



# Sex estimation using paranasal sinus discriminant analysis: a new approach via cone beam computerized tomography volume analysis

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## Abstract

Sex estimation is an important step for subject identification in forensic medicine, to which paranasal sinuses may contribute, as they remain intact even upon severe damage to the skull and other bones. Cone beam computerized tomography (CBCT) is an excellent tool in the examination of these structures. The present study aimed to evaluate the maxillary, frontal and sphenoidal sinuses through a discriminant analysis to determine the sex correlations with foramen magnum measurements were also assessed. Two-hundred cranial CBCT scans were analysed. The volume of the maxillary, frontal and sphenoidal sinuses were measured using the ITK-SNAP software (4.0.2). Student's *t* test and the Mann–Whitney test were applied for the descriptive analysis of independent samples, and data were subjected to discriminant analysis. The volumes of the maxillary, frontal and sphenoidal sinuses of female subjects were smaller than those of male subjects ( $p < 0.001$ ). Upon summing up the volumes of the evaluated paranasal sinuses, the chances to correctly determine an individual's gender are 96.2% and 92.7% for males and females, respectively. When correlating said values with foramen magnum measurements, sex identification chances increase to 100%. Thus, adult paranasal sinus volumes analysed by CBCT may be useful for sex identification when summed together and correlated with foramen magnum measurements.

**Keywords** Forensic science · Cone beam computed tomography · Sexual dimorphism · Paranasal sinuses · Foramen magnum

## Introduction

Computed tomography has been increasingly used to assist in forensic medicine investigations [1]. The potential value of CT in determining the probable cause of death, estimating

age, or visualizing features that may allow personal identification has been reported in the literature [2].

In a forensic context, sex determination is considered an important step in rebuilding the biological profile of an unknown individual. This determination is more reliable in adults. The hormonal variations, including variations in growth hormones and the development of puberty, affect the bone structures of young individuals [3]. Since most bones conventionally used for sex determination (pelvis, skull, long bones, etc.) are often recovered in a fragmented, incomplete, or mixed state—especially in catastrophes such as explosions, wars, natural disasters, and other mass calamities—sex identification becomes a difficult task [4]. Thus, the use of structures was protected by denser bones that are often recovered intact (e.g. the paranasal sinuses and skull base), an increasingly important alternative of skeletal regions that may be used in sex determination [5]. The fragmentation of important human structures makes forensic analysis difficult, requiring an evaluation of remaining structures, providing an osteobiography based on the individual's essential biological characteristics [6].

## Highlights

- Sex can be estimated by the volume of paranasal sinuses using CBCT.
- When FM measurements are added to the model, the correct classification rate is 100% for this sample.
- CBCT may be used in forensic medicine for sex estimation purposes.

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Radiology is a non-invasive method used to investigate the human body. As such, it plays a significant role in medicine legal investigations and in the identification of human remains [6]. Bone details such as shape, size, volume, and individual characteristics constitute consistent evidence [7]. Recent studies have used CT and CBCT volume measurements of several areas of the body for age and sexual dimorphism determinations [8–17].

The present study aimed to evaluate the maxillary, frontal and sphenoidal sinuses through a sex determination discriminant analysis, in conjunction with a correlation with foramen magnum measurements.

## Materials and methods

The present study was approved by the Research Ethics Committee of the Health Sciences Institute, Federal University of Pará, Belém, Pará, Brazil, with approval number 1.684.013.

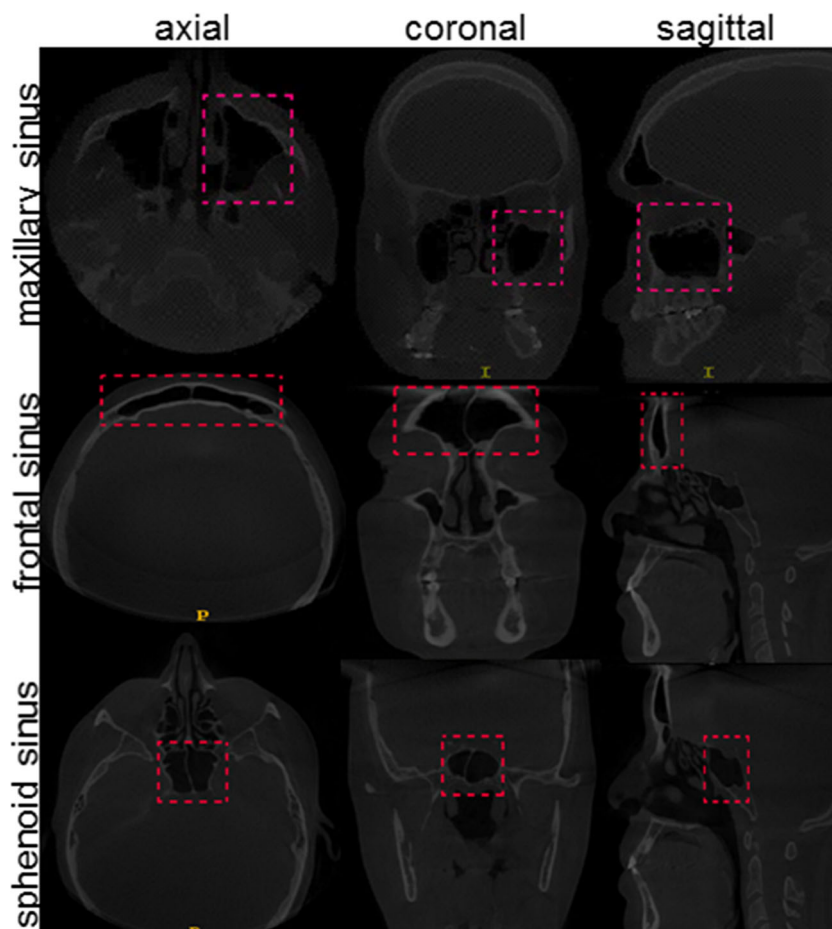
The sample consisted of 200 total cranial CBCT scans obtained using the I-Cat® tomography apparatus (Imaging Sciences-Kavo, Hatfield, PA, USA) operating at 110 kV,

40 mA, and belonging to the archives of a dental clinic. There were 100 scans each for males and females. The following inclusion criteria were adopted: patients 18 years of age or older, subjected to total cranial tomography, exhibiting a complete upper dental arch. Exclusion criteria included patients submitted to maxillary, sphenoidal, and frontal sinus surgery and images that present pathologies and/or facial deformities involving the aforementioned sinuses.

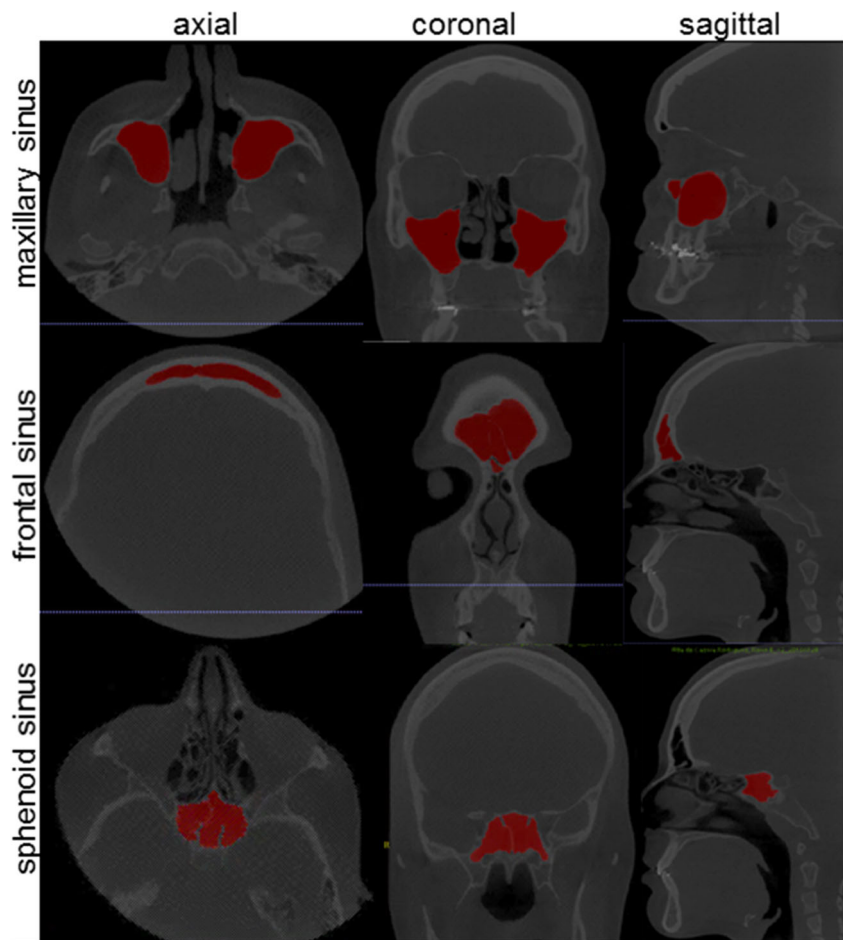
Images were evaluated via the ITK-SNAP software (version 2.1.4), which allowed reliable measurements. This software produces a complete filling of the delineated region, preventing the area differences from interfering with data reliability. The paraxial section images were displayed on a 17-in. LCD monitor with a screen resolution of 1280 × 1024 pixels and analysed.

The analysis was performed by two examiners, both properly trained dentomaxillofacial radiologists, who performed the maxillary, frontal and sphenoidal sinus image segmentations on two different occasions, for each examiner. Points were delimited according to the contour surfaces of the sinuses, carefully following their anatomical borders. For visualization and delineation, the axial, sagittal, and coronal sections were selected (Fig. 1). After full sinus segmentation, the

**Fig. 1** Axial, coronal, and sagittal CBCT reconstructions using the ITK-SNAP software, demonstrating the delimitation of the studied areas



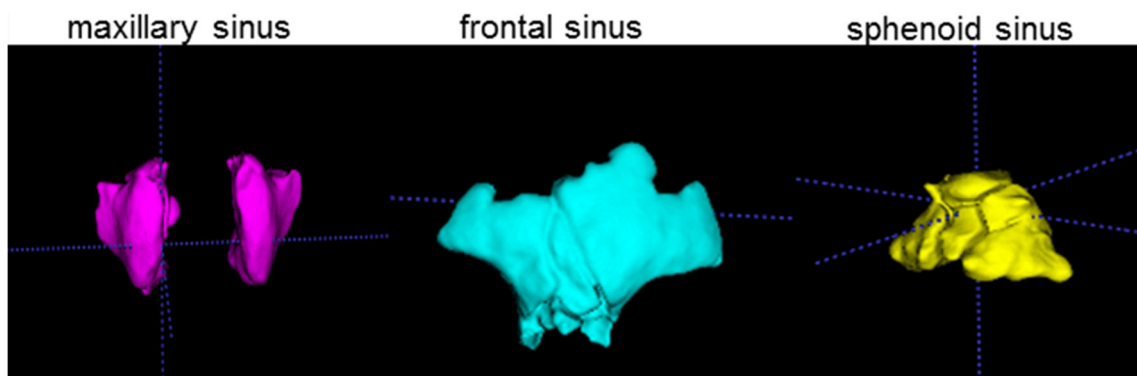
**Fig. 2** Volumetric filling (cm<sup>3</sup>) of the maxillary, frontal and sphenoidal sinuses through the ITK-SNAP software



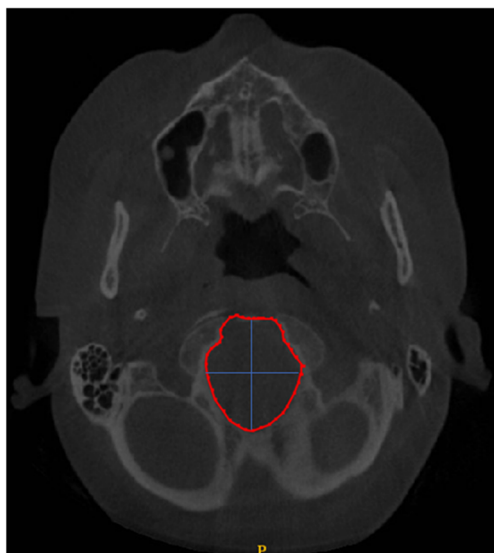
volume was displayed in cubic centimetres (Fig. 2), and one of the three-dimensional models (3D) was generated by the software (Fig. 3). After a period of 15 days, the same procedures were repeated for analysis of the intra and inter-rater agreement.

To reach a more accurate data evaluation, we opted for the foramen magnum evaluation, for its efficiency in the sexual dimorphism determination. Length as well as sagittal and transverse circumference measurements of the foramen magnum (FM) were obtained from the axial sections. The foramen

magnum analysis was made by its sagittal diameter (FMSD—recorded as the largest anteroposterior dimension of the FM), transverse diameter (FMTD—recorded from the largest FM width) and the circumference (FMC—measured after FM bone tracing on the CBCT image) (Fig. 4). Discriminant analysis has been made, with different combinations of paranasals volumes and foramen magnum measures. All measurements were performed using the CS 3D Imaging software (v. 3.2.9, copyright Carestream Health Inc.) on images displayed on a 17-in. LCD monitor with a 1280 × 1024-pixel screen



**Fig. 3** 3D volumetric image obtained from the maxillary, frontal and sphenoidal sinuses through the ITK-SNAP software



**Fig. 4** Axial section showing the linear measurements performed on the foramen magnum

resolution. The examiner was allowed to use twofold magnification ( $\times 2$ ) and adjust screen brightness, in addition to running through the entire axial section over a standardized 300- $\mu\text{m}$  thickness.

## Data analysis

Parametric and non-parametric data were statistically analysed using the Bioestat software (version 5.0, Belém, Pará, Brazil). A 5% significance level was considered statistically significant. Continuous data intra-class correlation was used to evaluate the degree of inter and intra-examiner agreement between the first and second evaluations. Student's *t* test and the Mann–Whitney test for independent samples were used for descriptive analysis comparing the volumes of the maxillary, frontal and sphenoidal sinuses and the foramen magnum among male and female. A discriminant functional analysis

was subsequently performed to assess whether paranasal sinuses and foramen magnum measurements could be used for sex determination, the one that was applied to the leave-one-out cross-validation.

## Results

A total of 200 CBCT exams were evaluated; however, the data presented are based on a sample of 163 exams, 80 exams in men and 83 exams in women, due to the exclusion of 37 samples, because they did not meet the inclusion criteria. A small difference in sample size is observed, but not enough to interfere with the statistical results.

The intra-class correlation showed excellent replicability, since correlation values were  $> 0.8$  and  $p < 0.0001$ , indicating reproducible, reliable measurements performed by the examiners.

Data were submitted to descriptive statistical analysis using Student's *t* test and the Mann–Whitney test for independent samples to assess whether there was a significant difference in volumes ( $\text{cm}^3$ ) between the male and female maxillary, frontal and sphenoidal sinuses. Table 1 shows the descriptive analysis of maxillary, frontal and sphenoidal sinus volumes according to sex; data are presented according to mean value, standard deviation, maxima, and minima. Significant differences were observed between men and women regarding the volume of the three sinuses ( $p < 0.001$ ).

The volumes of women's sinuses are smaller compared to men's, but the maximum values of sinus volumes of females overlap the minimum male sinus measurements. Thus, a discriminant function was performed to represent the chance of guessing an individual's sex from each analysed structure (Table 2; Fig. 5): scatterplot matrix of volumes ( $\text{cm}^3$ ), maxillary sinuses (right and left), frontal sinus, and sphenoidal sinuses (right and left). Males and females are depicted in different colours, evidencing the presence of sexual dimorphism. The density plots on the

**Table 1** Comparison of parameters between male and female groups of the maxillary, frontal and sphenoid sinuses

	Females		Males		<i>p</i> value*
	Mean $\pm$ SD	Min–max	Mean $\pm$ SD	Min–max	
Right maxillary sinus	6.8251 $\pm$ 0.7745	4.9950–8.8510	8.3558 $\pm$ 0.7903	6.3090–9.8890	< 0.001
Left maxillary sinus	6.9142 $\pm$ 0.8716	5.0950–8.8970	8.4819 $\pm$ 0.7150	6.7750–9.8550	
Frontal	2.2476 $\pm$ 0.5961	1.1350–3.5720	3.9442 $\pm$ 0.5327	3.0880–4.9210	
Right sphenoid sinus	5.0639 $\pm$ 2.3183	1.1690–9.4020	9.6577 $\pm$ 3.5381	2.2340–15.2620	
Left sphenoid sinus	5.4638 $\pm$ 2.3109	1.1910–9.7740	9.9560 $\pm$ 3.4469	2.9080–15.4350	

Student's *t* test and Mann–Whitney *U* test,  $p < 0.001$ ;  $p \leq 0.05$  = significant difference

SD standard deviation

\*Volume ( $\text{cm}^3$ )



**Table 2** Classification accuracies of the discriminant analyses of the volumes of maxillary, frontal and sphenoid sinuses in relation to sex

Study group → variables↓	Resubstitution			Cross-validation (leave-one-out)		
	Males n = 80	Females n = 83	Total N = 163	Males n = 80	Females n = 83	Total N = 163
Right maxillary sinus	64 (80%)	67 (80.72%)	131 (80.37%)	63 (78.75%)	67 (80.72%)	130 (79.75%)
Left maxillary sinus	69 (86.25%)	69 (83.13%)	138 (84.66%)	69 (86.25%)	69 (83.13%)	138 (84.66%)
Average (right and left)	67 (83.75%)	71 (85.54%)	138 (84.66%)	67 (83.75%)	71 (85.54%)	138 (84.66%)
Frontal	77 (96.25%)	77 (92.77%)	154 (94.48%)	77 (96.25%)	77 (92.77%)	154 (94.48%)
Right sphenoid sinus	59 (73.75%)	68 (81.93%)	127 (77.91%)	59 (73.75%)	68 (81.93%)	127 (77.91%)
Left sphenoid sinus	60 (75%)	69 (83.13%)	129 (79.14%)	60 (75%)	69 (83.13%)	129 (79.14%)
Average (right and left)	59 (73.75%)	68 (81.93%)	127 (77.91%)	59 (73.75%)	68 (81.93%)	127 (77.91%)
All sinuses	78 (97.5%)	78 (93.98%)	156 (95.71%)	77 (96.25%)	77 (92.77%)	154 (94.48%)

diagonal show the distributions of volumes for each sinus, according to sex. Correlation coefficients are written in the upper diagonal.

The chance of determining whether an individual is male or female reached 83.7% (male) and 85.5% (female), respectively. The accuracy rates by maxillary sinus volume measurement are 96.2% (male) and 92.7% (female), using the frontal sinus volume, and 73.7% (male) and 81.93% (female) using the sphenoidal sinus. When adding

all three paranasal sinus volumes, the accuracy rates increased to 96.2% (male) and 92.7% (female) for male and females, respectively.

The foramen magnum is a structure already considered in forensic medicine for sex identification. Table 3 shows the descriptive analysis of the evaluated FM parameters; the establishment of correlations with the aforementioned paranasal sinuses increased the chance of success (Table 4).

**Fig. 5** Correlation between volumes (cm<sup>3</sup>) of maxillary sinuses (right and left), frontal sinus, and sphenoidal sinuses (right and left) in relation to sex



**Table 3** Comparison of the foramen magnum parameters between the female and male sex

	Females		Males		<i>p</i> value*
	Mean ± SD	Min–max	Mean ± SD	Min–max	
FMSD	34.92 ± 0.69	33.91–35.92	38.03 ± 0.57	36.01–38.93	0.001*
FMTD	31.05 ± 0.57	30.03–31.94	33.25 ± 0.33	32.01–33.99	
FMC	101.89 ± 0.57	101.05–104.34	109.08 ± 0.52	180.04–109.84	

Student's *t* test  $p < 0.001$ ;  $p \leq 0.05$  = significant difference

FMSD foramen magnum sagittal diameter (mm), FMTD foramen magnum transverse diameter (mm), FMC foramen magnum circumference, SD standard deviation

The sagittal and transverse circumferences and lengths of the foramen magnum were compared between the male and female sex using Student's *t* test. The difference was statistically significant ( $p < 0.001$ ).

The accuracy rate of the FMC, FMSD and FMTD reached 100%, 99.39% and 96.93%, respectively. The FM measurement alone shows accuracy of 99.4%. The sum of all the paranasal sinuses obtained the accuracy of 95.7%. When all paranasal sinus volumes were included in the discriminant analysis together with FM measurements by the leave-one-out cross-validation, the sex identification accuracy rate reached 100%.

## Discussion

CT's reliability in the identification of human remain has been discussed [8]. Some of the existing literature on the subject has the goal of studying the volume measurement accuracy in tomographic examinations using specific software and comparing to the actual physical volume. Kirmeier [18] evaluated the volume of the maxillary sinus on CT scans and compared it with the physical volume calculated through a phantom with previously known dimensions, concluding that the CT volumetric measurement procedure can be strongly recommended for a reliable volume determination of human maxillary sinuses.

On a complete skeleton, the subject's sex can be determined with 100% accuracy. This rate decreases to 98% in the presence of the pelvis and skull, 95% of the pelvis only and 80–90% of the long bones only. After the pelvis, the skull is the most easily sexed part of the skeleton, but the determination of sex from the skull is less reliable pre-puberty [4, 19, 20]. The present study aimed to evaluate the maxillary, frontal and sphenoidal sinuses through a discriminant analysis for sex estimation, in conjunction with foramen magnum measurements. The growth of the maxillary and sphenoidal sinuses stabilizes around the age of 13–14 years. The frontal sinus still presents (slow) growth at age 18 years [8, 9]. Therefore, the present study included adult subjects with complete upper dental arches and no sinus pathologies.

When comparing the volumes of the maxillary, frontal and sphenoidal sinuses between male and female subjects, female's sinuses were smaller than male's ( $p < 0.001$ ). These results are in agreement with the results of previous studies [8–15, 17]. According to the results described herein, the maxillary sinus was accurate in identifying 83.7% and 85.5% of male and female subjects, respectively, with an overall precision of 84.6%. Ekizoglu [10], Sidhu [11] and Paknahad [12] showed a similar accuracy rate: 78% for females and 74% for males, with an overall precision of 76%. Sharma [13] calculates an overall accuracy of 69.81%.

Uthman [14] applied discriminative analysis to show that the frontal sinus analysis could correctly determine the individual's 76.9% of the times; when adding skull measurements

**Table 4** Classification of the discriminant functional analysis of the foramen magnum measurements in relation to sex and paranasal sinuses studied

Group	Original <i>N</i> (%)			Cross-validated <i>N</i> (%)		
	Males <i>n</i> = 80	Females <i>n</i> = 83	Total <i>N</i> = 163	Males <i>n</i> = 80	Females <i>n</i> = 83	Total <i>N</i> = 163
FMSD	79 (98.75%)	83 (100%)	162 (99.39%)	79 (98.75%)	83 (100%)	162 (99.39%)
FMTD	75 (93.75%)	83 (100%)	158 (96.93%)	75 (93.75%)	83 (100%)	158 (96.93%)
FMC	80 (100%)	83 (100%)	163 (100%)	80 (100%)	83 (100%)	163 (100%)
FM-M + all sinus volume	80 (100%)	83 (100%)	163 (100%)	80 (100%)	83 (100%)	163 (100%)

FMSD foramen magnum sagittal diameter (mm), FMTD foramen magnum transverse diameter (mm), FMC foramen magnum circumference, FM-M foramen magnum measurements

in conjunction with frontal sinus measurements, the accuracy raised to 85.9%. In Michel's study [15], 72.5% of the sample was correctly classified according to sex. In the present study, the frontal sinus yielded a 94.4% overall sex estimation accuracy rate. The accuracy rates achieved in the current study were higher than those reported in previous studies.

Few studies exist in the literature regarding the analysis of the sphenoidal sinuses, whose results greatly disagree on the use of this anatomical structure in sex identification studies. Oliveira [16] reported that the male and female groups' mean values hinder using this anatomical structure for sex estimation. However, Cohen [8] and Ginelli [17] found statistical difference ( $p < 0.05$ ) when analysing sphenoidal sinus volumes between male and female. The volume of the former was larger than that of the latter, with a mean volume of 10,005 cm<sup>3</sup> (SD 5.101 cm<sup>3</sup>) and 7920 cm<sup>3</sup> (3176 cm<sup>3</sup>), respectively. No study was found where in discriminant analysis had been applied to this paranasal sinus.

In the present study, the discriminant analysis showed 73.7% and 81.9% accuracy rates for male and female, respectively, with an overall accuracy rate of 77.9%. When adding the volumes of the three sinuses, the overall accuracy rate raises to 94.4%. Therefore, the present study attests that the maxillary, frontal and sphenoidal sinus volume measurements, when added, show great accuracy in sex identification.

Accuracy rate variations reported in the existing literature probably stemmed from ethnic and racial variabilities, different methodological and statistical analyses, different radiographic techniques and different sample sizes. Ethnic variations have been reported as having an impact on sinus volumes, which may have contributed to the extensive variability demonstrated in prior studies [21]. The current study includes the Amazonian population of Brazil in the sample.

Some skull base studies have shown substantial significance owing to the resistant nature of their parts (such as the mastoid, the foramen magnum, and the occipital condyles) during explosions, fire trauma, and aircraft accidents [22]. At the base of the skull, the FM also has a favourable anatomical position as it is covered by soft tissues and the head's skeleton, which protects this structure from direct impacts, thus preserving this area for forensic examination [23].

In the present study, sexual estimation was observed in three foramen magnum parameters: the sagittal, the transverse, and the circumferential diameter were obtained from axial sections, and the data were submitted to discriminant analysis to evaluate sexual dimorphism, yielding 99.3%, 96.9% and 100% accuracy rates, respectively. Generally, the predictive accuracy of the present study is superior to others, which include the following: 82% in South Africans [24], 83.9% in the Egyptian population [25], 84.1% in Japanese skulls [26] and 91% in black South Africans [27].

One study [28] correlating the FM and the linear measurements of the mandible for sexual dimorphism determination

exhibited an overall grouped predictive precision of 83.2% for the FM and mandibular measurements. It could correctly identify males or females in 77.3% or 87.4% of the cases, respectively. The authors concluded that angular measurements of the mandible and the FMSD assessed in CBCT scans could be used to determine sexual dimorphism. In the present study, the correlation of paranasal sinus volumes with FM measurements yielded an accuracy rate of the discriminant analysis of 100%, rendering these measurements reliable for sex estimation when other methods are inconclusive. The accuracy rate in the present study is comparable—if not higher—to that of many other methods used to predict an individual's sex from skeletal remains.

## Conclusion

CBCT volume analysis of paranasal sinuses may be useful for sexual dimorphism in forensic medicine. CBCT scans showed that the maxillary, frontal and sphenoidal sinuses exhibited larger volumes in male and female. According to the obtained results, measuring FMC, FMSD and FMTD with paranasal sinus volumes provides 100% discrimination between male and female, rendering these measurements reliable for sex estimation when other methods are inconclusive.

**Author contributions** AMVW, SMA-J and FMT carried out the design of the project and were responsible for the interpretation of results and writing of the manuscript. AMVW analysed the sample. L.A was responsible for the statistical analysis and interpretation of the results. JTG and MCCC assisted in the writing of the article. All authors reviewed, approved and contributed to the final version of the manuscript.

## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** This study was approved by the Ethics Committee and the Health Sciences Research Institute of the Federal University of Pará, Belém, Pará, Brazil under number 1.684.013.

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