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The Application of Frontal and Maxillary Sinuses Indices for Computed Tomography-Based Sex Estimation of a Brazilian Population

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Abstract. This investigation aimed to compare the sexing accuracy of frontal (FS) and maxillary (MS) sinus indices with multislice computed tomography (MSCT) in Brazilian adults. This cross-sectional study was conducted on 100 MSCT examinations (50 males and 50 females). The height, width, and diameter of the FSs and MSs were obtained with the RadiAnt software to measure four indexes (I): FSI-1 and MSI-1 (both width/ diameter); FSI-2 and MSI-2 (both height/diameter). Areas under receiver operating characteristic curves (AUROC) were determined. Sensitivity, specificity, likelihood ratio (LR), and accuracy values were also calculated. The highest area under the ROC curve for the FS was obtained by the FSI-1 (0.712 ± 0.052; $p < 0.001$), whereas for the MS it was found in the MSI-2 (0.431 ± 0.058; $p = 0.232$). FSI-1 showed greater specificity (64%) in predicting female sex as well as greater accuracy (64%) and LR (3.16). MSI-1 had the highest sensitivity value (68%) in estimating male sex and the second highest LR value (2.13). The FSI-1 developed in the present study exhibited higher accuracy compared to the other evaluated indices, which reinforces its importance for future studies with other populations.

Keywords: Sexual dimorphism; Frontal sinus; Maxillary sinus; Computed tomography.

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1. Introduction

Sex estimation of human remains is a crucial forensic procedure during the identification process[1,2]. In this context, research has highlighted the use of teeth as an additional tool in the distinguishment between male and female individuals because of their ability to withstand destruction. However, it is noteworthy that sexual dimorphism (SD) can be observed in other structures of the human body, with the most prominent skeletal variations between the sexes being found in the bony pelvis and its adjacent bone structures, especially those that constitute the hip joint, such as the acetabulum and the head of the femur[3].

The ability to classify the skull according to ethnicity is of great value when a skeleton or skull of unknown origin is found and no other methods of identification are possible due to decomposition[4]. In fact, the identification of human remains is one of the aspects of great relevance in the context of forensic anthropology, especially in investigation processes that require post-mortem identification[5,6].

In the contemporary population, there is a relative scarcity of specific morphometric landmarks for sex estimation in skeletal remains from unknown individuals. This may reflect a historical evidence of insufficient and poor documentation of human skeletons[1,7]. In this context, the skull and its various landmarks, such as the supraorbital margin, nasal opening, and mastoid process are useful indicators of sex, supporting the sex estimation process with high levels of accuracy[8].

There are several imaging modalities, ranging from conventional techniques, such as lateral cephalogram, to advanced technologies including multislice computed tomography (MSCT) and cone-beam computed tomography (CBCT)[9]. A current example that illustrates the relevance of modern imaging methods is the use of virtopsy, which has been gaining prominence in the field of forensic investigation. This technique employs three-dimensional (3D) imaging methods routinely used in medicine to map the outer surface of the body where it is possible to record and document detail-rich images[10].

Computed tomography (CT) facilitates the work of forensic anthropologists and pathologists by providing faster and more accurate identification[11]. The nasal cavity and the paranasal sinus (PS) are areas of significant structural variability and complexity that often require CT examination in preoperative evaluations and during the study of inflammatory nasosinusal diseases. This imaging exam has been increasingly used in recent decades to establish nasosinusal imaging parameters. Moreover, this type of examination has yielded agreeable results with anatomical dissection studies[12].

Several studies have indicated morphometric analysis of the maxillary sinus (MS) as an effective and faster method of sex identification[13,14]. The frontal sinus (FS) has also been proposed as an anatomical landmark, significantly improving sexing reliability. The term sinus index corresponds to the ratio between the height and width of the FS and it has been applied in lateral cephalometric radiographs to overcome limitations obtained from absolute cephalometric measurements[15]. Several studies have investigated the potential of the frontal and maxillary sinuses during sex estimation. However, the available results suggest that the frontal sinus index has little potential, as successful identification indices have consistently been low.

In the present research, the indices (ratio between height and diameter, and width and diameter) of the frontal and maxillary sinuses were used as study variables. The aim of this study was to evaluate the accuracy of frontal and maxillary sinuses indices for sex estimation among adult individuals in the State of Ceará, Brazil.

2. Material and methods

2.1 Study design, context, and participants

This observational, cross-sectional, and retrospective study was carried out with MSCT images from the imaging service of a reference hospital in the State of Ceará, Brazil. Therefore, the recommendations for observational research proposed by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) initiative were followed[16]. This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Federal University of Ceará, in accordance with Resolution n. 466, December 12, 2012, of the National Health Council.

2.2 Variables

The sample comprised CT images of individuals of both sexes who suffered cranial and facial trauma in the last ten years and who also met the following eligibility criteria: a) aged between 18 and 39 years; b) maxillary dentition from the first premolar to the second molar. Tomographic images exhibiting signs of fracture, sinusopathies, or artifacts (such as dental implants and fracture fixation plates or screws), and images with inadequate quality for the evaluation of the sinus structures were excluded. CT images of individuals who had undergone more than one tomographic examination during the study period were removed to avoid duplicate data (in this case, the tomographic image with the earliest acquisition date was excluded).

2.3 Data sources and measurements

The MSCT images for the present study were obtained from a single tomography device (Somatom Emotion 6, Siemens, Forchheim, MedicalSolutions, Germany) under the following acquisition protocol: 1-mm table increment, 130 kVp, voltage setting ranging 80 to 140 mA, 2.0-mm image cross-sectional thickness, 180-mm field of view, and 0.6-second rotation time.

Data collection was performed by an observer previously trained to perform the analyses, which were repeated after 3 weeks. In this training stage, 20% of the study images were randomly chosen and used for the intra-examiner reliability analyses. For validation of measurements, from the five repetitions, Cronbach's Alpha was calculated to measure the internal consistency, the interclass correlation coefficient to verify the systematic error and the Hotelling's T-Squared multivariate analysis to calculate the random error (Table 1).

Linear evaluations were performed on the same computer (Dell Inc., model G3 3590, Intel® Core ™ i5-9300H processor CPU @ 2.40 GHz, 2400 Mhz, 4 cores, 8 logic processors - HD LED backlight display). The observer was allowed to adjust the screen brightness to perform the analyses. For the SP measurements, the axial, sagittal, and coronal sections were standardized with a slice thickness of up to 2.0 mm. The positioning of the sections followed a parallel plane to the hard palate in the coronal section overlapping with the median palatal suture in the axial plane.

Table 1. Sample characterization and reproducibility analysis of maxillary sinus measurements to identify sexual dimorphism in cone beam tomography.

	Validation Coefficients			Mean				Coefficient of variation		
	Cronbach's α	Hotelling's T-Squared	ICC	Total	Female	Male	p-value[a]	Female	Male	p-value[b]
Frontal										
Height	0.999	**<0.001**	0.997	2.92±1.13	2.65±0.93	3.19±1.26	**0.018**	35.1%	39.5%	**0.035**
Width	0.993	**<0.001**	0.967	5.21±1.73	4.99±1.59	5.43±1.85	0.201	31.9%	34.1%	0.406
Diameter	0.993	**<0.001**	0.967	1.12±0.39	0.96±0.26	1.28±0.43	**<0.001**	27.1%	33.6%	**0.001**
Maxillary Right										
Height	0.999	**<0.001**	0.994	3.65±0.49	3.48±0.45	3.82±0.47	**<0.001**	12.9%	12.3%	0.699
Width	0.999	**<0.001**	0.994	2.83±0.51	2.70±0.42	2.95±0.56	**0.011**	15.6%	19.0%	0.337
Diameter	0.998	0.074	0.998	3.92±0.38	3.83±0.25	4.02±0.46	**0.011**	6.5%	11.4%	**0.015**
Maxillary Left										
Height	0.999	**<0.001**	0.999	3.67±0.50	3.51±0.45	3.84±0.49	**0.001**	12.8%	12.8%	0.966
Width	0.999	**<0.001**	0.994	2.82±0.49	2.66±0.41	2.98±0.51	**0.001**	15.4%	17.1%	0.287
Diameter	0.947	0.351	0.781	3.92±0.36	3.82±0.27	4.02±0.41	**0.004**	7.1%	10.2%	**0.048**

a Student's t test; b Levene test; mean ± standard deviation; ICC = Interclass Correlation Coefficient; H = Height; L = Width; Di = Diameter; D = Right; E = Left.

A linear assessment of the FS and the MS was performed in 100 CTs (50 males and 50 females). The longest linear distance in a straight line between the borders of the sinuses at different views was measured (Table 2) using the RadiAnt software (Medixant, Poznan-Poland, version 4.6.9.18463, 64 bit). Then, the indices (ratio between measurements) were determined in both sinuses: MSI-1: Width/Diameter; MSI-2: Height/Diameter; FSI-1: Width/Diameter; FSI-2: Height/Diameter (Figure 1).

Table 2. Linear parameters evaluated in the frontal and maxillary sinuses in their widest section.

Definition	View	Parameter
Distance between the superior and inferior borders	Coronal	Height
Distance between the anterior and posterior walls	Axial	Diameter
Maximum distance between the outermost limits of the sinus walls	Axial	Width

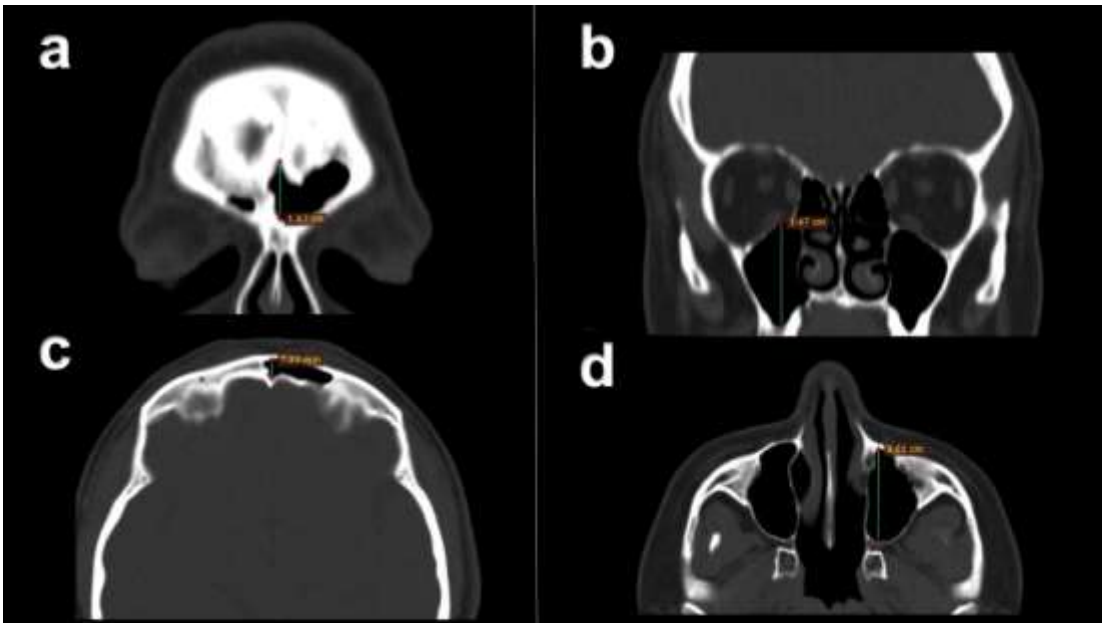

Figure 1. Axial and coronal multislice computed tomography views; a) maximum distance between the superior and inferior borders of the frontal sinus; b) maximum distance between the superior and inferior borders of the maxillary sinus; c) maximum distance between the anterior and posterior walls of the frontal sinus; d) maximum distance between the anterior and posterior walls of the maxillary sinus.

2.4 Bias

To avoid selection bias, the sample size calculation aimed at estimating an adequate and equally divided number of individuals of both sexes.

After sample selection and standardization, MSCT scans with signs suggestive of pathological changes or trauma, which may be considered confounding factors, were excluded. As an additional effort to avoid measurement errors, imaging exams were evaluated by two trained observers who were blinded to the sex of the participants, and the reliability of these measurements was calculated.

2.5 Statistical methods

The Kolmogorov-Smirnov test was used to assess the normality of the data. Measurements were expressed as mean and standard deviation values, and categorical data were expressed as absolute and relative frequencies. Bivariate analysis was performed with Student's t-test (linear measurements between males and females). The coefficient of variation was also calculated, and the homogeneity of variance regarding sex was assessed using Levene’s test.

A receiver operating characteristics (ROC) curve was developed to identify SD-related cutoff points and to obtain the area under the curve (AUC), sensitivity, specificity, positive and negative predictive values, accuracy, and likelihood ratio. To establish an age-related subgroup analysis, sensitivity, specificity, positive and negative predictive values, accuracy, and likelihood ratio for individuals aged 30 years and older were calculated.

3. Results

A total of 100 CT scans were evaluated, 50 of men and 50 of women. The mean age was 26.30 ± 3.22 years (18 – 40 years), with no significant difference between men (25.26 ± 5.06) and women (27.34 ± 6.49) ($p = 0.077$).

3.1 Reliability

The reliability with regard to the method was observed to be significant for the linear measurements relating to the sinuses, varying from satisfactory ($r = 0.822$) to highly satisfactory ($r = 0.997$). The paired t-test did not reveal any statistically significant difference between the initial set of measurements and the one repeated after 21 days. The ICC showed satisfactory values ranging from 0.896 to 0.998.

3.2 Reproducibility analysis

The validation analysis of the FS measurements exhibited high values of Cronbach's alpha (> 0.800) and interclass correlation index (ICC) (> 0.800), in addition to a significant correlation of Hotelling's T-squared ($p < 0.001$).

3.3 Cutoff points and ROC curves

The cutoff points based on the ROC curves (Figure 2) to estimate SD are shown in Table 3. The FSI-1 presented a moderate predictive capacity (between 60 and 80%) with a significant likelihood ratio (3,16) and the highest accuracy values (64.0%) (Table 4).

3.4 The measurements of the MS and FS indices were significant predictors of sexual dimorphism

The ROC curve-based (Figure 2) cutoff points for the estimation of sexual dimorphism are shown in Table 4. Most of the AUC values were significantly higher, compared to the null axis of the ROC curve (> 0.500); Higher AUC values were observed in relation to the FSI-1.

The MSI-1 displayed the maximum sensitivity with regard to the identification of the male sex (68.0%), as shown in Table 4. Among females, the FSI-1 (64.0%) and MSI-2 (58.0%) presented the most significant values of specificity. The Frontal index 1 (64.0%) displayed the highest accuracy with the highest likelihood ratio (3.16; 95% confidence interval [CI] = 1.39 to 7.15).

4. Discussion

Sex estimation is one of the integral aspects of the personal identification of an unidentified corpse, thus requiring a very precise diagnosis[17]. This research evaluated MSCT images of the frontal and maxillary sinuses for sex estimation purposes. Currently, sinus computed tomography has replaced X-ray radiographs in routine medical practice. According to French medical guidelines, there is almost no indication for the use of radiographs for the diagnosis of sinus pathologies[18].

Some authors have reported that the zygomatic bones and MS remain intact even in situations in which the skull and other bones may be severely disfigured such as in explosions, warfare, and other mass disasters[9]. Chandra et al.[19] established the accuracy and reliability of the MS in estimating sex through morphometric landmarks (area and perimeter) using lateral cephalograms. Predictive accuracy was 70.8% for males and 62.5% for females. Fernandes et al.[4] conducted a study on dry skulls with 53 individuals (13 males; 13 females of European origin and 13 males; 14 females of African origin) using linear measurements and estimated volume. Ethnic and sex variations were identified in different groups, thereby establishing a predictive role of the MS in ethnic classification.

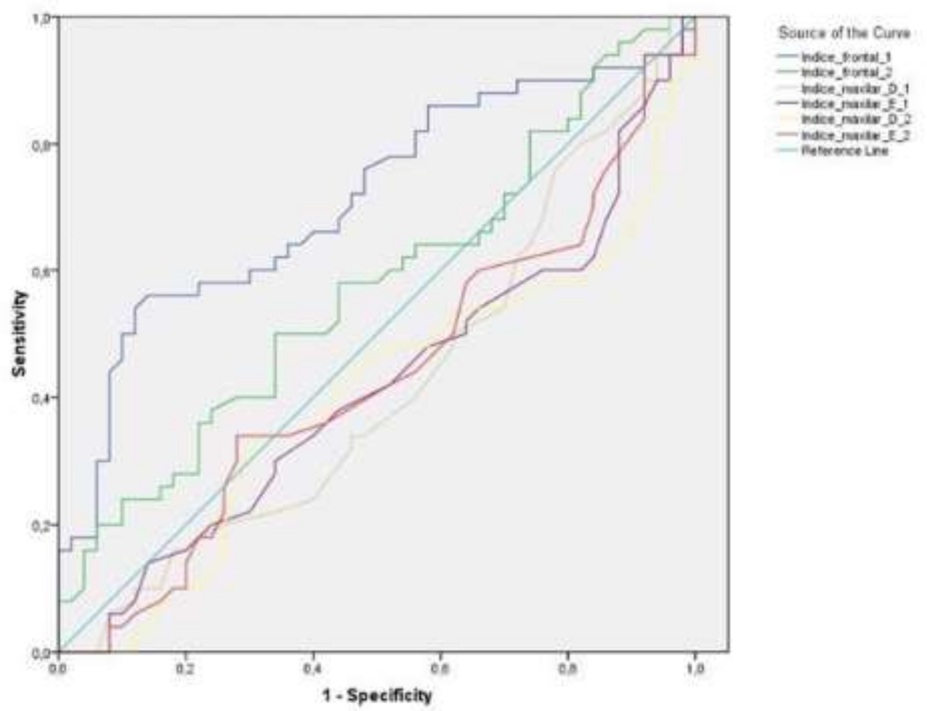

Figure 2. ROC curves showing cutoff values, sensitivity, and specificity of the frontal sinus indices (FSI-1 - blue and FSI-2 - green), right maxillary sinus indices (MSI-1 - brown and MSI-2 - yellow), left maxillary sinus indices (MSI-1 - purple and MSI-2 - red) and both maxillary sinuses (D).

Table 3. Sample characterization and reproducibility analysis of the maxillary sinuses in differentiating males from females.

Index	Area ± SEM (95%CI)	p-Value	Cutoff
Frontal 1	***0.712 ± 0.052 (0.609-0.815)***	***< 0.001***	***< 4.70***
Frontal 2	0.572 ± 0.057 (0.460-0.685)	0.213	> 2.50
Right maxillary 1	0.419 ± 0.057 (0.307-0.532)	0.165	> 0.70
Left maxillary 1	0.416 ± 0.057 (0.304-0.529)	0.150	> 0.70
Right maxillary 2	0.399 ± 0.057 (0.287-0.511)	0.082	> 0.95
Left maxillary 2	0.431 ± 0.058 (0.318-0.543)	0.232	> 0.95

* p < 0.05, ROC curve.

Table 4. Summary of sensitivity, specificity, accuracy, positive/negative predictive values, and likelihood ratio of the study variables (cm) in estimating sex.

	Sex		Sensitivity	Specificity	PPV	NPV		
	Male	Female	(M)	(F)	(M)	(F)	Accuracy	LR (95%CI)
Frontal index 1								
Female	18	32	64.0%	64.0%	64.0%	64.0%	64.0%	3.16 (1.39 to 7.15)
Male	32	18						
Frontal index 2								
Female	21	26	48.0%	42.0%	45.3%	44.7%	45.0%	0.67 (0.30 to 1.47)
Male	29	24						
Maxillary index 1								
Female	25	16	68.0%	50.0%	57.6%	61.0%	59.0%	2.13 (0.94 to 4.79)
Male	25	34						
Maxillary index 2								
Female	29	25	50.0%	58.0%	54.3%	53.7%	54.0%	1.38 (0.62 to 3.04)
Male	21	25						

M = Male, F = Female; PPV = Positive Predictive Value; NPV = Negative Predictive Value; LR = likelihood ratio; 95%CI = 95% confidence interval of the LR.

Kanthem et al.[9] in a study using tomography analysis conducted on an Indian population (17 males and 13 females), concluded that sex estimation may be possible using several parts of the body, such as the skull, pelvis, long bones, mastoid process, and PS. The following measurements were taken on the right and left MSs of the patients: height, depth, and thickness. The volume on the right side allowed for correct sex identification in 85.46% of cases, whereas the left side accounted for 78.38% of identification success.

The FS was first evaluated for SD purposes in 2014 by Kotrashetti et al.[20] who assessed the width, height, and area of the nasal sinuses in posteroanterior radiographs of an Indian population sample. These authors found a sex identification rate of 64.6%. The morphology of the FS may vary in different groups of individuals. The FS anatomy might not be captured on radiographs due to the angle and distance from the X-ray source, which reduces the credibility of research results using two-dimensional examinations[21]. Therefore, to reduce potential errors caused by these factors, 3D evaluations of tomographic exams must be performed.

Regarding other FS measurements, Luo et al.[22] considered the FS area to be of medium significance for sex estimation when using an index based on height and width from lateral facial radiographs. Several studies were developed based on the variability of the FS cavity to enable individual identification using logistic regression models, which were carried out with the inclusion of variables that proved to be relevant and yielded a sexing accuracy of 75.4%[14]. Uthman et al.[14] obtained the best accuracy for a sex estimation model, reporting a 76.95% success rate, which increased to 85.9% when other cranial measurements were added.

Periago et al.[23] performed CBCT measurements using the Dolphin Imaging System software and found that several linear measurements presented statistically significant differences compared to anatomical dimensions. The authors observed that bilateral measurements were significantly more accurate than midsagittal measurements. These results might help explain the findings of the present study, considering that we evaluated specific measurements for each sinus as well as measurements located in the midsagittal plane.

The use of PS for forensic purposes requires caution because of possible structural and developmental changes, such as in the FS, which can suffer hyperpneumatization in athletes[24]. As variations in radiographic techniques (distance, angle, and skull orientation) can modify FS dimensions, distorting its anatomical characteristics[25,26] we adopted MSCT as the imaging modality. The metric approach in sex estimation is more reliable than the morphological approach due to less interobserver variability and the presence of dimorphic features[24].

Sex estimation based on anthropometric methods has some limitations. It is specific to the study population, which in turn depends on several factors such as genetics, maternal health culture, environmental quality conditions during prenatal development, and race[27]. Therefore, the sex estimation measurements presented in this study may be more appropriate for a specific group, and the reliability of these measurements and the degree of SD evidenced in this article might be questionable for other populations. Therefore, specific assessments are required for each population, with further studies with larger samples being necessary to better represent these groups.

The methodology proposed for SD assessment in this study was based on indices of the frontal and maxillary sinuses. We used the ratio between linear measurements (indices) of MSCTs to assess the sinuses in our study. This study could help expand and prompt new research possibilities for the identification of humans, as the development of new indices might improve the selection of indicators for sex estimation.

5. Conclusion

In the present investigation, expressive mean values of the maxillary and frontal sinuses were found in both males and females. High values of reproducibility and precision were also observed.

The frontal and maxillary sinus indices constituted a valuable tool in the study of SD in MSCT images. The results of the present study are reliable and reproducible due to the standardization of the measurement procedures and the use of sagittal MSCT views.

These results indicate a potential role of FSI-1 as an auxiliary tool for sex estimation. We believe that this approach could be further investigated using other MSCT views or other imaging modalities such as CBCT focusing on SD.

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