207	0,24
DE/EH	128,00	0,76	0,695	0,71	0,070	-0,060	0,73

Table 7. Multivariate stepwise discriminant function coefficient and sectioning point. [a]: Parameters used in formulating the discriminant function score equation. M: Males; F: females.

Function variables[a]	Unstandarized Coefficient[a]	Standarized coefficient	Wilk´s Lambda	Structure coefficient	Constant[a]	Group Centroids	Sectioning point[a]	Percentage classified
DE/AD	0.865	0.184	0.980	0.431	-3.470	F = -0.254	0.078	79.41
FI/CF	2.739	0.936	0.903	0.984		M = 0.410		

Table 8. Binary logistic regression data. Degree of freedom: 1. β: Coefficient of regression; S.E.: Standard error; OR: e^{β}; I.C.: Upper and lower intervals of confidence.

Ratio	β	S.E.	Wald	Sig.	OR	I.C. (95%)
FI/CF	-2.320	14.163	0.027	0.870	0.098	0.00 - 1E+011
DE/AD	37.723	27.233	1.919	0.166	2E+016	0.00 - 4E+039
Constant	-25.819	10.403	6.159	0.013	0.000	-

Table 9. Results of the statistical tests applied to the morphological variables to assess its association with sex (Coefficient of Cramer *V*) and age-at-death (eta, η).

Variable	Sex recorded *vs.* obtained results		Age-at-death recorded *vs.* obtained results
	V	*p*	η
Overall morphology	0.802	0.03	0.567
Apex morphology	0.784	0.04	0.435
Inflection	0.042	0.80	0.627

Table 10. Percentages of correct classification obtained by Pizani Palacios (1996) for the *overall morphology* and the *apex morphology* of the auricular surface, by sex.

Variable	Category	Females		Males		% correct assignations
		N	%	N	%	
Overall morphology	Lying V	4	26.7	11	73.3	73.3
	Inverted L	11	73.3	4	26.7	
Apex morphology	Angular	5	33.3	12	80.0	73.3
	Rounded	10	66.7	3	20.0	

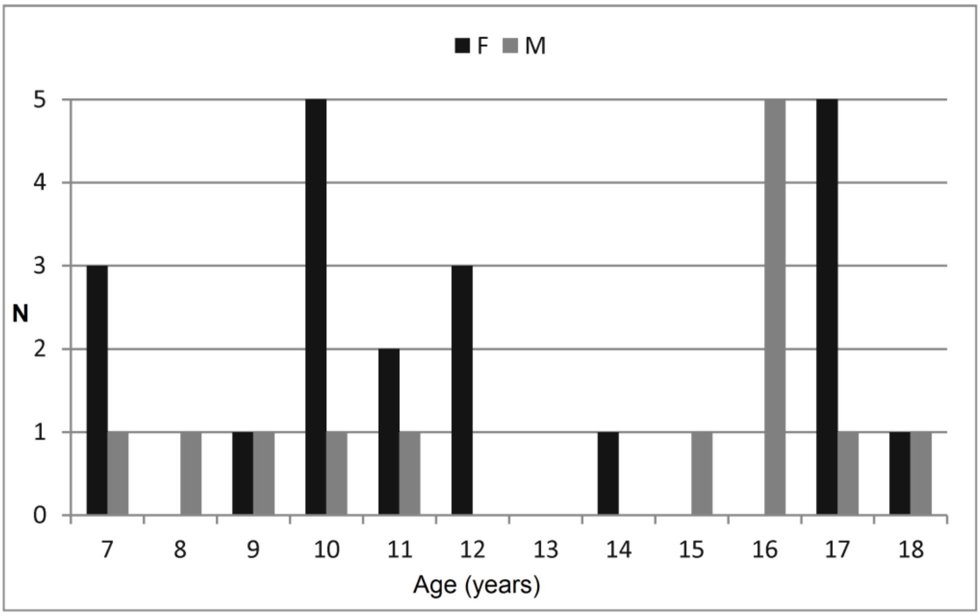

Figure 1. Age distribution of the sample.

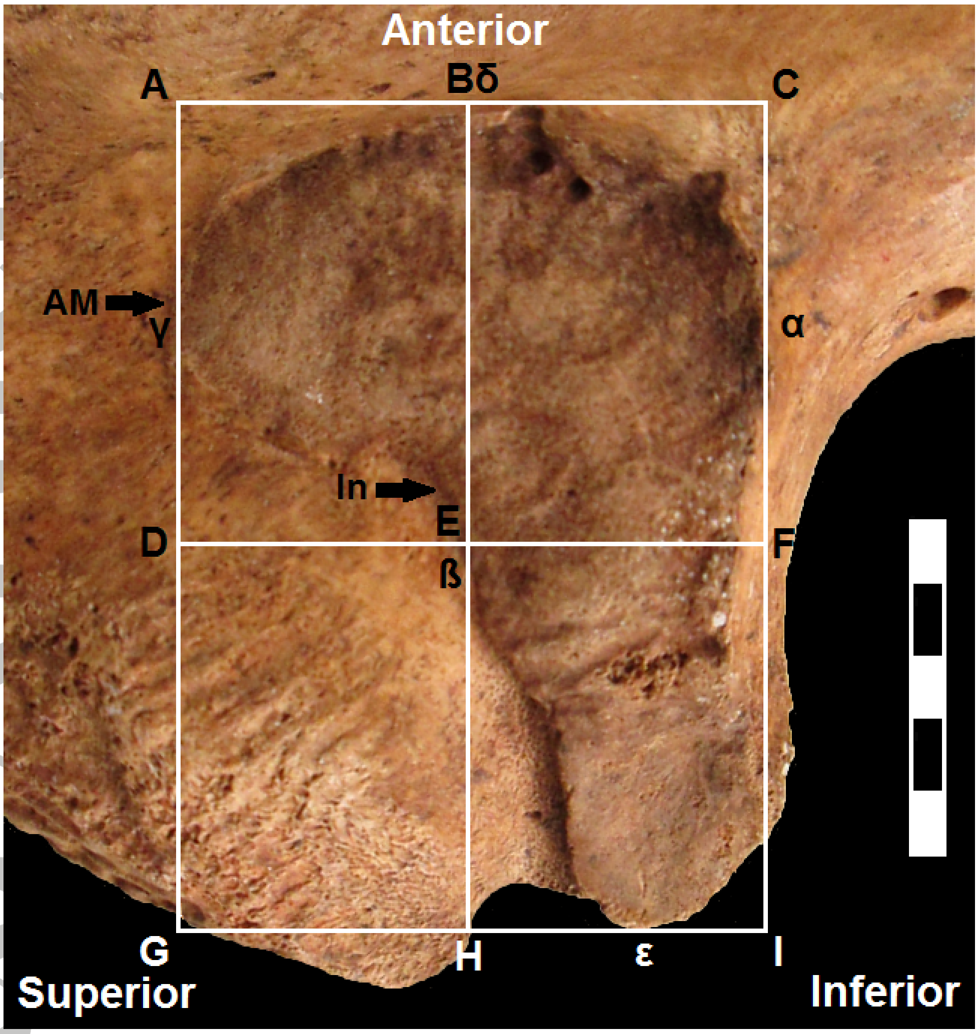

Figure 2. Grid on the auricular surface of the ilium with the location of the points described in the text. AM: location of the *apex morphology*; In: location of the *inflection*.

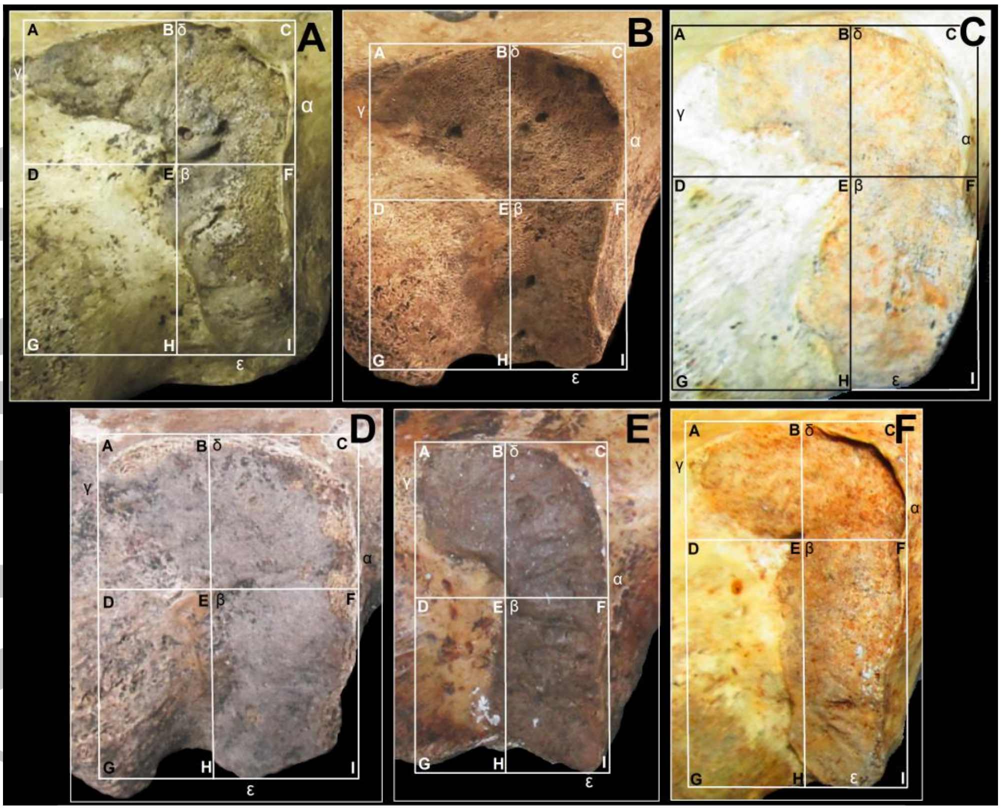

Figure 3. Examples of the variables observed. *Overall morphology*: heart-shaped or with a lying V-shaped (A, B and C) and inverted L-shaped (D, E and F). *Apex morphology*: angular (A, B and C) and rounded (D, E and F). *Inflection*: clearly defined (A, C, E and F) or attenuated (B and D). A: 17 years-old male; B: 16 years-old male; C: 9 years-old male; D: 8 years-old female; E: 11 years-old female; F: 7 years-old female.

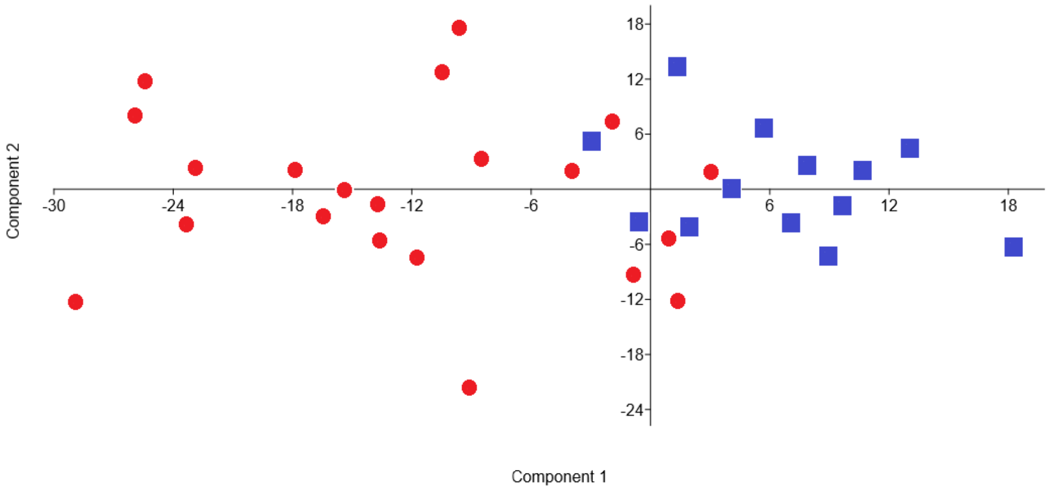

Figure 4. PCA space plots of the dimorphic variables identified (DE, AD, FI and CF). The first component shows the 73.69% of the variability, and the second component, the 24.94%. Females: circles. Males: squares.