Acta Scientiarum

http://periodicos.uem.br/ojs/acta
ISSN on-line: 1807-8648
Doi: 10.4025/actascihealthsci.v47i1.67122

Gender and age determination through linear and volumetric measurements of the sphenoid sinus using CBCT images

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ABSTRACT. This retrospective, observational, longitudinal study carried out a morphometric analysis of CBCT images of the sphenoid sinus to evaluate whether they can be used to determine gender and age in a mixed Brazilian population. 200 CBCT scans (100 females; 100 males) were retrospectively selected and the linear (maximum height, width, length) and volumetric measurements were taken in the right and left sphenoid sinuses. The sample was also divided according to age in 18-40 (n = 123) and>40 years (n = 77). The sinus volume was calculated using a formula (a multivariate discriminant analysis) and a software program, and the results were compared. All data were subjected to statistical analysis (p<0.05). Only the volume of the right sphenoid sinus showed a statistically significant difference (p ⩽ 0.05) between the genders, with lower values for females. Most measurements were higher in group 18-40 years (p<0.05). There was no difference between the volumes calculated using the formula and the software. The overall gender determination accuracy rate was 60.08%. For the>40 years group, the discriminant analysis achieved an accuracy index of 74%. Morphometric measurements of the sphenoid sinus in CBCT exams are useful for gender and age estimation in adult Brazilians. The greatest accuracy is obtained for determining age when individuals are over 40 years old.

Keywords: Radiography;cone-beam computed tomography; sphenoid sinus; forensic identification.

Received on February 14, 2023.
Accepted on August21, 2023.

Introduction

A challenging and time-consuming work performed by forensic doctors is the identification of mortal remains, particularly when they are fragmented, decomposed, partial, or when there are many bodies, such as in mass disasters. The gold standard for identifying human remains is DNA analysis. However, it is considered an expensive and slow method, which often makes it unfeasible. Thus, an alternative is identification through imaging exams. For many years, even with some limitations, radiographs have been used for identification in cases where bodies are in various stages of decomposition, and carbonization or when there are few remains available (Soares et al., 2016). Some of the limitations of two-dimensional examinations were overcome by computed tomography (CT), especially the cone beam CT (CBCT) which has very high accuracy for dry bones.

In forensic identification, structures more protected are being increasingly studied, as they are more likely to remain intact in cases of explosions, accidents, natural disasters, and other calamities(Wanzeler et al., 2019). Among these structures are the paranasal sinuses (Soares et al., 2016; Wanzeler et al., 2019). The sphenoid sinus is in the most inaccessible part of the face and its deep anatomical location can benefit forensic identification, as it is better protected from external traumas (Wanzeler et al., 2019; Souadih et al., 2020; Ramos et al., 2021).

Tomographic studies of the sphenoid sinus for forensic purposes are scarce and generally address homogeneous populations. There is a need to establish anthropometric standards for human identification in different populations (Dong et al., 2015; Shehri & Soliman, 2015; Ramos et al., 2021). As a result of increased human mobility around the world, the world's population is increasingly heterogeneous, leaving behind the old results of human identification studies, especially those carried out on samples of homogeneous populations. Brazil, which has continental dimensions, has a very mixed population, representing an interesting source for studies with forensic purposes. Therefore, this study aimed to assess whether the sphenoid sinus can be used to determine gender and age in a Brazilian population using CBCT images.

Material and methods

This retrospective and observational study was approved by the Permanent Ethics Committee for Experiments with Humans at the State University of Maringá (UEM), Brazil (CAAE: 03629118400000104) and was developed in accordance with the STROBE initiative (von Elm et al., 2007). Due to the retrospective nature of this study, the signed informed consent was not required by the Committee.

Sample collection

A total of 200 CBCT images were obtained from files from the Laboratory of Images in Clinical Research (LIPC), from the Oral and Maxillofacial Radiology Center (UEM), acquired between the years 2014 to 2019. All images were from Brazilians referred due to different clinical indications. The sample randomly included Caucasians (mainly of Italian, Portuguese, and Spanish descent), blacks, browns, mestizos, and Japanese descendants. The exclusion criteria were patients under 18 years of age and with poor-quality images, blurring, or artifacts caused by metallic objects in the region (Gibelli et al., 2018), and patients with a history of surgery and/or deformities in the sphenoid sinus region (Wanzeler et al., 2019).

CBCT image acquisition

All CBCT scans were performed by the same radiologist using i-Cat® Next Generation equipment (Imaging Sciences International, Hatfield, PA, EUA), with a field of view (FOV) of 17x23 cm or 16x13 cm, 120 Kvp, 3- 8 mA, 891.4 mGy * cm², 1 mm thick and an isometric voxel of 300 µm. Images were exported in DICOM (Digital Imaging and Communication in Medicine) format to ITK-SNAP®3.4.0 software (Cognitica, Philadelphia, PA, USA) (http://www.itksnap.org/download/snap/) for analysis.

Data analysis

All analysis and measurements were performed by a single independent radiologist, blinded to patient identification, and calibrated by the evaluation of 20 exams over two weeks, which were then discarded from the sample. All examinations were performed in duplicate with a minimum interval of one week to test intra-observer agreement. Only 10 exams were analyzed per day to avoid eye fatigue. The examiner was allowed to zoom the images twice and to change the brightness.

To detect sexual dimorphism, the sample was divided into male (n = 100) and female (n = 100). Considering that the sphenoid sinus tends to show a decrease in volume around 40 years of age (Yonetsu et al., 2000), for age prediction (regardless of gender), patients were classified as 18-40 years (n = 123) and >40 years (n = 77).

The positioning of multiplanar reconstructions (MPR) was standardized using the Frankfort horizontal plane as a reference in sagittal reconstruction. The following measurements (in mm) of the sphenoid sinus were taken: height, width, and length, as shown in Table 1 and Figure 1. The sinus volume was calculated using the formula V (volume) = (height x width x length) x 0.5 (Bangi et al., 2017). In addition, the volume of both sinuses was also calculated using a tool (*volume identification*) of the software ITK-SNAP. Sinuses were delimited according to their contour surfaces, carefully following the anatomical edges in MPR (Figure 2). After complete segmentation of the sinus, its volume was calculated in mm^3, and a three-dimensional (3D) model was generated by the software.

Table 1. Definition of linear measurements of the sphenoid sinus.

Definition	Reconstruction	Measurement	Initials
Maximum distance between the upper and lower edges of the sinus wall	Coronal	Maximum height	Maximum height right side – RMH
			Maximum height left side - LMH
Maximum distance between a more medial to a more lateral point of the sinus wall	Coronal	Maximum width	Maximum width right side – RMW
			Maximum width left side – LMW
Maximum distance between the anterior and posterior sinus walls	Axial	Maximum length	Maximum right length – RML
			Maximum left length – LML

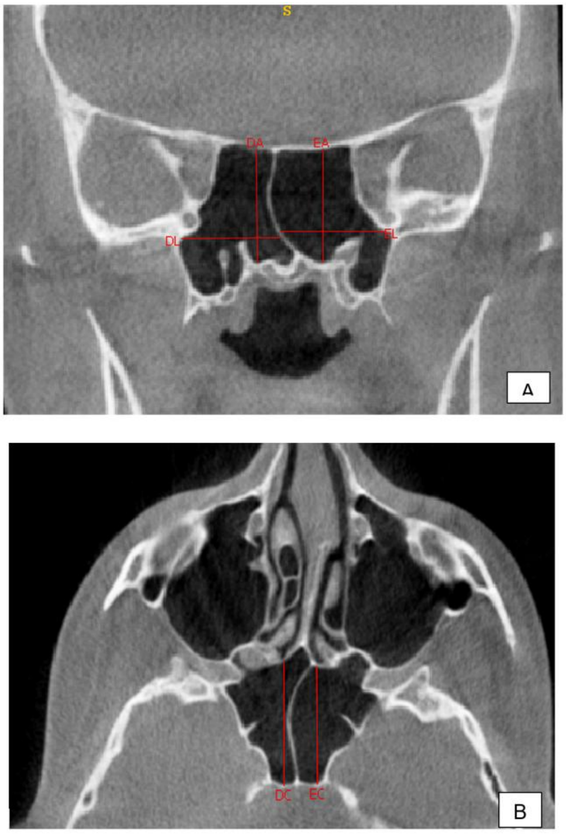

Figure 1. Linear measurements of right and left sphenoid sinuses. **A:** RMH, LMH, RMW, and LMW in coronal reconstruction; **B:** RML and LML in axial reconstruction.

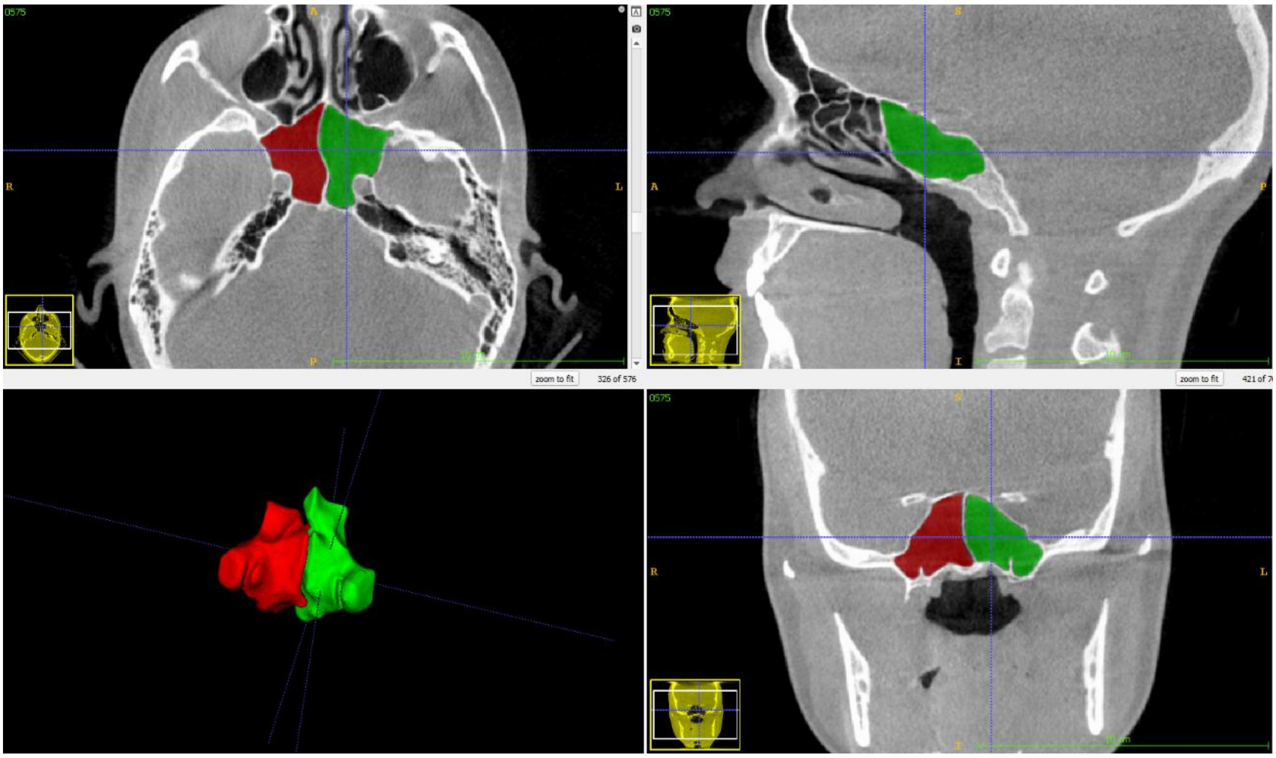

Figure 2. Delimitation of the sphenoid sinuses in axial, sagittal, coronal, and 3D reconstructions and volume calculation using the *volume identification* tool (software ITK-SNAP).

Statistical analysis

A database for qualitative and quantitative variables was constructed to allow tabulation and statistical analysis. All the statistical procedures were performed in SPSS22.0 (SPSS Inc., Chicago, IL, EUA) and Bioestat

5.3 (Mamirauá Institute, Pará, Brazil) softwares. Initially, a descriptive analysis was performed to obtain the absolute and relative numbers. The Intraclass Correlation Coefficient (ICC) was used to test intra-observer agreement. To assess the Gaussian distribution of the data, the Shapiro-Wilk test was adopted. The t-test was applied for independent variables between genders and age groups. To develop a formula capable of determining gender and age through measurements of the sphenoid sinuses, a multivariate discriminant analysis was performed using the direct method, for which the Lambda Wilks test was applied.

Results

The mean age of the sample was 37.15 years (standard deviation ± 14.60), ranging from 18 to 77 years. The ICC for all parameters obtained values >0.983, indicating excellent reliability.

Only the volume of the right sphenoid sinus showed a statistically significant difference ($p \leq 0.05$) between the genders (Table 2). This difference occurred both for the volume calculated by the formula and by the software. When comparing age groups, in general, the measurements were higher in group 18-40 years, as shown in Table 3).

Table 2. Means (± standard deviation) of linear measurements and volume of sphenoid sinuses in males and females.

Measurements	Gender	n	Mean	SD	p-value
RMH (mm)	M	100	21.30	4.32	0.496
	F	100	20.91	3.83	
RMW (mm)	M	100	19.71	6.42	0.065
	F	100	18.62	5.53	
RML (mm)	M	100	24.70	7.56	0.089
	F	100	23.07	5.80	
Right volume - software (mm^3)	M	100	5691.35	3227.27	0.005*
	F	100	4500.71	2723.72	
Right volume – formula (mm^3)	M	100	5897.47	3696.41	0.011*
	F	100	4673.65	3031.70	
LMH (mm)	M	100	21.38	4.39	0.869
	F	100	21.28	3.94	
LMW (mm)	M	100	19.36	6.31	0.800
	F	100	19.58	6.05	
LML (mm)	M	100	23.84	7.10	0.459
	F	100	24.54	6.17	
Left volume - software (mm^3)	M	100	5417.50	3354.16	0.983
	F	100	5427.02	2884.62	
Left volume – formula (mm^3)	M	100	5659.17	3823.69	0.957
	F	100	5632.12	3263.03	

Independent Student's t-test; SD (standard deviation); M: male; F: female; *statistically significant.

Table 3. Means (± standard deviation) of linear measurements and volume of sphenoid sinuses according to age groups.

Measurements	Age	n	Mean	SD	p-value
RMH (mm)	≤ 40	123	21.79	4.16	
	>40	77	20	3,71	0.002*
	Total	200	20.895	3.935	
RMW (mm)	≤ 40	77	19.94	6.4	
	>40	123	16.64	4.91	<0.001*
	Total	200	18.29	5.655	
RML (mm)	≤ 40	123	24.38	6.94	
	>40	77	23.09	6.46	0.191
	Total	200	23.735	6.7	
Right volume – software (mm^3)	≤ 40	123	5653.41	3302.56	
	>40	77	4205.66	2312.86	0.001*
	Total	200	4929.535	2807.71	
Right volume – formula (mm^3)	≤ 40	123	5935.63	3770.35	
	>40	77	4247.13	2482.03	0.001*
	Total	200	5091.38	3126.19	
LMH (mm)	≤ 40	123	21.63	4.39	
	>40	77	20.85	3.75	0.195
	Total	200	21.24	4.07	
LMW (mm)	≤ 40	123	20.2	6.93	

	>40	77	18.3	4.51	0.034*
	Total	200	19.25	5.72	
LML (mm)	≤ 40	123	24.53	6.81	
	>40	77	23.64	6.37	0.356
	Total	200	24.085	6.59	
Left volume – software (mm^3)	≤ 40	123	5768.68	3408.64	
	>40	77	4868.88	2517.67	0.47
	Total	200	5318.78	2963.155	
Left volume – formula (mm^3)	≤ 40	123	6084.5	3893.75	
	>40	77	4944.61	2787.09	0.027*
	Total	200	5514.555	3340.42	

Independent Student's t-test; SD (standard deviation); M: male; F: female; *statistically significant.

The results of the discriminant analysis function for gender differences are listed in Table 4. The calculated reference value was 0. Therefore, a value of D >0 indicates male, while a value<0 indicates female. Confidence in the male diagnosis (specificity) is greater when the D-value is much greater than the decision value of 0, and confidence in the female diagnosis (sensitivity) is greater when the calculated D-value is much smaller (in the negative direction) than the decision value of 0. When all parameters were combined, the overall gender determination accuracy rate was 60.08%. The age group that achieved greater precision in gender discrimination was>40 years, with 74%. When all variables are grouped, the same sensitivity and specificity values were found (Table 5).

Table 4. Discriminant analysis between genders and age groups.

Total (gender)			
D = 5.662 – 0.235* (RMH) – 0.039* (RMW) – 0.041*(RML) + 0.041* (LMH) – 0.158 (LMW) – 0.079 (LML) Wilks' Lambda = 0.925; p<0.001			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Overall
	58.9%	61.36%	60.08%
Functions at centroid group	Male	Female	Male
	0.283	-0.283	if D>0
18 – 40 years			
D = 5.248 – 0.052* (RMH) – 0.028* (RMW) + 0.003* (RML) - 0.045* (LMH) – 0.176 (LMW) – 0.156 (LML) Wilks' Lambda = 0.803; p<0.001			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Overall
	59.70%	64.28%	61.8%
Functions at centroid group	Male	Female	Male
	0.261	-0.274	if D>-0.013
>40 years			
D = 5.290 – 0.427* (RMH) – 0.169* (RMW) - 0.154* (RML) - 0.116* (LMH) – 0.017 (LMW) – 0.028 (LML) Wilks' Lambda = 0.723; p = 0.012			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Overall
	73.80%	74.28%	74%
Functions at centroid group	Male	Female	Male
	0.634	-0.587	if D>-0.030

Table 5. Discriminant analysis between genders and age groups with all measurements.

Total (gender)			
D = 5.662 – 0.235* (RMH) – 0.039* (RMW) – 0.041* (RML) + 4.07*10^{-4}*(Right volume – software) + 1.79*10^{-4}*(Right volume – formula) + 0.041*(LMH) – 0.158 (LMW) – 0.079 (LML) + 3.01*10^{-5}*(Left volume – software) + 3.43*10^{-4}*(Left volume – formula) Wilks' Lambda = 0.925; p<0.001			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Overall
	58.9%	61.36%	60.08%
Functions at centroid group	Male	Female	Male
	0.283	-0.283	if D>0
18 – 40 years			
D = 5.248 – 0.052*(RMH) – 0.028*(RMW) + 0.003*(RML) + 4.09*10^{-4}*(Right volume – software) – 1.14*10^{-4}*(Right volume – formula) - 0.045*(LMH) – 0.176 (LMW) – 0.156 (LML) – 3.54*10^{-5}*(Left volume – software) + 5.36*10^{-4}*(Left volume – formula) Wilks' Lambda = 0.803; p < 0.001			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Overall

	59.70%	64.28%	61.8%
Functions at centroid group	Male	Female	Male
	0.261	-0.274	if D>-0.013
>40 years			
D = 5.290 – 0.427*(RMH) – 0.169*(RMW) - 0.154*(RML) + 4.55*10^{-4}*(Right volume – software) + 9.46*10^{-4}*(Right volume – formula) - 0.116*(LMH) – 0.017 (LMW) – 0.028 (LML) + 2.58*10^{-4}*(Left volume – software) – 1.95*10^{-4}			
Wilks' Lambda = 0.723; p = 0.012			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Overall
	73.80%	74.28%	74%
Functions at centroid group	Male	Female	Male
	0.634	-0.587	if D>-0.030

In Table 6, only the measurements that showed statistically significant differences between the male and female groups (right volume by software and formula) were used. The calculated reference value was 0. Therefore, a value of D >0 indicates male, while a value <0 indicates female. Confidence in the male diagnosis (specificity) is greater when the D-value is much greater than the decision value of 0, and confidence in the female diagnosis (sensitivity) is greater when the calculated D-value is much smaller (in the negative direction) than a decision value of 0. When the two measures were analyzed together, the accuracy for predicting gender was 59.5%.

Table 6. Gender discriminant analysis using the predominant measure of discrimination (right volume by formula and software).

Total (gender) Right Software Volume			
D = -1.707 + 0.235*10^{-4}*(right volume - software)			
Wilks' Lambda = 0.961; p = 0.005			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Accuracy
	60.0%	63.52%	60.08%
Functions in the group centroid	Male	Female	Male
	0.199	-0.199	se D>0
Total (gender) Right Formula Volume			
D = - 1.564 + 2.96*10^{-4}*(right volume - formula)			
Wilks' Lambda = 0.968; p = 0.011			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Accuracy
	61.01%	65.85%	63.0%
Functions at centroid group	Male	Female	Male
	0.181	-0.181	se D>0
Total (gender) Right Software Volume + Right Formula Volume			
D = - 1.721 + 5*10^{-4}*(right volume - formula) – 1.57*10^{-4}*(right volume - formula)			
Wilks' Lambda = 0.960; p = 0.019			
Percentage of accuracy in predicting sex	Specificity	Sensitivity	Accuracy
	57.98%	61.72%	59.5%
Functions in the group centroid	Male	Female	Male
	0.202	-0.202	se D>0

Discussion

Determining gender and height are some of the most important aspects of forensic anthropology (Ramos et al., 2021), with several methods described. Especially in cases of violent trauma, identification from the skeleton remains a viable alternative (Auffret et al., 2016). In a complete skeleton, gender can be determined with 100% accuracy (Wanzeler et al., 2019). This rate decreases to 98% in the presence of the pelvis and skull (Wanzeler et al., 2019) and tends to decrease as the bony remnants decrease.

The anatomical characterization of the paranasal sinuses has proven to be valuable for identification purposes (Souadih et al., 2020). There are significant differences between the normal paranasal sinuses of different individuals, especially the sphenoid sinuses, due to their extreme variability in shapes and extent of pneumatization, which make them different even between identical twins (Chaiyasate et al., 2007). In addition, they are in a position of relative depth in the center of the skull base, offering good protection against external traumatic factors (Souadih et al., 2020). Summing up all the factors, it is possible to infer that the sphenoid sinuses are of great value for forensic identification, especially when using CBCT for analysis (Chaiyasate et al., 2007; Souadih et al., 2020).

CBCT has shown excellent results compared to conventional radiographs, maximizing the accuracy of these analyses (Auffret et al., 2016), without overlap and allowing a three-dimensional scan of bone structures. Regardless of the positioning during image acquisition, it allows accurate measurements, functioning as a more modern and reliable identification method for forensic medicine (Soares et al., 2016). The reliability of this technology in identifying human remains has already been proven in some studies (Michel et al., 2015; Radulesco et al., 2018; Wanzeler et al., 2019; Teixeira et al., 2020;). Although this method is still poorly used in this medical modality, gender estimation in CBCT images proved to be efficient for the maxillary (Radulesco et al., 2018; Teixeira et al., 2020) and frontal sinuses (Gibelli et al., 2018). As for the sphenoid sinus, CBCT images are less used for identification purposes and sexual dimorphism, and the results of studies differ (Cohen et al., 2018; Wanzeler et al., 2019; Yonetsu et al., 2000; Ramos et al., 2021), demonstrating an important environment for study (Wanzeler et al., 2019; Ramos et al., 2021).

Studies on sexual dimorphism in human bones demonstrate the need to establish anthropometric standards for different populations around the world (Dong et al., 2015; Shehri & Soliman, 2015; Ramos et al., 2021). Currently, with increasing human mobility between countries and continents, the world population has become more heterogeneous, making the old results of human identification studies outdated, especially those carried out with samples from homogeneous populations (Tunis et al., 2017). With a large and highly mixed population, Brazil can be considered a heterogeneous country (Caucasians, Africans, descendants of Orientals, Indigenous, etc.), an interesting site for forensic studies of human identification (Zanutto, Tolentino, Iwaki, Walewski, & da Silva, 2021). Due to the scarcity of studies on the applicability of the dimensions of the sphenoid sinus in the sexual dimorphism of unknown individuals in the Brazilian population, this research was developed to contribute to this theme. In forensic identification, one of the main points to be analyzed is the determination of gender (Zanutto, Tolentino, Iwaki, Walewski, & Silva, 2021). Some authors (Oliveira et al., 2017) reported that the mean values of the sphenoid sinuses of the male and female groups make it difficult to use this anatomical structure to estimate gender. However, other studies (Cohen et al., 2018; Gibelli et al., 2018; Ramos et al., 2021) detected statistically significant differences ($p<0.05$) between male and female when the sphenoid sinus volume was calculated. Only Wanzeler et al. (2019) applied the discriminant analysis, similarly to the present work. Corroborating some studies, we found smaller linear and volumetric measurements of the sinus in females (Özer et al., 2018; Nejaim et al., 2019; Yonetsu et al., 2000; Ramos et al., 2021). The volumetric differences, calculated both with the software and with the formula, were statistically significant ($p = 0.005$; and $p = 0.011$ respectively) for the right side. Although the literature does not indicate a reason for this unilateral difference, we can speculate that the sphenoid sinus has a dominant side (Tan & Ong, 2007) and that the discrepancy between the sides can be statistically significant (Oliveira et al., 2017).

In the discriminant analysis for gender, when all linear measures were included in the formula, the specificity was 58.9%, the sensitivity was 61.36%, and the overall accuracy index was 60.08%. When all measures or measures with statistically significant differences were applied to the formula, these values differed very little. These values are lower than those found by Wanzeler et al. (2019), whose hit rate for male and female was respectively 73.7 and 81.9%, with an overall hit rate of 77.9%.

For age, in the discriminant analysis, the sensitivity, specificity, and general accuracy index were higher, being 59.70, 64.28, and 61.8% for the 18-40 age group, respectively. For >40 years, these values were 73.80, 74.28, and 74%, respectively. Due to the lack of investigations on age prediction, our findings may be a starting point for further investigations in this area.

To ensure the analysis of fully developed sphenoid sinuses, we selected individuals over 18 years of age. We consider that the size and shape of the paranasal sinuses are correlated with gender and age (Cohen et al., 2018; Yonetsu et al., 2000; Ramos et al., 2021) and that measurements are more reliable in adults (Wanzeler et al., 2019). Hormonal variations, including growth and development hormones during puberty, affect the bone structures of young people and, with advancing age, there is a decrease in the volume of the sphenoid sinus (Yonetsu et al., 2000; Cohen et al., 2018).

We found higher measurements in the younger group, with some statistically significant parameters, such as RMH ($p = 0.002$), RMW ($p = 0.001$), LMW ($p = 0.034$), right volume – software ($p = 0.001$), and right and left volume – formula ($p = 0.001$ and $p = 0.027$, respectively). These findings confirm a decrease in the volume of sphenoid sinuses with age, which has already been shown in some studies (Yonetsu et al., 2000; Karakas & Kavaklı, 2005).

Differences in volumetric measurements led to speculation on the feasibility of calculating the sphenoid sinus volume for *postmortem* estimation of both gender and age, with greater sensitivity and specificity. For specialists in forensic anthropology to be able to reproduce measurements, reliability, and reproducibility are important factors (Ramos et al., 2021). In the present study, the intraclass correlation index was 0.983, showing excellent reproducibility for linear and volumetric measurements taken in the sphenoid sinus. Variations in accuracy rates reported in the literature are likely due to ethnic and racial variability, different methodologies and statistical tests, different radiographic techniques, and sample sizes (Wanzeler et al., 2019). From an ethnic point of view, similar studies address exclusively Amazonian (Wanzeler et al., 2019) or Caucasian populations (Cohen et al., 2018).

Part of this work was dedicated to checking the accuracy of a software (ITK-SNAP 3.4.0®) for calculating the volume using CBCT images, to estimate gender and age, since the sphenoid sinuses have an irregular shape, thus reducing the possibility of errors. Their results were compared to linear measurements and mathematical volume calculations, with no differences between the two methods. This software was used because it allows for reliable measurements, with complete filling of the outlined region, preventing area differences from interfering with data reliability. In addition, since 2006, the software has been cited in more than 1,700 papers and has been validated as a reliable tool by the scientific community (Yushkevich et al., 2016).

Among the methodological limitations of this study are those inherent in estimating gender based on linear or volumetric measurements of skull components, since skull size is generally larger in male (Teixeira et al., 2020). The small differences in measurements between male and female (about 3 to 4 mm) may be experimentally significant but irrelevant in practice. Still, the method is an alternative for determining gender and age, especially when other methods are inconclusive. Due to the lack of investigations on age prediction, the findings of the present study may be a starting point for further research in this area.

Conclusion

To summarize, only the volume of the right sphenoid sinus showed a statistically significant difference ($p \leq 0.05$) between genders, with lower values for females. Most measurements were higher in group 18-40 years ($p < 0.05$). There was no difference between the volumes calculated using the formula and the software. The overall gender determination accuracy rate was 60.08%. For the>40 years group, the discriminant analysis achieved an accuracy of 74%. These results demonstrate that morphometric measurements of the sphenoid sinus in CBCT exams are useful for gender and age estimation in adult Brazilians. The highest accuracy is obtained for determining age when individuals are over 40 years old.

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