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Tomographic-cephalometric evaluation of the *pars petrosa* of temporal bone as sexing method

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ABSTRACT

This study assesses a common issue in Forensic Anthropology: sex determination in fragmented or incomplete human skeletal remains. Previous studies have reported a significant sexual dimorphism in adult individuals for the lateral angle and acoustic pore of the *pars petrosa* of temporal bone. Our aim is to test the usefulness of *pars petrosa* as method for estimating sex using standardized CT axial images and cephalometric techniques. We evaluate four cephalometric markers of the *pars petrosa* (lateral angle, acoustic pore diameter, the divergence of the medial-posterior and medial-anterior segments, and a proposed angle named “Cephalometric Angle of *pars petrosa*”) in 150 adult individuals of known sex and age treated in the *Hospital Beneficência Portuguesa* (São Paulo, Brazil). Discriminant analysis using these four parameters allows correct sex classification in 72 % of individuals, however, the Cephalometric Angle, individually, reaches 74 % of correct classifications. Our results suggest that tomographic-cephalometric evaluation of the *pars petrosa* of temporal bone can be employed as indicial method for differentiating sex in some contexts.

1. Introduction

The determination of sex in skeletal human remains, based on the recognition of dimorphic anatomical traits of the pelvic bones and skull, is a standardized procedure of wide application in physical and forensic anthropology [1,2]. However, human bones are not always well-preserved and forensic-anthropologists are compelled to work with fragmented, cremated or taphonomically altered bones (i.e., environmental factors, burial conditions, mass disasters, time), which represents a serious problem in Forensic Anthropology when the identification of individuals is imperative.

The search for alternative methods on sex determination in skeletonized individuals has guided the study of sexual dimorphism in various anatomical traits. The *pars petrosa ossis temporalis*, a compact structure that houses the internal organs of the auditory system, has been part of these attempts. Due to its density and robustness, *pars petrosa* is often the only bone that survives integrally to the effects of disasters, cremation, or long burial periods, so it has great informative potential from a forensic viewpoint [3–6].

Several anatomical features of the *pars petrosa* have reported significant sexual dimorphism [3,7–12]. Among them, the diameter of the acoustic pore [9] and the course of the *meatus acusticus internus* [10,8–12] have been tested as methods of sex discrimination. The “lateral angle” (LA) denotes, in cross-section, the inclination of the internal acoustic canal (which contains the vestibulocochlear and facial nerves) relative to the medial surface of the *pars petrosa*. The pioneering method of the LA measurement was developed by Wahl [10] in a forensic sample of 70 individuals using negative casts (replicas) of the *meatus acusticus internus* obtained using clay as impression material. Prior sectioning of the replica with a scalpel, he measures LA, the acute angle formed by the surface of the medial facies of the petrous bone and the anterior wall of the *meatus acusticus internus*, with an angle protractor. This research concluded that LA measurements equal to or greater than 45° were more frequent in females.

Further research using silicone replicas in forensic samples of known sex [5,6,11–13] confirmed that mean values of LA differed in approximately 10° between sexes (39.4° in males; 48.3° in females; $p < 0.001$ [11]). None of these studies accused significant side differences, so either side could be used for sex discrimination. These studies also showed that the number of correctly classified individuals varied between 63 % and 83.2 % [5,6,11–13].

Considering the relative technical difficulties of obtaining reliable measurements from silicone replicas [5,13,14], the use of multislice computed tomography (MSCT) in the evaluation of LA was introduced.

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Akansel et al. [15] evaluated 92 individuals (47 women and 45 men of Turkish origin) using a measurement technique modified from skeletal studies [11] and concluded that the mean LA was higher in women (F = 45.5° ± 7.18; M = 41.6° ± 6.78; significant $p < 0.01$), also demonstrating that CT was able to replicate the results obtained using casts. Although it was not possible to obtain a single cutoff value to discriminate sex, LA values ≤35° were 93.6 % specific for males and LA values ≥60° were 97.7 % specific for females. However, other studies using CT have shown opposite results [16–18] reporting non-significant differences between sexes (46.5° in females and 43.4° in males), considerable overlap of values, and poor classification performance (correct sexing approximately 56 %, on average); categorizing the method as "non-conclusive" for sex determination.

The diameter of the internal acoustic pore (PA), another trait of the temporal bone tested to differentiate sex, was examined by Lynnerup et al. [9] in 113 known-sex skeletons by introducing drills calibrated in millimeters (diameters of 1.0–10.0 mm, with an increase of 0.5 mm), finding a mean difference of approximately 0.3 mm (mean diameter of 3.7 mm in males and 3.4 mm in females; significant $p < 0.009$). This study concluded that a diameter of 2.5 mm can be classified as female and a diameter of 4.0–4.5 mm as male. The tests of correct sex classification using a cutoff point (<3.0 mm = female; >3.5 mm = male) reach 70 %.

CT studies have shown lower values of correct sex classification than those observed in dry bones. These inconsistencies are possibly related to methodological issues (i.e., sample size, asymmetry between sexes, ancestry differences, sampling techniques) that would be better evaluated in "controlled" samples. Until now, all studies on LA and AP were conducted in populations characterized by relatively low phenotypic variability [19] such as Scandinavian [9,11], Central [3,10,12,14,17] and Southern [5,6,13] European, and Turkish [15,18]. Thus, their results may be inadequate to be interpolated to more heterogeneous or miscegenated populations.

Although the discriminatory potential of LA and AP for sexing is relatively limited when applied independently, the combination of both with other potentially dimorphic traits of the *pars petrosa* using multivariate statistics can improve the method and make it applicable to the resolution of forensic cases, especially in contexts of considerable bone fragmentation or lack of viable DNA (4,19).

Considering the advantages that CT images provide, in this research we explore the potential of new cephalometric tracing for sex discrimination. After preliminary explorations of the *pars petrosa* we notice a slight morphological difference between males and females in the convexity or bending the medial surface of pars petrosa. Accordingly, the medial surface in males is commonly straighter in the anteroposterior direction, while in women it has a more convex or irregular shape. This observation led us to explore the levels of divergence between the anterior and posterior segments of the medial facies (using the acoustic pore as reference), introducing two angular measurements. The first, called Medial-surface Inflection Angle of the *pars petrosa* (MIA), which characterizes the bending degree of the *pars petrosa* between its anterior (spheno-petrous) and posterior (tympanic-petrous) segments. The second, a cephalometric tracing called Cephalometric Angle of *pars petrosa* (CAPP), that shows the degree of divergence between the anterior and posterior segments relative to the internal acoustic canal direction.

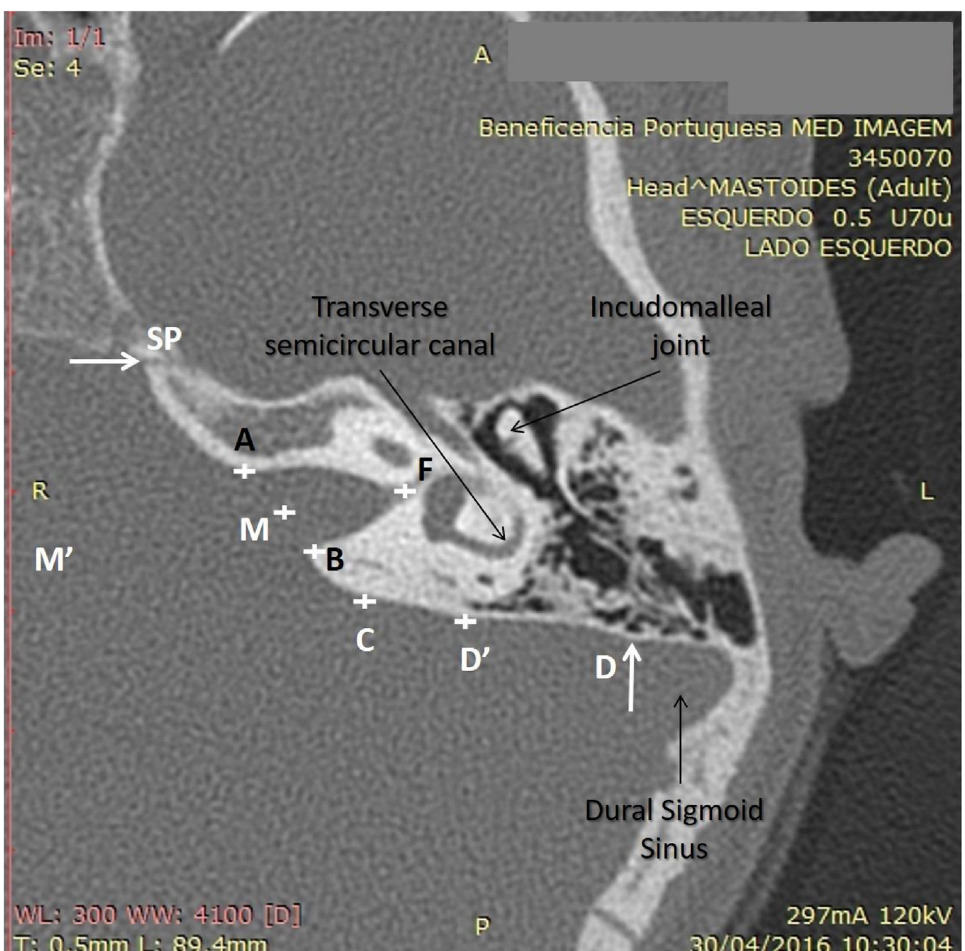

Fig. 1. Landmark points for the recording of the four cephalometric measurements of the *pars petrosa ossis temporalis* used in this work.

This study evaluates the performance of these four parameters for the determination of sex using CT axial images of living individuals from a multiethnic sample (Brazilians). First, we describe the parameters in males and females. Next, we assess their reliability (repeatability, replicability, and accuracy), and finally, we test their discriminatory potential.

2. Material and methods

2.1. Sample and inclusion criteria

The sample consisted of 150 adult individuals of known sex (M = 75; F = 75), aged between 19 and 89 years (M: $\bar{x}$ = 49.19 σ = 18.2; F: $\bar{x}$ = 46.95 σ = 14.4; p = 0.405), which had CT studies of temporal bones indicated for the diagnosis of otological or neurological diseases, attended in the radiology unit (*Med Imagem - BP Medicina Diagnóstica*) of the *Hospital Beneficência Portuguesa* (São Paulo, Brazil). Individuals with congenital or developmental ear anomalies, temporal bone fractures, post-surgical alterations or neoplasms, and CT technically inadequate [11] were excluded. The images were acquired with Somatom Flash (dual source, 256), Somatom AS Definition Plus (128), and Somatom Perspective (128) Siemens CT scanners. Axial images were recorded according to the following parameters: 120−140 kV, 100−297 mA, slice thickness 0.5−2 mm standardized between WW 3600–4400 D and WL = 360–400, reconstruction filter H60 sharp for bone.

2.2. Recording methods

2.2.1. Image selection

The proposed cephalometric parameters were measured in the same tomographic image of the temporal bone, so this is a crucial step for the application of the method. For the selection of the most appropriate image (tomographic slice) a method adapted from Akansel et al. [15: 94, 98], was used. They used the CT image slice in which the apex of the internal acoustic canal (fundus) appears more pointed (selected from the slices that clearly showed the meatus) with the individual oriented transversally to the canthomeatal line. The selected image should show the following anatomical structures: 1) internal acoustic canal; 2) the transverse or lateral semicircular canal; 3) the opening of the facial nerve canal or Fallopian canal (in the slice of maximum permeability); 4) the sphenopetrosal synchondrosis, and 5) the sigmoid sinus of the occipital bone (Fig. 1).

For most cases, this was the upper slice closest to the one that presented the incudomalleal joint more clearly (ice cream in cone) [15]. In some cases, not all anatomical structures appeared in the same slice, so, the image showing the facial nerve canal and the greatest number of anatomical structures was selected.

2.2.2. Linear and angular measurements

In a pilot study, 6 angular measurements of the *pars petrosa* and 3 linear measurements of the internal acoustic canal were examined. Only 4 parameters were selected, three angles (measured in sexagesimal degrees): 1) Lateral Angle - LA; 2) Medial-surface inflection angle - MIA; 3) Cephalometric angle of the *pars petrosa* - CAPP; and one linear measurement (in mm): 4) Acoustic Pore Diameter - AP. A total of 9 landmarks and 5 lines were drawn on the selected image (Table 1 and Fig. 1). The parameters were measured, as described in Table 2 and Fig. 2, in a blind test using the “length” and “angle” tools of the RadiAnt DICOM Viewer 3.02 software.

2.2.3. Statistical analysis

The four parameters were submitted to descriptive analysis (determination of mean, maximum and minimum values, standard deviation, and outliers) according to sex. After exploratory analysis (Kolgomorov-Smirnov and Levene’s tests, Tables S1 and S2, respectively), intergroup differences were examined with *t*-test for independent samples and Mann-Whitney *U* test at $p < 0.05$. In order to explore differences between right and left side, the values of the four parameters were

Table 1
Landmarks and lines for cephalometric tracing of the *pars petrosa*.

Landmark points	
Point A	Maximum curvature point between the anterior wall of the internal acoustic canal and the medial-anterior surface of the *pars petrosa*. In the image, that is the most concave point in the curvature of the anterior rim of the acoustic pore.
Point B	Maximum curvature point between the posterior wall of the internal acoustic canal and the medial-posterior surface of the *pars petrosa*. In the image, that is the most concave point in the curvature of the posterior rim of the acoustic pore.
Point C	The most prominent point of the medial-posterior surface of the *pars petrosa*. If there are two or more prominences, the most pronounced should be considered. If they have approximately the same size, the point located closer to the acoustic pore should be considered.
Point D	Point D is located on the external cortical of the medial-posterior surface of the *pars petrosa*, which coincides with the septum or bony prominence of the sigmoid sinus from the occipital bone.
Point D’	Point D’ is located on the external cortical of the medial-posterior surface of the *pars petrosa*, which coincides with the boundary between the compact bone (roughly at the projection of a 90° line tangent to the transverse semicircular canal) and the mastoid cells.
Point SP	The more outer point of the sphenopetrosal synchondrosis of the *pars petrosa* exposed in the image.
Point F	The middle point of the opening of the facial nerve or Fallopian canal.
Point M	The middle point of the line A–B.
Point M’	Point in the projection of the line F–M at the intersection of the Basal and Pendular lines.
Reference Lines	
Line 1	The line between the points SP and A and its projection. Represents the inclination of the medial-anterior surface of *pars petrosa* (*Apex partis petrosae*).
Line 2	The line between the points C and D and its projection. Represents the inclination of the medial-posterior surface of *pars petrosa (Facies posterior partis petrosae)*.
Line 3	The line between the points C and D’ and its projection. It is also called the Basal line.
Line 4	The line between the point SP and the point of intersection of the Basal and F-M’ lines. It is also called the Pendular line.
Line F-M’	The line between the opening of the facial nerve (point F), that cross the middle point of the diameter of acoustic pore (point M), to the intersection point between the Pendular and Basal lines (M’).
Procedure	
1	Localize and mark the points A, B, F, and M
2	Localize and mark the points SP, C, D, and D’
3	Draw the lines
4	Localize and mark the point M’
5	Measure the angles

Table 2
Cephalometric tracing of the parameters of the *pars petrosa* evaluated in this work.

1	**Lateral Angle (LA).** The first line is traced tangential to the anterior and posterior lips of the internal acoustic canal (not necessarily the points A and B). The second line is traced between the anterior lip of the meatus and the outermost point of the anterior surface of the internal acoustic canal. The lower of the two angles at the point of intersection of both the lines is recorded.
2	**Acoustic pore (AP).** The maximum diameter of the acoustic pore. The length between points A and B measured in mm.
3	**Medial-surface Inflection Angle of the*pars petrosa*(MIA).** MIA measures the divergence between the anterior (spheno-petrous, Line 1) and posterior (tympanic-petrous, Line 2) bony bases. The angle is formed by the intersection of projection of Line 1 (A-SP) and the projection of the Line 2 (D-C). Line 2 is tangential to the posterior facies of the *pars petrosa*. When the surface is sinuous, the line should cross the most anterior tangential point of the surface. The inner angle of the intersection of both the lines is recorded in sexagesimal degrees. Because in some individuals the anterior surface (*Apex partis petrosae*) is convex and the posterior surface is rounded and voluminous, we drawn lines that simplified these shapes (i.e., the A-SP line) to reflect only the inclination of the bony bases.
4	**Cephalometric Angle of the*pars petrosa*(CAPP).** The angle formed by intersecting Line 3 (Basal line, that crosses the points M'-C-D' or the two more external points of the posterior wall of the *pars petrosa*.) and Line 4 (Pendular line, from SP to M' points). The angle of intersection of both the lines with the Line F-M' is recorded in sexagesimal degrees.

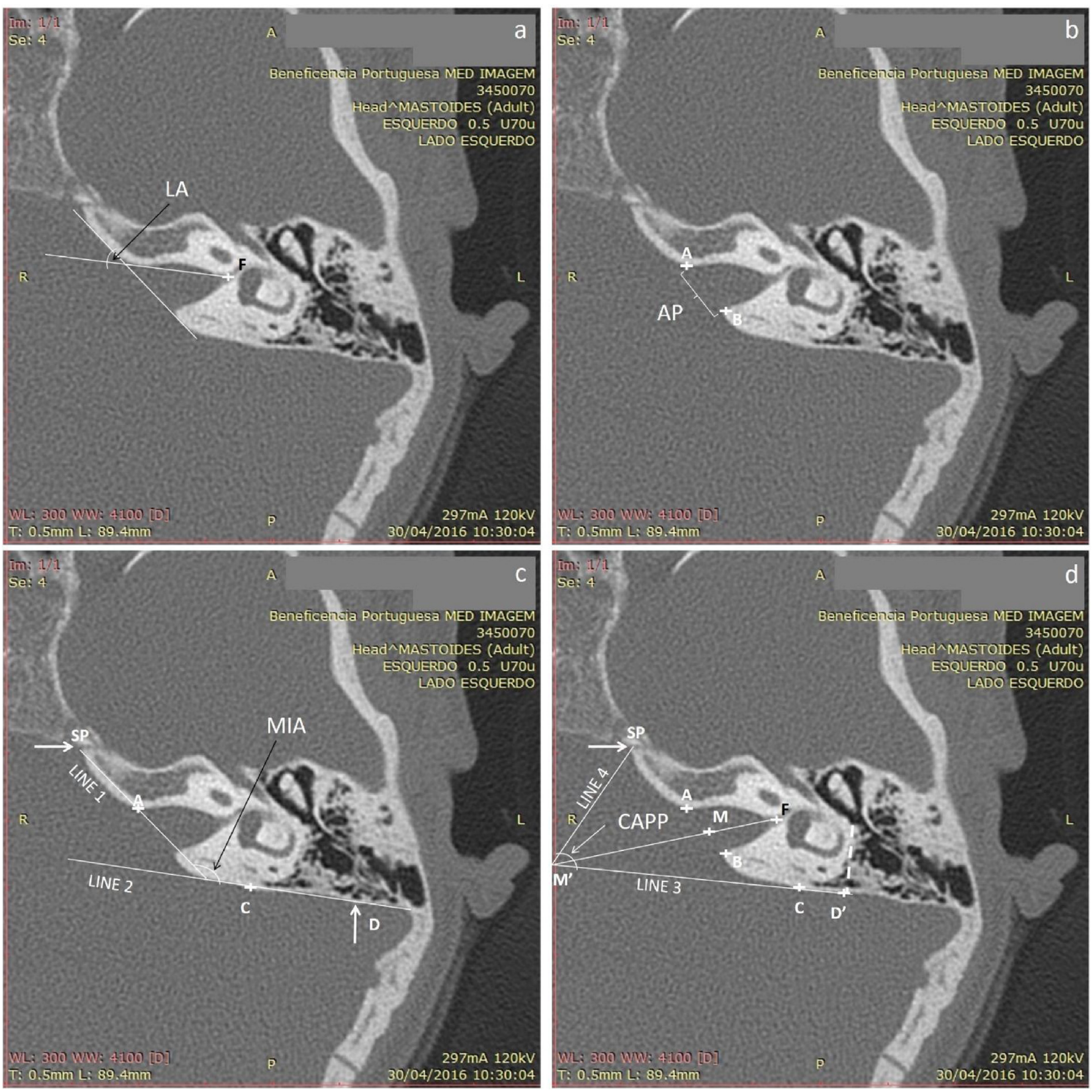

Fig. 2. Cephalometric tracing: a) lateral angle of the internal acoustic canal (LA); b) diameter of Acoustic Pore (AP); c) Medial-surface inflection angle (MIA); and d) cephalometric angle of *pars petrosa* (CAPP).

Table 3
Mean values of the evaluated parameters by sex.

Sex		N	Min.	Max.	Median	Mean	SD	IC 95 %
males	LA	75	24.20	64.60	39.30	40.46	8.58	38.48–42.43
	AP	75	3.60	14.10	8.70	8.63	2.23	8.12–9.15
	MIA	75	130.30	179.20	156.40	157.42	10.77	154.94–159.90
	CAPP	75	93.60	180.00	142.40	139.47	20.61	134.73–144.22
females	LA	75	26.70	67.90	45.50	45.78	8.24	43.88–47.67
	AP	75	2.80	12.80	8.20	8.26	1.86	7.84–8.70
	MIA	75	129.0	177.0	150.10	151.03	9.70	148.80–153.26
	CAPP	75	34.70	167.90	112.20	106.34	31.71	99.05–113.64

compared in 20 % of the sample (16 male and 16 female individuals) randomly selected. Only the measures on the left side were used, by convention, for comparisons between males and females [1:44].

The intra (repeatability) and interobserver (replicability) errors of the measurements were examined in 10 % of the sample (8 males and 8 females) randomly selected. For this purpose, we examined the difference of means between the two measurements conducted by one of the researchers (LPL) at different times, and the difference of means between the measurements of both researchers, using *t*-test for paired samples and Pearson correlation coefficient at $p < 0.05$.

To evaluate the accuracy of the method, the determined sex was contrasted with the known sex of the individual. A Discriminant Analysis was performed to determine the percentage of correct classifications achieved using the four proposed parameters and to detect the discriminatory power of each of them in terms of probability. Statistical analysis was conducted with SPSS v. 21 (IBM®).

3. Results

The results of descriptive analysis and confidence intervals (95 % CI) of each parameter are showed in the Table 3. The distribution of the values is observed in the Fig. 3. The pairwise comparisons do not show significant differences (LA: t = −1.131 p = 0.262; AP: t = −1.375 p = 0.174; MIA: t = 0.460 p = 0.647; and CAPP: t = 1.552 p = 0.176; see Tables S3 and S4).

The evaluation of intraobserver error show significant differences between the first and second measurement for MIA (t = 2.461; p = 0.026), but not for the other parameters (LA: t = −1.887 p = 0.079; AP: t = −0.715 p = 0.485; CAPP: t = 1.625 p = 0.125). The evaluation of the interobserver error showed significant differences for LA (t = −2.299 p = 0.036) and CAPP (t = 3.290; p = 0.005), but not for PA (t = −1.683 p = 0.113) and MIA (t = 3.290 p = 0.225). The correlations between measurements are high, positive, and significant in

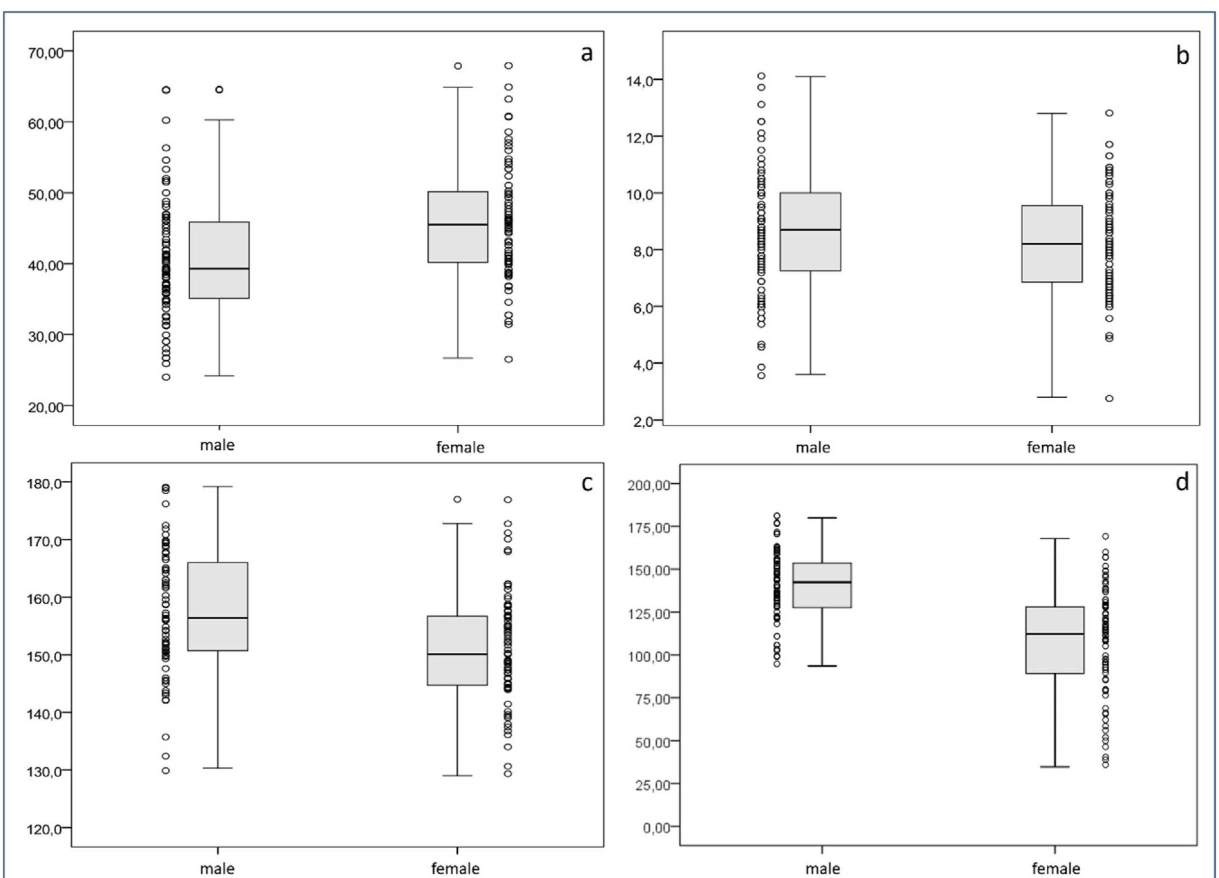

Fig. 3. Box plots and values distributions of the evaluated parameters: a) Lateral Angle (LA), in sexagesimal degrees; b) Diameter of Acoustic Pore (AP), in mm; c) Medial-surface inflection angle of the *pars petrosa* (MIA), in sexagesimal degrees; d) Cephalometric angle of the *pars petrosa* (CAPP), in sexagesimal degrees.

Table 4
Comparison of means of evaluated parameters according sex.

Parameter	Test t						
	t	df	Sig.	Mean difference	Standard error of difference	Confidence Interval 95 %	
						Inferior	Superior
LA	−3.872	148	.000	−5.32	1.37	−8.03	−2.60
AP	1.076	148	.284	.36	.33	−.30	1.02
MIA	3.818	148	.000	6.39	1.67	3.08	9.70
CAPP*	7.585	148	.000	33.12	4.36	24.49	41.76

* CAPP showed normal distribution and non-equal variance, for *post-hoc* comparison of means the Mann-Whitney *U* test was conducted: *U: 1861.500; Z: -3.575; Sig: <0.001.*

all cases, with only one exception to the evaluation of interobserver error (AP: ρ = 0.373 p = 0.155; see Tables S5–S7).

The comparison of means between sexes, examined with a *t*-test for independent samples, reveal significant differences for LA, CAPP, and MIA, but not for AP (Table 4). Females show a more open lateral angle, a medial-surface of the *pars petrosa* slightly more divergent between their anterior and posterior segments, and a more acute cephalometric angle.

In all cases, however, there is considerable overlap of values, and establishing a cutoff point to reasonably differentiate between both sexes is somewhat difficult. When the individuals were allocated in categories according to the cutoff points recommended by Norén et al. [11] for LA (M < 45° and F > 45°), only 63 % individuals (94/150) were correctly classified. Based on the means, medians, standard deviations, and confidence intervals obtained from our observations were established as cutoff points 154° for MIA (F < 154° and M ≥ 154°) and 134° for CAPP (F < 134° and M ≥ 134°). With these cutoff points these parameters allowed a correct classification of 61 % (91/150) and 71 % (107/150) of individuals, respectively.

The discriminant analysis using the four combined parameters allowed classifying the correct sex in 72 % of the individuals (108/150 individuals). The parameters used individually allowed correct classifications of 62.7 % of individuals for LA; 60 % for MIA and 74 %, the maximum value reached, for CAPP (Table 5). Although can be considered "low", the CAPP showed higher classification potential than LA [9–12,15].

4. Discussion

Despite their apparent potential for determination of sex in skeletonized individuals, the combined use of cephalometric measures of the *pars petrosa* shows a relatively limited efficacy in the correct classification of sex. There is a remarkable congruence between the values obtained in this research and previously published studies (anatomical and tomographic) for the Lateral Angle (LA) [3–18], which reinforces the statement that studies with CT images can replace osteological studies. However, in the case of the diameter of Acoustic Pore (AP), our results are approximately 3 mm higher on average for both sexes. This finding is possibly related to the method used by Lynnerup et al. [9] and the more accurate measurements obtained from this study. It can also be related to the two-dimensional nature of CT images and cephalometric tracing.

As reported by previous studies [3,12–17], LA and AP, show high overlap of values and low efficacy when used individually. Between the two newer traits proposed in this work, the Medial-surface Inflection Angle of the *pars petrosa* (MIA) proved to be ineffective, while the parameter called Cephalometric Angle of the *pars petrosa* (CAPP) showed greater discriminating power. Although three parameters show significant differences between sexes, in all cases it is difficult to establish cutoff points that allow differentiation between males and females. Possibly the confidence intervals (95 % CI) obtained in this study represent a good point of departure for future explorations.

Discriminant analysis revealed which parameters were the most appropriate to differentiate between sexes. The Cephalometric Angle of *pars petrosa* (CAPP) has the highest discriminant value and correctly classify 74 % of cases. The concomitant use of the other three measures, reduces the discriminant potential of the model by 1 %. The low discriminating value of the Medial-surface Inflection Angle (MIA) and Acoustic Pore diameter (AP) can be attributed to the high degree of overlay of measurements. AL reached a classification value of approximately 63 % similar to the observed in other studies [6,11,16,17]. In all tests, the parameters worked better in male individuals.

Higher discriminant power in males was reported for LA [5,6]. The overlap of LA values is greater in older females. As observed by pioneering studies [3,12] the age of individuals seems to be a significant factor in LA expression. A decrease in LA values with ageing was observed, especially in females over 70 years old. When the sample is divided into age-ranges, LA is more reliable in the younger cohorts [6]. Has been hypothesized that LA is affected by the general masculinization and atrophic processes in

Table 5
Results of individuals' classification with Discriminant Analysis.

Parameter	Sex	Group of classification				Total		Cases correctly classified (%)
		male		female				
		n	(%)	n	(%)	n	(%)	
LA	male	51	(68.0)	24	(32.0)	75	(100.0)	62.7 %
	female	32	(42.7)	43	(57.3)	75	(100.0)	
AP	male	Do not qualifies for the analysis						
	female							
MIA	male	44	(58.7)	31	(41.3)	75	(100.0)	60.0 %
	female	29	(38.7)	46	(61.3)	75	(100.0)	
CAPP	male	60	(80.0)	15	(20.0)	75	(100.0)	74.0 %
	female	24	(32.0)	51	(68.0)	75	(100.0)	
LA + AP + MIA + CAPP	male	54	(72.0)	21	(28.0)	75	(100.0)	72.0 %
	female	21	(28.0)	54	(72.0)	75	(100.0)	

female skull (especially the cranial base and the petrous bone) linked to hormonal changes caused by menopause (for an expanded discussion on this issue see Massoti et al. [6]). Thus, the discriminating power of our markers can be related to differences in the age distribution of the sample. A new study considering age-ranges is ongoing and should answer this issue.

The variability observed among the parameters could be also related to differences of ancestral group or ethnic origin and correlated differences in the skull shape linked to the high level of admixture between caucasoids, negroids, mongoloids and Amerindians in the Brazilian population [20]. An observation that deserves future evaluation suggests that individuals of Asian ancestry (inferred by the last name) have a lower inflection of the medial surface of the *pars petrosa* (with approximate angles of 180°) in possible association with greater brachycephaly. Thus, parameters such as MIA and CAPP could be more efficient in Amerindians or Asian individuals. On the other hand, mongoloid females could also mimic values from males of other groups.

The greatest difficulty of applying this method in forensic cases is the acquisition of adequate CT images. However, there are other limitations that represent potential sources of error that deserve consideration: 1) problems with image standardization and post-processing of CT images that can affect the accuracy of measurements; 2) difficulty to select the best image for measurements; 3) the limitation that imposes the two-dimensional nature of cephalometric tracing in the representation of the three-dimensional petrous bone; 4) partial volume effects caused by pixels containing mixture of tissues that result in loss of resolution [16].

All these factors may also explain the intra- and interobserver error, which in this research proved to be significant. Due to the morphology of the *pars petrosa* and its highly variable topography, the correct tracing of the parameters is the main obstacle to a correct application of the method in practical terms. Considering that several studies have already focused on the morphology of *pars petrosa* as a useful trait for the determination of sex using osteometric methods [3,7,8,11], future studies applying geometric morphometrics techniques could provide new insights on sexual dimorphism and differences between populations.

5. Conclusion

The significant differences between males and females for LA, MIA, and CAPP in our sample suggests some degree of sexual dimorphism of the *pars petrosa* that should be evaluated with more sophisticated methods. The discriminatory value of the integrated parameters reaches 72 % of correct classifications. When used individually, the Cephalometric Angle of the *pars petrosa* showed higher discriminating power (74 % of correct classifications). Tomographic-cephalometric tracing, due to its methodological limitations, may be useful for the determination of sex only as indicial method of identification, in cases involving very fragmented bones, where it is impossible to apply more reliable methods.

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Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fsir.2021.100174.

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