Original Article

Forensic Evaluation of Highmore Antrum Sexual Dimorphism by Cone Beam Computed Tomography: A Retrospective Study of a Peruvian Population

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ABSTRACT

Objective: The aim of this study was to evaluate Highmore antrum sexual dimorphism by cone-beam computed tomography (CBCT) in a Peruvian population. **Materials and Methods:** This was a retrospective analytical study. The sample consisted of 190 CBCT scans. Inter-observer concordance was performed previously obtaining an intraclass correlation coefficient (ICC) of 0.99 for the width, length, and height of the right and left maxillary sinus. Then the dimensions of the maxillary sinus (left and right) were measured. All statistical analyses were performed using the Student's t test and Lambda de Wilks, establishing a level of significance of $P < 0.05$. **Results:** It was observed that on the right side of the maxillary sinus there were only statistically significant differences between the width, height, area, perimeter, and volume of the Highmore's antrum and sex with a $P < 0.05$. Statistically significant differences were observed between sex and the width, height, area, perimeter, and volume of the Highmore's antrum in the right side of the maxillary sinus ($P < 0.05$), whereas the left side only showed statistically significant differences between the height and volume of the Highmore's antrum and sex ($P < 0.05$). **Conclusion:** The maxillary sinuses have significant sexual dimorphism, with the parameter of height showing the greatest dimorphism according to the discriminant analysis.

KEYWORDS: *CBCT, Highmore antrum, Peruvian, sexual dimorphism*

INTRODUCTION

Human identification of human remains is performed based on the evaluation of multiple factors: the degree of deterioration of the body, length of exposure to the weather, and the related changes affecting the quality of postmortem data and the possibility of applying some identification methods. Comparative dental analysis (odontogram), fingerprint analysis, and DNA analysis are several of the most accurate measures for identification, whereas secondary methods include clothing analysis, tattoos, and medical history.[1-4]

Forensic Anthropology consists of the expert forensic study of challenges to human bone and the environment and the identification process (sex, age, affiliation, race, size, body proportions, individual features, and other anatomical regions). For example, Highmore's maxillary sinus or antrum is one of the cavities that

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make up the paranasal sinuses on the face, being the largest cavity and pyramidal in shape. It is located in the upper maxillary bone, with one on each side of the face and provides resonance to the voice, decreases the weight of the skull, and heats and cleans the inspired air.[5-7]

Knowledge of the topographic anatomical relationships of the dental system with the maxillary sinuses can help avoid complications derived from bucosinusal communication in implant treatments, endodontics, oral surgery, and oral pathology[8,9] Structures that are recovered intact are ideal for the purposes of forensic studies. The maxillary sinuses meet this requirement because they present fewer alterations in human remains and are used for the identification of sex.[10]

The skull and other bones of victims who are cremated can be very disfigured unlike the maxillary sinuses which, in certain cases, remain intact. Therefore, the maxillary sinuses can be used to aid in the identification of bodies which are fragmented. The presence of sexual dimorphism in the maxillary sinuses by cone-beam computed tomography (CBCT) can predict the sex of an individual in 71% of the cases [3]. For this reason, CBCT is used to morphometrically analyze the maxillary sinuses. CBCT can determine the width, length, height, perimeter, area, and volume of the maxillary sinuses, which in turn can establish sexual dimorphism and thereby assist in human identification.[11-13]

For this reason, the objective of this study was to evaluate sexual dimorphism of the antrum of Highmore by CBCT in a Peruvian population.

MATERIALS AND METHODS

PARTICIPANTS
The patients were recruited from the Faculty of Dentistry of the *Universidad Nacional Mayor de San Marcos* (UNMSM). A descriptive, observational, retrospective, transversal study was performed. The unit of analysis was made up of axial, coronal slices of the maxillary sinuses in CBCT. The sample consisted of *n* = 190 CBCT studies. The sampling was of the probabilistic type (simple random sampling technique) and the formula for estimating a proportion with an α = 0.05 and a β = 0.8 using the Stata15 was used to calculate the size. The STROBE guidelines (Strengthening the reporting of observational studies in epidemiology) were used for preparing this manuscript.

SELECTION CRITERIA
Inclusion criteria
• Patients between 20 and 70 years of age.

• CBCT scans with the presence of full permanent dentition.

Exclusion criteria
• Patients associated with diseases of the maxillary sinus.
• CBCT scans of patients with deciduous dentition.
• CBCT images showing distortions or quality alterations that do not adequately distinguish the various anatomical and dental structures.

CALIBRATION FOR MEASUREMENT
The calibration consisted of performing the measurements of the maxillary sinuses in each of the 13 CBCT: width and length in axial section, height in coronal section. At first, the investigator and the specialist analyzed the same tomography separately and noted the data in their respective files. Inter-observer agreement was obtained with an intraclass correlation coefficient (ICC) of 0.99 for the length and width of right and left maxillary sinus, indicating an almost perfect inter-examiner correlation.

EVALUATION OF THE IMAGES
The dimensions of the maxillary sinuses (left and right) of 190 CBCT scans were measured using the PointNix Realscan-CDviewer 2.0 program. The image was obtained with a volume thickness of 2 mm to obtain more enhanced measurements in coronal and axial slices. The CBCT images were measures by the same clinician. To verify the desired structure, it was located in the axial section axial slices were made to show the zygomatic process of the upper jaw and the mandibular condyle oriented to establish the greatest width of the maxillary sinuses. The following measurements were made: (a) width of the maxillary sinus: The greatest distance from the zygomatic process of the maxilla to the medial wall of the maxillary sinus, and (b) length of the maxillary sinus: The greatest distance from the anterior to the posterior wall of the maxillary sinus [Figure 1].

TOMOGRAPHIC SLICES
Coronal slices were made by superimposing the axis on the width of antrum of Highmore in axial view to measure the height of the maxillary sinus. (a) Maxillary sinus height: The greatest distance from the base of the orbit to the floor of the maxillary sinus. Then, the perimeter, area, and volume measurements were made manually by measuring: the area of the maxillary sinus (length by width), maxillary sinus perimeter (2 by length + 2 by width), and maxillary sinus volume (length by width by height / 2). To determine the sex
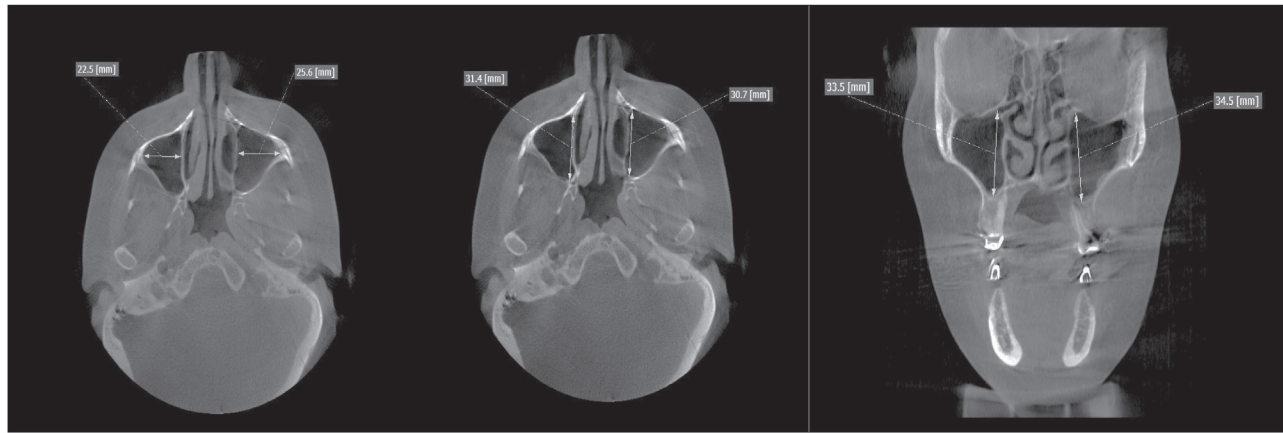
Figure 1: Dimensions: length, width, and height of antrum of Highmore in a Peruvian population

of each sample, it was compared with the formula of Paknahad *et al.*[2] was used to determine the sex of each sample. A score greater than zero indicates male sex and less than zero indicates female sex. Each measurement was recorded with CS 3D software and was registered on a data collection tab.

STATISTICAL ANALYSIS

Descriptive analysis was performed by obtaining the frequency and percentage of the qualitative variables. Next, normality was determined by Kolgomorov–Smirnov test. As the distribution of the sample was normal, it was decided to use the Student's *t* test for independent data. Finally, linear discriminant analysis was applied with the significant parameters, which established which parameter was more significant for the determination of sexual dimorphism of the antrum of Highmore by means of the Wilks Lambda test. All the statistical analyses were performed with Software Stata 15 with a *P* value <0.05 being considered as significant.

RESULTS

As shown in Table 1, the sample included 127 patients (100%) distributed into four age groups: (1) from 20 to 29 years (52.8%), (2) from 30 to 39 years of age (19.7%), (3) from 40 to 49 years (15.7%), and from 50 to 68 years (11.8%).

Table 2 shows that statistically significant differences were observed among the width, height, area, perimeter, and volume of the Highmore's antrum and sex on the right side of the antrum of Highmore ($P < 0.05$). However, on the left side there was only a statistically significant difference between the height and volume of the antrum of Highmore and sex with a $P < 0.053$. Table 3 shows the results of the discriminant analysis. The Wilks Lambda test was applied, and on the right side of the maxillary sinus only a significance

Table 1: Sample distribution according to age group				
Age	**Female**	**Male**	**Total**	**%**
20–29	31	36	67	52.8
30–39	20	5	25	19.7
40–49	11	9	20	15.7
50–68	10	5	15	11.8
Total	72	55	127	100

$P < 0.05$ was found for width, height, area, perimeter, and volume, which determines that if they have the power to discriminate between both sexes. Use of the Wilks Lambda test showed that the width, height, area, perimeter, and volume of the right side of the maxillary sinus were significant ($P < 0.05$) and were therefore useful to discriminate between the two sexes. However, the length had a level of significance $p > 0.05$ which determines that it has no power to discriminate between the two sexes. Otherwise, on the left side it was only evident that height and volume had the power to discriminate between both sexes with a $P < 0.05$. However, the length of the maxillary sinus was not found to be significant ($P < 0.05$), and was thus not able to discriminate between the two sexes. On the contrary, only the height and volume of the left maxillary sinus had the power to discriminate between the two sexes with a $P < 0.05$.

DISCUSSION

Populations vary according to their phylogenetic, racial, sexual and ontogenetic origins, as well as age and the characters of each individual, according to their life history. The human species is dimorphic, having an index of sexual dimorphism that has varied over time. The size and shape of men and women varies according to their phylogenetic and population origin and this is known as sexual dimorphism Different anatomical structures are used for the estimation of sexual dimorphism and age in post mortem identification.

Table 2: Comparison of the different metrics of the left and right maxillary sinus according to sex

	Parameter	Sex	Mean	SD	P
Right maxillary sinus	Width	Female	24.9	3.6	0.049
		Male	26.2	3.4	
	Length	Female	36.4	3.4	0.058
		Male	37.6	3.6	
	Height	Female	35.6	5.5	0.001
		Male	39.4	5.0	
	Area	Female	9.1	2.0	0.037
		Male	9.9	1.9	
	Perimeter	Female	12.2	1.3	0.033
		Male	12.7	1.2	
	Volume	Female	16.7	5.5	0.002
		Male	19.8	5.6	
Left maxillary sinus	Width	Female	25.6	3.3	0.096
		Male	26.7	3.6	
	Length	Female	36.4	3.5	0.217
		Male	37.2	3.9	
	Height	Female	35.6	5.6	0.001
		Male	39.3	5.0	
	Area	Female	9.4	1.9	0.095
		Male	10.0	2.1	
	Perimeter	Female	12.4	1.2	0.105
		Male	12.8	1.3	
	Volume	Female	17.1	5.6	0.005
		Male	20.1	6.0	

SD = standard deviation

Table 3: Coefficients and level of precision of the discriminant analysis function in the determination of sex according to the side of the maxillary sinus

	Parameter	Female %	Male%	Constant	Coefficient	P
Right maxillary sinus	Width	52.7	63.3	−7.11	0.27	<0.05
	Length	54.1	49.0	−9.87	0.26	>0.05
	Height	62.5	67.2	−6.98	0.18	<0.01
	Area	59.7	60.0	−4.78	0.5	<0.05
	Perimeter	56.9	58.1	−9.75	0.77	<0.05
	Volume	69.4	58.1	−3.22	0.17	<0.05
Left maxillary sinus	Width	52.7	44.4	−7.41	0.28	>0.05
	Length	51.3	52.7	−9.87	0.26	>0.05
	Height	62.5	67.2	−6.95	0.18	<0.01
	Area	61.1	60.0	−4.81	0.49	>0.05
	Perimeter	56.9	58.1	−9.75	0.77	>0.05
	Volume	62.5	56.3	−3.1	0.17	<0.05

The main bone structures include the pelvis, ilium, sacrum, scapula, clavicle, sternum, skull, humerus. Sexual dimorphism of the teeth is very variable, with the teeth of females usually being smaller, especially the mesiodistal diameter of the permanent molars, although it may sometimes be very difficult to distinguish them by this unique feature. In the field of dentistry, the following structures are evaluated to determine sexual dimorphism: palatine wrinkles, coronal dimensions of the teeth, canine teeth, jaw, maxillary sinus, and shape of the dental arch.[14-18]

According to the results obtained regarding the determination of the sexual dimorphism of the antrum of Highmore through morphometric analysis in tomographs of a Peruvian population, a significant difference was obtained through the unpaired student t test ($P < 0.05$) in the right maxilla (for width, height, perimeter, area, and volume) and in the left maxillary sinus (for height and volume), thus showing the presence of significant sexual dimorphism for this population. The results obtained by morphometric analysis of CBCT images aimed at determining the sexual dimorphism

of the antrum of Highmore in a Peruvian population showed significant differences ($P < 0.05$) in width, height, perimeter, area and volume of the right maxilla and in the height and volume of the left maxillary sinus, thereby showing the presence of significant sexual dimorphism in this population. In addition, according to the discriminant analysis, height was the best parameter to determine sexual dimorphism with an accuracy of 64.57%. In relation to the measurement of the width of the maxillary sinus, a greater value was observed in males. In addition, an average of 24.94 mm in female and 26.22 mm in male was obtained for the right antrum of Highmore and 25.69 mm in female and 26.75 in male in the left maxillary sinus. The right antrum of Highmore was on average 24.94 mm in females and 26.22 mm in males, whereas the left maxillary sinus was 25.69 mm in females and 26.75 in males. The study by Meindl *et al.*[1] used measurements of width, length, perimeter height, area, and volume to determine sexual dimorphism. According to the unpaired t-test between the female and male sex groups, the female group showed statistically significantly higher values for the width of the left maxillary sinus ($P = 0.041$), which can be used to determine gender with a global precision of 60%. On the contrary, in another study,[4] measurements of the width, length, and height of the maxillary sinuses were made by CBCT scans to determine sexual dimorphism, and according to the discriminant analysis, height followed by the length of the antrum of Highmore showed the greatest differentiation between the two sexes, with an accuracy of 78% in women and 74% in 71 men and with a global accuracy of 76%. Therefore, our results agree with those of these latter authors, with the height of the left and right maxillary sinus being the best discriminant parameter with an accuracy of 62.50% in women and 67.27% in men and with a general accuracy of 64.57%.

Similarly, Prabhat *et al.*[5] evaluated sexual dimorphism through the dimensions of the maxillary sinus: length, height, and width on CBCT and showed that the overall values of the metrics of the maxillary sinus were significantly higher in men compared to women. The right height (90.0%) and the left height (83.3%) are the best predictors of sexual dimorphism. The results obtained in our study also agreed with these results, finding that the height of the right and left maxillary sinus is the best discriminant parameter with a level of precision in the determination of sex was 62.50% in women and 67.27% in men with a general accuracy of 64.57% for the right and left height. Similarly, when evaluating sexual dimorphism according to the width, height, and length of the maxillary sinus by CBCT, and reported that the overall values of the parameters of the maxillary sinus were significantly

higher in men compared to women, with the height of the right (90.0%) and the left maxillary sinuses (83.3%) being the best predictors of sexual dimorphism. Our results agree with these findings, showing that the height of the right and left maxillary sinus is the best discriminant parameter with a level of precision in the determination of sex of 62.50% in women and 67.27% in men and with a general accuracy of 64.57%.

On the contrary, when evaluating sex through the height, length, width, and volume of the antrum of Highmore and discriminant analysis, another study[6] determined that sexual dimorphism of the right maxillary sinus was 29.44% for height, 20.51% for length, 17.937% for width and 85.46% for volume, being 28.01%, 19.55%, 5%, and 78.38%, respectively, for the left maxillary sinus. In contrast to this study, the discriminant analysis performed in our study showed the height of the right and left antrum of Highmore to have the best discriminant parameters, with an accuracy level of 64.57% for determining gender.

Finally, several studies[3-5] have determined that there is sexual dimorphism in the maxillary sinuses. In addition, some investigations[4,7,10] describe a formula for determining sex by discriminant analysis. The importance of the present investigation is oriented to evaluate if there is sexual dimorphism through the study of the maxillary sinuses in a Peruvian population and as a consequence to establish a multiple regression formula that is used to estimate the sex in case of identity of isolated corpses or in major disasters, which would help in the process of human identification. The importance of the present investigation is that it showed that sexual dimorphism in a Peruvian population can be determined by study of the maxillary sinuses and that a multiple regression formula can be used to estimate sex in the identification of isolated corpses or in major disasters, thereby being of great utility in the process of the identification of human remains. In addition, the research is justified because it would allow to obtain anatomical dimensions of the maxillary sinus in the Peruvian population in men and women: height, width, length, area, perimeter, and volume, which will allow it to be used as a tool to standardize the measurements of the antrum volume. As standardization is very important for comparisons among other investigations, which will provide a better understanding of the role of the maxillary sinus and establish the factors that influence the size of the antrum of Highmore under normal conditions. In addition, the use of CBCT for measuring the height, width, length, area, perimeter, and volume of the maxillary sinus in the Peruvian population of men and women makes it a useful tool to standardize the measurements of antrum volume.

Standardization is very important for comparisons among other investigations which will provide a better understanding of the role of the maxillary sinus and establish the factors that influence the size of the antrum of Highmore under normal conditions. These values will support clinical radiological evaluation and procedures that can affect the maxillary sinus in the case of maxillary surgeries and implants. Finally, it is recommended that the results be taken into account, so that it can be used as a method of prediction of sex being helpful in cases of identification of bone remains, as it would achieve a greater contribution to the methods already known. Finally, the present results show that measurement of the maxillary sinus is useful for the prediction of sex in the identification of bone remains.

Conclusion

In conclusion, CBCT images showed significant sexual dimorphism of the maxillary sinuses of the Peruvian population studied, with height being the parameter with the highest dimorphism according to the discriminant analysis. Finally, CBCT images showed that the length, width and height, perimeter, and area of the maxillary sinuses were greater in men compared to women.

Conflicts of interest
There are no conflicts of interest.

Author contributions
Study conception (RBC, DSP), data collection (RBC, DSP), data acquisition and analysis (FMT, DAT, RW), data interpretation (DSM, GA, RW, FMT, DSM), manuscript writing (FMT, DAT, RW, GA, DSM).

Ethical policy and institutional review board statement
This study used secondary data and respected the principles of patient confidentiality.

Patient declaration of consent
Not applicable.

Data availability statement
The data that support the study results are available from the author (Dr. Daniel G. Suárez-Ponce, e-mail: dsuarezp@unmsm.edu.pe) on request.

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