The posterior portion of the ilium as a sex indicator: a validation study.

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Declaration of interests: none.

ACKNOWLEDGMENTS

The authors would like to thank Pierrick Negre for taking the photographs of the *os coxae* used in this study and Dr Ralph Thompson for the language editing and proofreading.

Highlights:

- Visual traits of the auricular surface are not adequate sex indicators for Greeks
- Satisfactory performance of the greater sciatic notch in sex estimation
- Sex discriminatory formula for a modern Greek sample was created
- High intra- and inter-observer agreement for all the traits examined

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ABSTRACT

Establishing a biological profile of skeletal remains is a key task of forensic anthropologists. Sex estimation is essential in forensic examination, as other elements of the biological profile, such as age at death or stature, are sex dependent. Visual assessment is considered low-cost and quick, therefore it is a commonly applied method of sex estimation. The most reliable results can be obtained with the analysis of the anterior part of the pelvis, however, these skeletal elements are fragile and prone to destruction. In contrary, the more robust posterior portion of the pelvis is often recovered. Several features of the posterior pelvis have been explored in the context of sexual dimorphism. The aim of the present study was to test three previously published methods of sex assessment based on the analysis of the inferior shape of the auricular surface [Novotnỳ, 1975], the greater sciatic notch shape [Walker, 2005 (revised)] and overall morphology, apex morphology and inflection of the auricular surface [Luna et al., 2017].

The sample consisted of 194 individuals of Greek origin from a documented modern collection. Four features of the auricular surface and shape of the greater sciatic notch were examined. Logistic regression analysis was applied to produce a sex discriminatory formula.

The method proposed by Luna et al. [2017] failed to produce satisfactory results with overall accuracies of 36%, 50% and 53% for overall morphology, apex morphology and inflection respectively. Slightly better results (64%) were obtained with the inferior shape morphology [Novotnỳ, 1975]. However, the highest accuracy rate of 81% was noted for the greater sciatic notch shape [Walker, 2005 (revised)]. The formula produced in this study allowed correct classification of 83.2% of the sample.

This study illustrates that in spite of the presence of sexual dimorphism in the posterior portion of ilium, features of the auricular surface proposed as sex indicators by Novotnỳ [1975] and Luna et al. [2017] should not be used for sex estimation purposes in the Greek population. The formula produced in this study and the greater sciatic notch shape should only be used as additional methods in cases where neither the cranium nor the anterior portion of the pelvis is present.

Key words: Forensic Anthropology Population Data, Pelvic Morphology, Ilium, Sexual Dimorphism, Greeks

INTRODUCTION

In both forensic and archeological contexts, sex assessment represents the first step in building the biological profile of unknown skeletal remains. In addition, age and stature estimation are also highly sex-dependent features. Sexual dimorphism in adult human remains consists of differences in size, shape and proportion of certain features and body parts [1-2]. Different approaches have been developed for sex assessment and any methodological choice is driven by reliability and applicability of each procedure according to the degree of completeness and preservation of the remains. In terms of reliability, the legal environment requires a higher degree of accuracy in sex estimation compared to archaeological settings, that is 95% and 85% respectively. In addition, each method must be appropriate for the population under examination [2]. As a consequence, there is still great need in testing existing procedures on different reference populations. The application of genetics to forensic anthropology has shown the potential of DNA analysis as an accurate tool for establishing sex of skeletal remains [3-5]. This method, however, is time consuming, expensive and includes destruction of the skeletal material through the sampling process [6]. Metric analysis has also been widely employed in biological profiling. While this technique is relatively quick and inexpensive, it is also highly population specific. This introduces significant limitations to the applicability of the metric methods and requires developing population-specific standards [7-15]. The most traditional approach to sex assessment relies on visual evaluation of specific morphological traits of various skeletal elements [16-19]. In the present study, morphological features of the posterior ilium will be evaluated in the context of sexual dimorphism.

The potential of the pelvis in sex assessment has long been recognized [2, 20-21]. Despite the high reliability of metric [22-23] and non-metric [17, 24] methods that use the anterior part of pelvis, these skeletal elements do not always survive harsh taphonomic conditions due to their fragility [25]. Walker [26] states that only 10-20% of archaeological remains include well preserved pubic bones. In contrast, the posterior portion of ilium is more often recovered [26], possibly due to robustness of the iliac pillar which supports the ilium against the great forces generated by the hip abductors [27].

In the erect position, approximately half of the individual’s body weight is sustained by the sacro-iliac joint [28-29]. It is reasonable to assume that sexual differences in general body mass and pelvic shape in humans could lead to sexual dimorphism of the auricular surface. Several authors have previously attempted to explore the sexual dimorphism of the sacro-iliac joint by studying various features, such as: the general size [27, 30-31], the elevation of the surface [32-36], the angle between two arms of the surface [27, 31, 35, 37-38] and their dimensions [27, 31, 35, 39]. Several other traits in close proximity to the sacro-iliac joint, have also been previously studied to understand the potential for sex assessment. Those include: the composite arch [20, 37], the preauricular sulcus [20, 36, 38] and the greater sciatic notch (GSN), for which potential for sex estimation has been broadly studied in anthropological examinations of both adult [20, 40-47] and juvenile individuals [48-51].

While limitations to the visual methods (such as: the high level of subjectivity and the absence of consistency in scoring of traits) are often mentioned in literature, they can be advantageous compared to the metric methods in cases when the examined bones are fragmentary and complete measurements cannot be taken. A solution to the problem of high level observer subjectivity was proposed by Brůžek [20]. He suggested a binary scoring system along with an intermediate category, instead of descriptive or ordinal evaluation of the morphological traits [20]. Both metric and non-metric methods, however, are limited by the reference sample which was primarily used in the process of developing the method [41, 52], as the expression of sexual dimorphism in human skeleton is population-specific [11-12, 20].

While these differences substantially affect the morphometrics of the dimorphic traits, they bare restricted influence on the morphology, due to functional constraints [53]. Inter-population differences, however, must be taken into account when developing standards for sex estimation and when applying existing methods.

The aim of the present study is: to assess the reliability of several visual techniques previously presented in literature and to evaluate the utility of the posterior portion of ilium for sex estimation purposes in a sample comprised of 194 individuals of Greek origin, of known sex. The methods of sex estimation proposed by Novotnỳ [18] and Luna et al. [55] were carried out according to guidelines reported in the original papers. Walker's method [26] was, however, revised in the present study (see: material & methods), and testing of the revised method was performed.

MATERIAL & METHODS

For the purpose of this study, *os coxa* of 194 individuals (106 males and 88 females), from a documented modern collection housed in the the Department of Forensic Sciences at the University of Crete, were examined [11, 54]. The sample consisted of mostly elderly individuals (mean age = 70.1) with the mean age of 71.8 for females and 68.7 for males.

Four morphological variables of the auricular surface were considered: *overall morphology*, *apex morphology*, *inflection* [55] and *shape of the inferior portion* of the joint surface [18]. The features described as *overall morphology* and *apex morphology* were first defined by Pizani Palacios in his unpublished study on sexual dimorphism of ilium in 102 subadult individuals [55]. According to the author, V-shaped joint surface with slightly obtuse angle between the anterior and inferior edges of similar length is characteristic for male individuals (Fig 1A), while in females the auricular surface appears to have a more L-shaped outline, with the inferior margin evidently longer (Fig. 1B). Moreover, the angle formed between the two parts of the joint is approximately 90 degrees. In turn, the apex is more angular in males (Fig. 1A) and rounded in females (Fig.1B). The *inflection* is defined as an indentation in the posterior margin of the anterior part of the auricular surface (Fig. 1B). Luna et al. [55] proposed that female individuals exhibit an easily distinguishable inflection, while the feature is absent in males. In 1975, Novotný [18] examined 10 different features of the human pelvis in the context of sexual dimorphism and observed that the inferior portion of the auricular surface was curved in females (Fig. 1B) and straight in males (Fig. 1A). In addition, general *shape of the greater sciatic notch* was evaluated based on the scoring scale previously published by Walker [26]. In order to simplify the method and possibly reduce the rate of misclassification, the variable was categorized using a binary scoring system (Fig. 2): wide (corresponding to scores 1 and 2) or narrow (4,5) followed by the intermediate category (3).

All five variables were taken into account and separately scored in the visual assessment of the photographs of ilium bones in the present study. As the method's reproducibility is imperative, intra-observer and inter-observer errors were evaluated by repetition of the scoring of each variable for 20 randomly chosen bones without considering sex, age or preservation of the specimens [56]. Each set of observations was carried out at least one week apart without prior knowledge of the documented sex of each individual.

Cohen’s Kappa coefficient was employed to assess observer bias between the two observers, both postgraduate research students with similar level of experience. The discriminatory capacity of each trait was established by comparing sex assignments to previously documented data. Due to the high average age of the sample, age effect on the examined features was not tested. Finally, logistic regression was employed to produce a formula using the visual traits from Luna et al. [55], plus the additional features of the sciatic notch and the angle of the auricular surface. The score for male traits was set as 0 and female at 1. All statistical procedures were computed in SPSS 18 (SPSS Inc., Chicago, IL).

Fig. 1. A – V-shaped auricular surface with an angular apex and straight inferior portion; B – L-shaped auricular surface with a rounded apex, curved inferior portion, and a clear inflection. (AM – *apex morphology*; In – *inflection*)

Fig 2. Shape of the greater sciatic notch. Left – narrow (male trait); Right – wide (female trait).

RESULTS

Inter- and Intra-Observer error

When analyzing each variable between different observers (Table 1.), the most satisfactory results were given by *apex morphology*, with a Cohen’s Kappa coefficient of 0.900 (SD ± 0.097, p = 0.000), followed by shape of the GSN (Kappa = 0.894, SD ± 0.103, p = 0.000), *inferior shape* (Kappa = 0.794, SD ± 0.135, p = 0.000) and *overall morphology* 0.783 (SD ± 0.142, p = 0.000). The lowest inter-observer agreement was noted for *inflection* (Kappa = 0.571, SD ±0.219, p = 0.010). Repeatability of the scoring (intra-observer reliability) noted in this study was also high (Table 2.). Two of the examined features (*shape of the sciatic notch* and *apex morphology*) were assigned the same score for all 20 individuals, providing a perfect agreement between the first and second round of observations (Kappa = 1, p<0.000). Only one individual was allocated in a different category for both *overall morphology* and *inferior shape* (Kappa = 0.875, SD ± 0.121, p = 0.000 and Kappa = 0.894, SD ± 0.103, p = 0.000 respectively). The lowest level of agreement was observed for the *inflection*, with the Cohen’s Kappa index of 0.634 (SD ± 0.181, p = 0.002).

Table 1. Inter-observer error.

Traits	Kappa coefficient	SD	Sig.
Overall morphology	0.783	0.142	p = 0.000
Apex morphology	0.900	0.097	p = 0.000
Inflection	0.571	0.219	p = 0.010

Greater Sciatic Notch	0.894	0.103	p = 0.000
Inferior shape	0.794	0.135	p = 0.000

Table 2. Intra-observer error.

Traits	Kappa coefficient	SD	Sig.
Overall morphology	0.875	0.121	p = 0.000
Apex morphology	1.000	-	p < 0.000
Inflection	0.634	0.181	p = 0.002
Greater Sciatic Notch	1	-	p < 0.000
Inferior shape	0.894	0.103	p = 0.000

Validation of existing methods for the Greek sample

Results showed a noticeable lower accuracy for each feature compared to Luna et al. [55] (Table 3.), with the highest overall correct assignment score of 53% for inflection, with correct assignment of 71% and 31% respectively for male and females. Similarly, overall morphology correctly assigned 36% of the cases and 44% for males and 22% for females. Apex morphology also provided a low accuracy rate (50%). In this case however, females were classified correctly slightly more often (51%) compared to males (48%). Overall the results indicate that correct assignment was assigned by random chance. Shape of the greater sciatic notch generated the most accurate sex determination rates of 88.24% and 74.73% for males and females respectively. Evaluating shape of the inferior portion of the auricular surface did not provide a satisfactory level of accuracy, correctly classifying over 60% of the sample (80.4% of males and 44.9% of females) (Table 4.).

Table 3. Accuracy rates in % for *overall morphology*, *apex morphology* and *inflection*.

Sample		Overall Morphology	Apex Morphology	Inflection
Luna et al. (2017) [55]	Male	77%	72%	50%
	Female	81%	78%	66%
	Overall	79%	76%	59%
	Bias	*4%*	*6%*	*16%*
Present Study	Male	44%	48%	71%

	Female	22%	51%	31%
	Overall	36%	50%	53%
	Bias	*22%*	*3%*	*40%*

Table 4. Accuracy rates in % for *inferior shape* and *shape of the greater sciatic notch.*

Trait		**Accuracy rate [%]**
Inferior shape	Male	80.2
	Female	44.9
	Overall	64.7
	Bias	*35.3*
Greater sciatic notch	Male	88.24
	Female	74.73
	Overall	81.87
	Bias	*13.51*

<u>Logistic regression analysis</u>

Logistic regression was applied to the entire pool of features in order to produce sex predictive formulae. The first involved overall morphology, sciatic notch and inferior shape as shown in Table 5. It produced an overall correct assessment of 83.1%, with 88.6% for males and 76.1% for females respectively.

After considering inter-observer error, degree of correct assessment for each feature and the possibility of observation in the photographs, we decided to only include sciatic notch shape and overall morphology as the best combination of variables. The formula (Table 6.) revealed that for more than 50% of the sample the sex was correctly assessed with 96% confidence and an overall percentage of individuals correctly assigned of 83.2% (male = 88.6%, female = 76.9%). For both formulae, the demarking point was set at 0.5, meaning that with x<0.5 the individual was assigned as male and x>0.5 the individual was assigned as female.

Table 5. Logistic regression model for all variables.

Variables	**ß**	**S.E.**	**Wald**	**Sig.**	**Exp(ß)**
Overall Morphology	2.02	0.494	16.734	0.000	7.539
Greater Sciatic Notch	-3.533	0.487	52.704	0.029	0.027

Inferior Shape	-0.765	0.435	3.099	0.078	0.465
Constant	*1.183*	*0.484*	*5.973*	*0.015*	*3.265*

Table 6. Logistic regression parameters for the selected variables.

Variables	**ß**	**S.E.**	**Wald**	**Sig.**	**Exp(ß)**
Overall Morphology	2.08	0.491	17.981	0.000	8.007
Greater Sciatic Notch	-3.616	0.484	55.904	0.000	0.027
Constant	*0.688*	*0.377*	*3.342*	*0.068*	*1.991*

DISCUSSION

The visual technique previously presented by Luna et al. [55] applied to the Greek sample produced unsatisfactory results in the present study. The highest percentage of correctly classified individuals (52.57%) was obtained by scoring the *inflection,* which proved slightly better than chance at correctly discriminating sex of the examined individuals. Discrepancy between the accuracies observed in this paper and the original study could possibly be a result of morphological differences between populations. Inter-population differences in sexual dimorphism levels of pelvic traits were observed in several previous studies [26, 41, 44, 57-59]. A recent study [39] confirmed the existence of differences in shape of the auricular surface between populations (English, French and Portuguese), although the levels of sexual dimorphism did not vary. Similar findings were noted by Listi et al. [60] in their study exploring the influence of inter-population metric variation in human pelvis on sex estimation based on the analysis of *os coxae*. This issue remains a matter of debate. Additionally, the surface of the sacro-iliac joint is highly variable on an individual level [61-62]. It is imperative to mention that the sample of the previous study [55] comprised of 34 subadult individuals between the age of 7 and 18. Majority of the individuals examined in the present study were elderly (mean age: 70.1 years of age). It has been shown that significant changes with age occur in the morphology of the auricular surface of the ilium which include increasing porosity, fading of the transverse ridges and granularity of the joint surface, densification of the joint surface and lipping of the joint margins [62-65]. Thus, age distribution of the sample could have possibly influenced the results. Reduced classification accuracies could also be a product of unfamiliarity of the authors with the new method, which would lead to different interpretation of the examined features. Yet the observer agreement was good in consistency with other morphological studies [34, 36, 55].

Assessment of the inferior portion of the joint surface produced slightly better results, correctly classifying 64.7% of the sample. While over 80% of males were assigned to the right category, only 44.9% of females were correctly identified as such. It was suggested by Meindl et al. [66], that functional constraints applied to the female pelvis lead to reduced variability and, therefore, should result in decreased rates of misclassification [67]. This statement, however, has not been statistically confirmed [68]. In the present study, the predicted bias towards female individuals held true only for the *apex morphology*, and the accuracies noted differed only by 3% between the sexes. Overall, the rates of correct classification were higher for males, which is in contrast to results produced in the preceding study by Luna et al. [55]. Unequal sex distribution in the original sample (21 females and 13 males), however, could be the reason behind the discrepancies.

Traits reflecting shape of the auricular surface examined in this study (*overall morphology*, *apex morphology*, *infection* and *shape of the inferior portion* of the joint surface) proved to be poor sex discriminators in the sample comprising of Greek individuals. Size of the sacro-iliac joint was not a subject in this study, however, statistically significant differences concerning the auricular surface dimensions were noted by several authors [27, 30-31, 34-35, 39, 69]. Future work should focus on establishing a metric method with clearly identifiable landmarks in order to explore the dimensions of auricular surface in the context of sexual dimorphism. It is also imperative to empirically test the method for different populations and determine appropriate standards for each population.

Shape of the greater sciatic notch (GSN) produced the highest accuracy rates of over 80% for the pooled sample and 88.24% and 74.73% for males and females respectively. Similar results were obtained by Novak et al. [35] for their sample comprised of specimens from Robert J. Terry and William M. Bass Collections, and by Schutkowski [49] for his juvenile sample. Metric analysis of the GSN by MacLauglin and Bruce [41] gave comparable accuracy of 79.5% for the English subsample and a slightly lower accuracy (76.5%) for the Portuguese subsample. The results of several previous studies were not as satisfactory (Table 1.) [20, 38, 47]. A narrow and deep notch with a small angle is considered to be typical for males, while a wide and shallow notch with an obtuse angle is commonly assigned to females [70]. Bilfeld et al. [71], however, found the female notch to be deeper than the male notch. The discrepancies are probably a result of a different measuring technique. The relatively high degree of sexual dimorphism of the GSN noted in this study was expected. Inter-sexual differences observed in this area of the pelvis are present already in the fetal period and are attributed to adaptation for childbearing in women [50]. Human neonates are very large relative to the body size of the mother, thus the typical female GSN shape ensures the backward position of sacrum and increases dimensions of the birth canal [43]. Already in 1954, Genovés demonstrated the significance of relative ratio of GSN chords, rather than depth, breadth or angle measurements for sex estimation purposes [72]. In his study on Australian Aboriginal pelvises, Davivongs [40], described a typical male sciatic notch as J-shaped, while the female one as parabolic in shape. Later publications confirmed that major differences of the GSN shape are related to the length and shape of the posterior chord [20, 26, 47], which is shorter in relation to the anterior chord in males, decreasing the distance between acetabulum and sacro-iliac joint, favoring bipedal locomotion. On the other hand, functional constraints placed on female pelvis result in a longer posterior chord [43].

Repeatability of the scoring of all five features proved to be excellent. Reproducibility was also very high with the exception of *inflection* for which the agreement was moderate. Visual assessment of some features reflecting shape of the auricular surface is difficult. Irregular edges of the joint surface could be erroneously identified as presence of an inflection, and this can be a possible reason behind the discrepancies in scoring. Metric methods are generally thought to be more objective and better applicable, especially in instances when only fragments of the *os coxae* are present [73]. In 2005, Murail and collegues

[74] proposed a new sex estimation method (Diagnose Sexuelle Probabiliste – DSP) based on 10 metric variables of the pelvis. Both repeatability and reproducibility of the method were confirmed in several following studies [73, 75-77]. Moreover, in a previous study on the sex dimorphism of posterior pelvis only, Rmoutilová et al. [39] found metric methods more reliable than morphological assessment due to the large intra-observer error noted for the visual evaluation of the auricular surface. Rogers and Saunders [34] evaluated sex discriminatory potential of 17 traits of the human pelvis. Two out of three features with unacceptably high intra-observer error (over 10%) concerned the area of auricular surface: surface height and preauricular sulcus. The GSN shape is also commonly regarded as difficult to score due to influences placed on its shape by the general pelvis size and presence of the adjacent bony structures, such as the piriform tubercle [20]. Qualitative variables might lead to increased subjectivity in the scoring process and eventually result in a high level of disagreement between the observers. Lastly, photographs used in this study could play an important role, as the pictures did not show the whole bone, and the angle from which the photographs were taken varied.

Considering the overall accuracies and errors produced by each examined feature, two traits, *overall morphology* (OM) and *greater sciatic notch* (GSN), were chosen to create a sex discriminatory formula with the use of logistic regression:

$$[OM \times 2.08 + GSN \times (- 3.616)] - 0.688$$

The formula, however, did not significantly increase the percentage of correctly classified individuals (83.2% for the overall sample) compared to 81.9% achieved by scoring a single trait (GSN). It is possibly a result of primary low discriminatory potential of the *overall morphology*. Yet, these results should be verified using a larger sample with better balanced age groups to account of any bias introduced by the high mean age of the current sample.

CONCLUSION

Luna's et al. [55] method, proved to be ineffective in the sample of Greek origin. Shape of the inferior arm of the sacro-iliac joint previously investigated by Novotný [18] generated slightly better results. Our findings suggest that traits reflecting shape of the auricular surface (*overall morphology*, *apex morphology*, *inflection*, and *shape of the inferior portion*) are not suitable for sex estimation of Greek individuals.

As suspected, evaluation of the sciatic notch shape generated relatively high accuracy rate of 81.87%. *Shape of the greater sciatic notch* and *overall morphology* were used to produce a sex-discriminatory formula. The formula, however, increased the percentage of individuals with correctly assigned sex only by 1.33%. While, it could be an accessible tool for archaeological studies in cases when the anterior pelvis and skull are not available, the regression formula is not reliable enough for forensic cases.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

[1] Piontek J., 1996, *Biologia populacji pradziejowych. Skrypt dla studentów biologii i archeologii.* Rozdział IV: Określanie płci na podstawie cech morfologicznych kośćca, p.132-136. Wydawnictwo Naukowe Uniwersytetu Im. Adama Mickiewicza w Poznaniu, Poznań.

[2] Scheuer L.. *Application of osteology to forensic medicine*, 2002. Clinical Anatomy 15:297-312.

[3] Stone A. C., Milner G. R., Pääbo S., Stoneking M.. *Sex determination of ancient human skeletons using DNA*, 1996. American Journal of Physical Anthropology 99:231-238.

[4] Luptáková L., Bábelová A., Omelka R., Olena B., Vondráková M., Bauerová M.. *Sex determination of early medieval individuals through nested PCR using a new primer set in the SRY gene*, 2011. Forensic Science International 207:1-5.

[5] Ălvarez-Sandoval B., Manzanilla L. R., Montiel R.. *Sex determination in highly fragmented human DNA by high-resolution melting (HRM) analysis*, 2014. PLOS ONE 9(8):e104629.

[6] Roberts C., Ingham S.. *Using ancient DNA analysis in Palaeopathology: A critical analysis of published papers, with recommendations for future work*, 2008. International Journal of Osteoarchaeology 18:600-613.

[7] Schultz A. H.. *Sex differences in the pelvis of primates*, 1949. American Journal of Physical Anthropology 7:401-424.

[8] Giles E., Eliot O.. *Sex discrimination by discriminant function analysis of crania*, 1963. American Journal of Physical Anthropology 21:53-68.

[9] Giles E.. *Sex discrimination by discriminant function analysis of mandible*, 1964. American Journal of Physical Anthropology 22:129-135.

[10] Purkait R.. *Tringle identified at the proximal end of femur: a new sex determinant*, 2005. Forensic Science International 147:135-139.

[11] Kranioti E. F., Michalodimitrakis M.. *Sexual dimorphism of the humerus in contemporary Cretans: A Population-Specific Study and a Review of the Literature*, 2009. Journal of Forensic Science 54(5): 996-1000.

[12] Kranioti E. F., Apostol M. A.. *Sexual dimorphism of the tibia in contemporary Greeks, Italians, and Spanish: forensic implications*, 2015. International Journal of Legal Medicine 129:357-363.

[13] Nathena D., Gambaro L.,Tzanakis N., Michalodimitrakis M., Kranioti E. F.. *Sexual dimorphism of the metacarpals in contemporary Cretans: Are there differences with mainland Greeks?*, 2015. Forensic Science International 257:515e1-515e8.

[14] Nathena D., Michopoulou E., Kranioti E. F.. *Sexual dimorphism of the calcaneus in contemporary Cretans*, 2017. Forensic Science Inernational 277:260.e1-260.e8.

[15] Soltani S., Aghakhani K., Fallah F.. *Sex prediction potential of hyoid metric measurements in Iranian adults*, 2017. Legal Medicine 25:6-10.

[16] Comas J., 1960, *Manual of Physical Anthropology*. Chapter VII: Craniology. Osteology., p. 433-438. Thomas Publisher, Springfield , Illinois.

[17] Phenice T. W.. *A newly developed visual methods of sexing the os pubis*, 1969. American Journal of Physical Anthropology 30:297-301.

[18] Novotný V.. *Diskriminanzanalyse der Geschlechtsmerkmale auf dem Os coxae beim Menschen*, 1975. XIII Czechoslovakian Anthropological Congress, Brno.

[19] Vance V. L., Steyn M., L'Abbé E. N.. *Nonmetric sex determination from the distal and posterior humerus n black and white South Africans*, 2011. Journal of Forensic Scinces 56(3):710-714.

[20] Brůžek J.. *A method for visual determination of sex, using the human hip bone*, 2002. American Journal of Physical Anthropology 117:157-168.

[21] Iscan M. Y., Steyn M., 2013, *The human skeleton in forensic medicine*. *Third Edition.* Chapter IV: Sex, p. 146-153. Charles C Thomas Publisher LTD, Springfield.

[23] Blake K. A. S., Hartnett-McCann K.. *Metric assessment of the pubic bone using known and novel data points for sex estimation*, 2018. Journal of Forensic Sciences, doi: 10.1111/1556-4029.13732.

[22] Luo Y.C.. *Sex determination from the pubis by discriminant function analysis*, 1995. Forensic Science International 74:89-98.

[24] Klales A. R., Ousley S. D., Vollner J. M.. *A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods*, 2012. American Journal of Physical Anthropology 149:104-114.

[25] Mays S., 2002, *The Archaeology of Human Bones.* Chapter III: Determination of sex, p. 33. Routledge, New York.

[26] Walker P. L.. *Greater sciatic notch morphology: Sex, age, and population differences*, 2005. American Journal of Physical Anthropology 127:385-391.

[27] Ali R. S., MacLaughlin S.M.. *Sex identification from the auricular surface of the adult human ilium,* 1991. International Journal of Osteoarchaeology, 1:57-61.

[28] Solonen K.A.. *The sacro-iliac joint in the light of anatomica, roentgenological and clinical studies*, 1957. Arta Orthopedia Scandinavia 27:1-127.

[29] Krmek N., Jo-Osvatić A., Nikolić T., Krmek V., Šalamon A.. *Anthropological measurement of the sacroiliac joint*, 2006. Collegium Antropologicum 30(4):811-814.

[30] Ohba S.. *Morphological study of the sacroiliac joint of the aged Japanese and macroscopic and microscopic observations of its articular surface*, 1985. Journal of Orthopaedic Science 59:13-27.

[31] Valojerdy M. R., Hogg D. A.. *Sex differences in the morphology of the auricular surfaces of the human sacroiliac joint*, 1989. Clinical Anatomy 2:63-67.

[32] Hunt D. R.. *Sex determination in the subadult ilia: an indirect test of Weaver's nonmetric sexing method*, 1990. Journal of Forensic Sciences 35(4):881-885.

[33] Mittler D. M., Sheridan S. G.. *Sex determination in subadults using auricular surface morphology: a forensic science perspective,* 1992. Journal of Forensic Sciences 37(4):1068-1075.

[34] Rogers T., Saunders S.. *Accuracy of sex determination using morphological traits of the human pelvis*, 1994. Journal of Forensic Sciences 39(4):1047-1056.

[35] Novak L., Schultz J. J., McIntyre M.. *Determining sex of the posterior ilium from the Robert J. Terry and William M. Bass Collections*, 2012. Journal of Forensic Sciences 57(5):1155-1160.

[36] Wescott D. J.. *Sexual dimorphism in auricular surface projection and postauricular sulcus morphology*, 2015. Journal of Forensic Sciences 60(3), doi: 10.1111/1556-4029.12737.

[37] Genovés S.. *L'estimation des diffe´rences sexuelles dans l'os coxal; diffe´rences me´triques et diffe´rences morphologiques*, 1959. Bulletins Et Memoires De La Societe D'Anthropologie De Paris 10:3–95.

[38] Novotný V. *Pohlavní rozdíly a identifikace pohlavá pínevní kosti* [*Sex differences and identification of sex in pelvic bone*], 1981. Ph.D. thesis, Purkyně University, Brno.

[39] Rmoutilová R., Dupej J., Velemínská J., Brůžek J.. *Geometric morphometric and traditional methofd for sex assessment using the posteriori ilium*, 2017. Legal Medicine 26:52-61.

[40] Davivongs V.. *The pelvic girdle of the Australian Aborigine; sex differences and sex determination*, 1963. The American Journal of Physical Anthropology 21(4):443-455.

[41] MacLaughlin S. M., Bruce M. F.. *The sciatic notch/acetabular index as a discriminator of sex in European skeletal remains*, 1986. Journal of Forensic Sciences 31(4):1380-1390.

[42] Novotný V., Vancata V. E., Pesce-Delfino V.. *Sexual differentiated form of "incisura isquiadica major": Metric versus shape analysis*, 1992. In: VIIIth Congress of the European Anthropological Association, Madrid.

[43] Hager L. D.. *Sex difference in the sciatic notch of great apes and modern humans*, 1996. American Journal of Physical Anthropology 99:287-300.

[44] Steyn M., Pretorius E., Hutten L.. *Geometric morphometric analysis of the greater sciatic notch in South Africans*, 2004. Homo 54:197-206.

[45] Bytheway J., Ross A. H.. *A geometric morphometric approach to sex determination of the human adult os coxa*, 2010. Journal of Forensic Sciences 55(4):859-864.

[46] Biwasaka H., Aki Y., Sato K., Tanijiri T., Fujita S., Dewa K., Yoshioka K., Tomabechi M.. *Analyses of sexual dimorphism of reconstructed pelvic computed tomography images of contemporary Japanese using curvature of the greater sciatic notch, pubic arch and greater pelvi*s, 2012. Forensic Science International 219:288.e1-288.e8.

[47] Gómez-Valdés J. A., Quinto-Sánchez M., Menéndez G. A., Veleminska J., Sánchez-Mejorada G., Brůžek J.. *Comparison of methods to determine sex by evaluating the greater sciatic notch: Visual, angular and geometric morphometrics*, 2012. Forensic Science International 221(1-3):156.e1-156.e7.

[48] Weaver D. S.. *Sex differences in the ilia of a known sex and age sample of fetal and infant skeletons*, 1980. American Journal of Physical Anthropology 52:191-195.

[49] Schutkowski H.. *Sex determination of infant and juvenile skeletons: I. Morphognostic features*, 1993. American Journal of Physical Anthropology 90:199-205.

[50] Holcomb S. M. C., Konigsberg L. W.. *Statistical study of sexual dimorphism in the human fetal sciatic notch*, 1995. American Journal of Physical Anthropology 97:113-125.

[51] Wilson L. A., MacLeod N., Humphrey L. T.. *Morphometric criteria for sexing juvenile human skeletons using the ilium*, 2008. Journal of Forensic Sciences 53(2), doi: 10.1111/j.1556-4029.2008.00656.x.

[52] Albanese J.. *A metric method for sex determination using the hipbone and the femur*, 2003. Journal of Forensic Sciences 48:1-11.

[53] González P. N., Bernal V., Perez S. I., Barrientos G.. *Analysis of dimorphic structures of the human pelvis: its implications for sex estimation in samples without reference collections*, 2007. Journal of Archaeological Science 34:1720-1730.

[54] Kranioti E. F., İşcan M. Y., Michalodimitrakis M.. *Craniometric analysis of the modern Cretans*, 2008. International Journal of Forensic Science 180(2-3): 110.e1-5.

[55] Luna L. C., Aranda C. M., Santos A. L.. *New method for sex prediction using the human non-adult auricular surface of the ilium in the collection of identifies skeletons of the University of Coimbra*, 2017. International Journal of Osteoarchaeology, 10.1002/oa.2604.

[56] Bujang M. A., Baharum N.. *Guidelines of the minimum sample size requirements for Cohen's Kappa*, 2017. Epidemiology Biostatistics and Public Health 14(2):e12267-1-e12267-10.

[57] Letterman G. S.. *The greater sciatic notch in American whites and Negroes*, 1941. American Journal of Physical Anthropology 28:99-116.

[58] Işcan M. Y.. *Assessment of race from the pelvis*, 1983. American Journal of Physical Anthropology 62:205-208.

[59] Patriquin M. L., Loth S. R., Sten M.. *Sexually dimorphic pelvic morphology in South African whites and blacks*, 2003. Homo 53:255-262.

[60] Vleeming A., Schuenke M. D., Masi A. T., Carreiro J. E., Danneels L., Willard F. H.. *The sacroiliac joint: an overview of its anatomy, function and potential clinical implications*, 2012. Journal of Anatomy 221:537-567.

[61] Listi G. A.. *The impact of racial metric variation in the os coxae on the morphological assessment of sex,* 2010. Journal of Forensic Sciences 55(5), doi: 0.1111/j.1556-4029.2010.01428.x.

[62] Lovejoy C. O., Meindl R. S., Pryzbeck T. R., Mensforth R. P.. *Chronological metamorphosis of the auricular surface of the ilium: A new method for the determination of adult skeletal age at death*, 1985. American Journal of Physical Anthropology 68(1):15-28.

[63] Buckberry J. L., Chamberlain A. T.. *Age estimation from the auricular surface of the ilium: a revised method*, 2002. American Journal of Physical Anthropology 119(3):231-239.

[64] Igarashi Y., Uesu K., Wakebe T., Kanazawa E.. *New method for estimation of adult skeletal age at death from the morphology of the auricular surface of the ilium*, 2005. American Journal of Physical Anthropology 128:324-339.

[65] Milner G. R., Boldsen J. L.. *Transition analysis: a validation study with known-age modern American skeletons*, 2012. American Journal of Physical Anthropology 148(1):98-110.

[66] Meindl R. S., Lovejoy C. O., Mensforth R. S., Don Carlos L.. *Accuracy and direction of error in the sexing of the skeleton: implication for paleodemography,* 1985. American Journal of Physical Anthropology 68:79-85.

[67] Kurki H. K., Decrausaz S.L.. *Shape variation in the human pelvis and limb skeleton: Implications for obstetric adaptation*, 2016. American Journal of Physical Anthropology 159(4):630-638.

[68] Tague R. G.. *Variation in pelvic size between males and females*, 1989. American Journal of Physical Anthropology 80:59-71.

[69] Anastasiou E., Chamberlain A. T.. *The sexual dimorphism of the sacro-iliac joint: an investigation using geometric morphometric techniques*, 2013. Journal of Forensic Sciences 58(S1):126-134.

[70] Ubelaker D., 1989, *Human skeletal remains: excavation, analysis, interpretation. Second edition*. Chapter III: Sex, stature, and age, p. 52-60. Taraxacum, Washington.

[71] Bilfeld M. F., Dedouit F., Rousseau H., Sans N., Braga J., Rougé D., Telmon N.. *Human coxal bone sexual dimorphism and multislice computed tomography: geometric morphometric analysis of 65 adults*, 2012. Journal of Forensic Sciences 57(3):578-588.

[72] Genovés S.. *The problem of the sex of certain fossil hominids, with special reference to the Neanthertal skeletons from Spy*, 1954. Journal of the Royal Anthropological Institute 84:131-144.

[73] Brůžek J., Santos F., Dutailly B., Murail P., Cunha E.. *Validation and reliability of the sex estimation of the human os coxae using freely available DSP2 software for bioarchaeology and forensic anthropology*, 2017. American Journal of Physical Anthropology 164:440-449.

[74] Murail P., Brůžek J., Houët F., Cuhna E.. *DSP: A tool for probabilistic sex diagnosis using worldwide variability in hip-bone measurements*, 2005. De La Société D'Anthropologie De Paris 17:167–176.

[75] Chapman T., Lefevre P., Seman P., Moiseev F., Sholukha V., Louryan S., Van Sint Jan S.. *Sex determination usinf the Probabilistic Sex Diagnosis (DSP: Diagnose Sexuelle Probabiliste) tool in a virtual environment*, 2014. Forensic Science International 234:189.e1-189.e8.

[76] Mastekova S., Brůžek J., Veleminska J., Chaumoitre K.. *A test of the DSP sexing method on CT images from a modern French sample*, 2015. Journal of Forensic Sciences 60:1295-1299.

[77] Quatrehomme G., Radoman G., Nogueira L., Du Jardin P., Alunni V.. *Sex determination using the DSP (probabilistic sex diagnosis) method on the coxal bone: Efficiency of method according to number of available variables*, 2017. Forensic Science international 272:190-193.

Figure

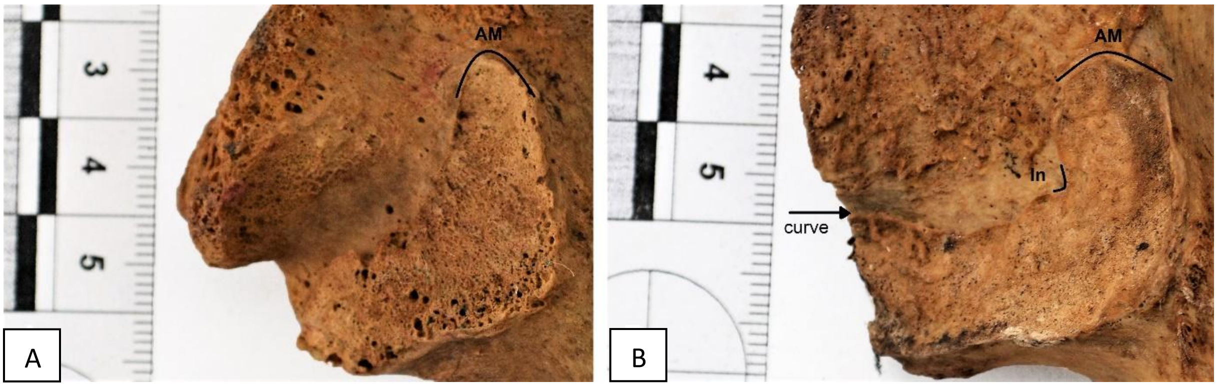

Fig. 1. A – V-shaped auricular surface with an angular apex and straight inferior portion; B – L-shaped auricular surface with a rounded apex, curved inferior portion, and a clear inflection. (AM – *apex morphology*; In – *inflection*)

Fig 2. Shape of the greater sciatic notch. Left – narrow (male trait); Right – wide (female trait).

Table

Table 1. Inter-observer error.

Traits	Kappa coefficient	SD	Sig.
Overall morphology	0.783	0.142	p = 0.000
Apex morphology	0.900	0.097	p = 0.000
Inflection	0.571	0.219	p = 0.010
Greater Sciatic Notch	0.894	0.103	p = 0.000
Inferior shape	0.794	0.135	p = 0.000

Table 2. Intra-observer error.

Traits	Kappa coefficient	SD	Sig.
Overall morphology	0.875	0.121	p = 0.000
Apex morphology	1.000	-	p < 0.000
Inflection	0.634	0.181	p = 0.002
Greater Sciatic Notch	1	-	p < 0.000
Inferior shape	0.894	0.103	p = 0.000

Table 3. Accuracy rates in % for *overall morphology*, *apex morphology* and *inflection*.

Sample		Overall Morphology	Apex Morphology	Inflection
Luna et al. (2017) [55]	Male	77%	72%	50%
	Female	81%	78%	66%
	Overall	79%	76%	59%
	Bias	*4%*	*6%*	*16%*
Present Study	Male	44%	48%	71%
	Female	22%	51%	31%
	Overall	36%	50%	53%
	Bias	*22%*	*3%*	*40%*

Table 4. Accuracy rates in % for *inferior shape* and *shape of the greater sciatic notch.*

Trait		Accuracy rate [%]
Inferior shape	Male	80.2
	Female	44.9
	Overall	64.7
	Bias	*35.3*
Greater sciatic notch	Male	88.24
	Female	74.73
	Overall	81.87
	Bias	*13.51*

Table 5. Logistic regression model for all variables.

Variables	ß	S.E.	Wald	Sig.	Exp(ß)
Overall Morphology	2.02	0.494	16.734	0.000	7.539
Greater Sciatic Notch	-3.533	0.487	52.704	0.029	0.027
Inferior Shape	-0.765	0.435	3.099	0.078	0.465
Constant	*1.183*	*0.484*	*5.973*	*0.015*	*3.265*

Table 6. Logistic regression parameters for the selected variables.

Variables	ß	S.E.	Wald	Sig.	Exp(ß)
Overall Morphology	2.08	0.491	17.981	0.000	8.007
Greater Sciatic Notch	-3.616	0.484	55.904	0.000	0.027
Constant	*0.688*	*0.377*	*3.342*	*0.068*	*1.991*

Reviewer's comment:

"Walker's method [26] was, however, revised in the present study (see: material & methods), and validation of the revised method was performed."

You cannot state that the revised method is being validated. You revised it and tested it, you did not validate it. In order to validate a method you have to take the exact method and apply it to another sample to determine if you are still getting the same results and accuracies. If you used the original scoring of Walker then you would be validating the method, otherwise you are just creating a new method based on the original Walker method. If someone else uses your revised to test a different sample (it can still be Greek but it has to consist of specimens not included in the original sample used to create the revised method) then THAT would be a validation study.

If you are going to include the revised Walker method then you are going to have to state that you created and tested a revised scoring method and you have to remove all "validation" references. You creased new formulae to estimate sex and didn't refer to this as a validation of the formulae.

Author's response:

It is now clear that the revised Walker's method is tested in the present study rather than validated:

<u>Abstract:</u>

"The aim of the present study was to test three previously published methods of sex assessment based on the analysis of the inferior shape of the auricular surface [Novotnỳ, 1975], the greater sciatic notch shape [Walker, 2005 (revised)] and overall morphology, apex morphology and inflection of the auricular surface [Luna et al., 2017]."

<u>Introduction:</u>

"Walker's method [26] was, however, revised in the present study (see: material & methods), and testing of the revised method was performed."

***Author Contributions Section**

Author contributions

JB: study design, data acquisition, data analysis, writing and editing

AB: data acquisition, data analysis, writing and editing

AP: writing, review and editing

EK: study design, supervision, writing, review and editing