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ORIGINAL ARTICLE

Sexual dimorphism of maxillary sinus using cone beam computed tomography

Shahnaz S. Tambawala *, Freny R. Karjodkar [1], Kaustubh Sansare [2], Nimish Prakash [3]

Department of Oral Medicine and Radiology, Nair Hospital Dental College, Mumbai 400008, India

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Abstract: The aim of this study was to evaluate the sexual dimorphism of maxillary sinus dimensions using the CBCT imaging modality. Thirty CBCT scans of bilateral maxillary sinuses (60 maxillary sinuses) were retrospectively selected and the height, width, and depth of the sinuses were measured. All data were subjected to descriptive and discriminative functional analysis with generation of multiple logistic regression model and ROC analysis.

The overall values of the parameters were significantly greater in the males as compared to the females with the right height (90.0%) and the left height (83.3%) being the best predictors. This study proposes the importance of sexual dimorphism of maxillary sinus dimensions particularly the sinus height, when other methods used in the field of forensics seem to be indecisive. It suggests the use of CBCT in forensics thus obviating the complete dependence on the usage of conventional CT.

1. Introduction

Forensic personal identification by its inherent nature is a multidisciplinary team effort depending on positive identification methodologies as well as supposition or exclusionary approaches. However, typical identification methods may be indecisive, especially when certain extreme post-mortem alterations have occurred.[1] In spite of the leaps in medical breakthroughs, modern technology, investigations and its holistic application in forensics, identification of remnants of skeletal and decomposing parts of humans remains challenging. Forensic odontology aids personal identification through the processes of comparative dental identification, post mortem

* Corresponding author at: Oral Medicine and Radiology Department, Ground floor, Room no – 2, Nair Hospital Dental College, Opposite Maratha Mandir, Dr. A. L. Nair Road, Mumbai Central, Mumbai 400 008, Maharashtra, India. Mobile: +91 9819708414; fax: +91 22 23080655.
E-mail addresses: shezt3@gmail.com (S.S. Tambawala), fkarjodkar@yahoo.co.in (F.R. Karjodkar), kaustubhsansare@yahoo.com (K. Sansare), nimishprakash@gmail.com (N. Prakash).
[1] Mobile: +91 9869652213.
[2] Mobile: +91 9821237185.
[3] Mobile: +91 9167604865.

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profiling from dental records, identification from dental DNA etc.[2]

Sexual dimorphism is one of its integral aspects as it is one of the initial steps in personal identification of an unknown cadaver thus narrowing down the diagnosis toward a correct possibility. Since, most bones that are conventionally used for sex determination (pelvis, skull & long bones etc.) are often recovered either in a fragmented, incomplete or commingled state especially in catastrophes like explosions, warfare, natural calamities, and other mass disasters like aircraft crashes, identification and sex determination are not easily achievable tasks.[3] It has thus become important to use denser bones that are often recovered intact, e.g. the maxillary sinus and thus alternate areas of the skeleton to be researched for sex estimation.[1] It has been reported that zygomatic bones and maxillary sinus remains intact although the skull and other bones may be badly disfigured in victims who are incinerated.[1,4] Maxillary sinuses are air spaces, located in the maxillary bone and can be in various sizes and shapes.[5] They appear at the end of the second embryonic month and reach their mature sizes at the age of about 20 years, when the permanent teeth fully develop.[4] They tend to stabilize after the second decade of life and the radiographic images could provide adequate measurements of maxillary sinuses for use in morphometric forensic analysis that cannot be approached by other means.[5]

In present times, the latest imaging modality of cone beam computed tomography (CBCT) provides images that represent a series of contiguous cross-sections like conventional CT (computerized tomography), thus providing three-dimensional information of an entity within an object that can be studied in an integrated interactive manner. The multiplanar sectioning of the reconstructed data set permits unlimited virtual dissections of the specimen without further physical damage. Also a single scan of the specimen can later be compared to any possible variety of submitted ante mortem plain film images.[6] Today there is a widespread and increasing use of CBCT for point-of-service head and neck and dentomaxillofacial imaging.[7] The applications extend from implantology, oral and maxillofacial surgeries, temporomandibular joint assessment, endodontics, orthodontics, periodontics, sinus imaging, temporal bone/lateral skull and skull base studies.[7,8] This gives the opportunity to use CBCT in forensic medicine. CBCT may be useful in some forensic contexts, offering several advantages for post-mortem forensic imaging including good resolution for skeletal imaging, relatively low cost, portability, and simplicity.[9] Certain studies on 3D reconstruction,[10] bite-mark analysis,[11] age estimation,[12] person identification[13] and anthropological assessment[14] have been done using CBCT with promising results. However their number is still limited to validate its full potential in the field of forensic science.

In a study by Amin and Hassan on maxillary sinus using multi detector CT (MDCT) scan, it was concluded that the cephalo caudal and size of the left maxillary sinuses are useful features in sex determination in Egyptians.[15] Another study by Teke et al. showed that the computerized tomography measurements of maxillary sinuses may be useful to support sex determination in forensic medicine; however, with a relatively low-accuracy rate (less than 70%).[4]

The CBCT imaging technology could broaden and facilitate many of the forensic science applications and serve as an alternative to CT. The aim of this study was therefore to evaluate whether sexual dimorphism from the height, width and length measurements of the maxillary sinus could be determined using the CBCT imaging modality.

2. Materials and methods

2.1. Collection of samples

One hundred and thirty-two CBCT scans of bilateral maxillary sinuses were retrospectively retrieved from the database of the Oral Radiology unit for a period of June 2013 to May 2014. After initial screening for adaptability to the inclusion and exclusion criteria's finally 30 CBCT scans of bilateral maxillary sinuses (60 maxillary sinuses) with 15 male and 15 female subjects and age ranging from 20 to 70 years were selected. Only high quality reconstructed images of bilateral maxillary sinuses were selected and all low quality images with blurring or artifacts caused by metallic objects were excluded. Scans that were not covering the entire extent of the sinus were excluded. Also, scans with pathologically destructive maxillary sinus from tumor, trauma, cleft or any other disease within or in the vicinity of the sinus or previous surgery were excluded. Scans with inflamed lining of the sinus were included in the study. All the scans were made using a Kodak 9000 C 3D unit (Carestream Health Inc., 150 Veronal Street, Rochester, NY 14608, USA), with variable field of view, voxel size – $76.5 \times 76.5 \times 76.5$ μm, X-ray pulse time of 30 ms, kVp – 60 to 90 kV (max), mA – 2 to 15 Ma, exposure time of 10.8 s. Images were reconstructed using a high spatial frequency reconstruction algorithm.

2.2. Measurements

Two independent observers (both experienced radiologists) blind to the details of age and sex of the subjects, used the Digital Image Communication in Medicine (DICOM) compatible CS 3D Imaging software (version 3.2.9, copyright Carestream Health Inc.) to analyze the reconstructed image sections. All the CBCT images obtained in the DICOM format were transferred to a separate workstation and the measurements done in a quiet windowless room with dimmed lighting. The images were viewed on HP Envy Spectre XT Ultrabook 13 – 2015tu, 13.3″ diagonal HD Bright View LED-backlit Display (Hewlett Packard Company, 71004 Boeblingen, Germany) at a $1{,}366 \times 768$ resolution and measurements were done in axial and coronal cross section views. Observers were allowed to use two – fold magnification and modify screen brightness as well as scroll through the axial, sagittal and coronal sections with slice thickness standardized at 300 μm. The three straight distances (height, width, and depth), were taken on the axial and coronal cross sections, where the longest distances could be measured. The width and depth distances measured on axial section while the height distances measured on coronal cross section.

- The width was defined as the longest distance perpendicular from the medial wall of the sinus to the most lateral wall of the lateral process of the maxillary sinus in the axial view (Fig. 1).

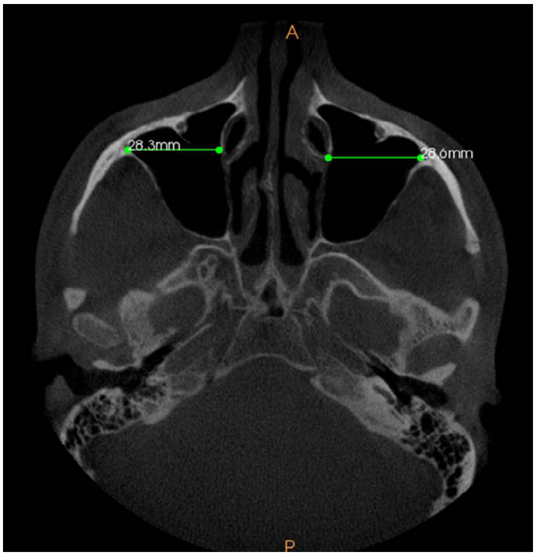

Figure 1 Width of the maxillary sinus on axial view.

- The depth was defined as the longest distance from the most anterior point to the most posterior point of the medial wall in the axial view (Fig. 2).
- The height was measured away from the inner surface of the anterior border of maxillary sinus and was defined as the longest distance from the lowest point of the sinus floor to the highest point of the sinus roof in the coronal view[16] (Fig. 3).

2.3. Data analysis

All data were transferred on Microsoft Excel 2003 software (Microsoft Corporation, Redmond, USA) and subjected to descriptive analysis where comparison between gender groups was done with the help of unpaired t test with a p value less than 0.05 taken as significant level. Correlation was done with Pearson's Correlation coefficient with significance at the 0.01 level (2-tailed). A discriminant functional analysis was then performed to assess whether the measurements of the maxillary sinuses could be used for sex determination. Multiple logistic regression was performed to generate an equation that could reliably classify the observations according to sex. The Receiver Operating Curve (ROC) analysis was then used to determine the fit of the regression model as well as to identify the optimum cut off criteria for the equations. Data analysis was done using the software, SPSS version 15.

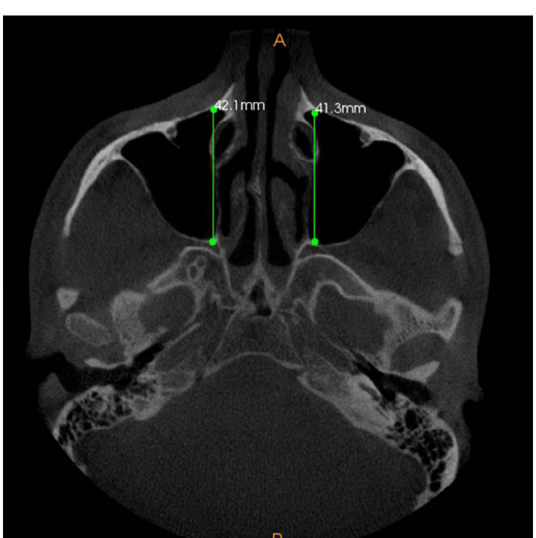

Figure 2 Length of the maxillary sinus on axial view.

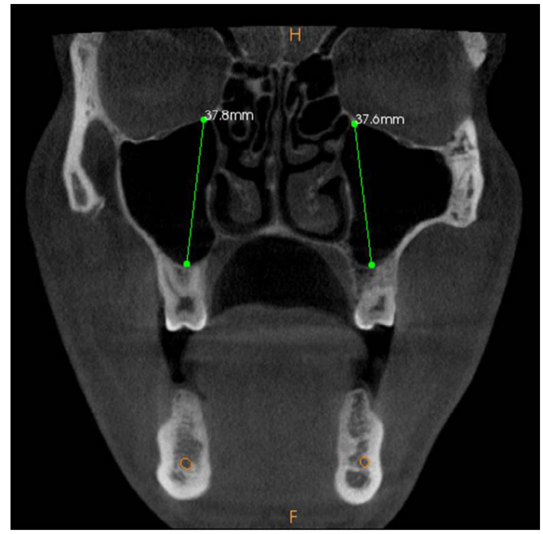

Figure 3 Height of the maxillary sinus on coronal view.

3. Results

In this study the overall values of the parameters were significantly greater in males as compared to females. Table 1 shows the descriptive analysis of the parameters of the right and left maxillary sinuses according to sex where the quantitative data are presented with the help of Mean, Standard Deviation (SD), Median and Inter quartile range (IQR). Significant mean differences were observed among all the three parameters between the two sexes.

Qualitative data are presented with the help of Frequency and Percentage table. The cross validated classification of each parameter showed that with the right width 86.7% of original grouped cases could be correctly classified as males and 60% of original grouped cases could be correctly classified as females (see Table 2). With the right length 80.0% of original grouped cases could be correctly classified as males and 73.3% of original grouped cases could be correctly classified as females (see Table 3). With the right height 86.7% of original grouped cases could be correctly classified as males and 93.3% of original grouped cases could be correctly classified as females (see Table 4). With the left width 86.7% of original grouped cases could be correctly classified as males and 73.3% of original grouped cases could be correctly classified as females (see Table 2). With the left length 80.0% of original grouped cases could be correctly classified as males and 73.3% of original grouped cases could be correctly classified as females (see Table 3), and with the left height 80.0% of original grouped cases could be correctly classified as males and 86.7% of original grouped cases could be correctly classified as females (see Table 4).

Table 1 Comparison of parameters among male and female groups of right and left maxillary sinuses.

Parameters	Male				Female				*p value
	Mean	SD	Median	IQR	Mean	SD	Median	IQR	
Right width (mm)	29.78	2.25	30.40	3.10	23.80	5.04	25.15	9.30	< 0.001
Right length (mm)	40.22	3.02	39.80	4.25	35.66	3.84	34.85	4.50	0.001
Right height (mm)	39.71	3.79	39.45	4.85	30.29	3.34	31.05	6.70	< 0.001
Left width (mm)	29.75	2.39	29.60	2.55	23.61	4.24	25.10	7.95	< 0.001
Left length (mm)	39.59	2.97	39.35	4.20	35.12	3.91	34.60	5.55	0.001
Left height (mm)	39.67	4.17	39.35	3.80	30.64	4.24	31.25	7.20	< 0.001

SD, standards deviation; IQR, interquartile range.
*p value calculated for unpaired t test.

Table 2 Classification results of discriminant functional analysis of right width[b,c] and left width [d,e].

		Study group	Predicted group membership (right width)		Predicted group membership (left width)	
			Males	Females	Males	Females
Original	*N*	Males (15)	13	2	13	2
		Females (15)	6	9	4	11
	%	Males (100.0)	86.7	13.3	86.7	13.3
		Females (100.0)	40.0	60.0	26.7	73.3
Cross-validated[a]	*N*	Males (15)	13	2	13	2
		Females (15)	6	9	4	11
	%	Males (100.0)	86.7	13.3	86.7	13.3
		Females (100.0)	40.0	60.0	26.7	73.3

[a] Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
[b] 73.3% of original grouped cases correctly classified.
[c] 73.3% of cross-validated grouped cases correctly classified.
[d] 80.0% of original grouped cases correctly classified.
[e] 80.0% of cross-validated grouped cases correctly classified.

Table 3 Classification results of discriminant functional analysis of right length[b,c] and left length[d,e].

		Study group	Predicted group membership (right length)		Predicted group membership (left length)	
			Males	Females	Males	Females
Original	*N*	Males (15)	12	3	12	3
		Females (15)	4	11	4	11
	%	Males (100.0)	80.0	20.0	80.0	20.0
		Females (100.0)	26.7	73.3	26.7	73.3
Cross-validated[a]	*N*	Males (15)	12	3	12	3
		Females (15)	4	11	4	11
	%	Males (100.0)	80.0	20.0	80.0	20.0
		Females (100.0)	26.7	73.3	26.7	73.3

[a] Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
[b] 76.7% of original grouped cases correctly classified.
[c] 76.7% of cross-validated grouped cases correctly classified.
[d] 76.7% of original grouped cases correctly classified.
[e] 76.7% of cross-validated grouped cases correctly classified.

The Multiple Logistics Regression proposed the following equation for sex determination from measurements of the:-

Right maxillary sinus: sex $= -2082.963 + (32.392 \times$ right width$) - (7.335 \times$ right length$) + (43.331 \times$ right height$)$.

Left maxillary sinus: sex $= -68.961 + (1.272 \times$ left width$) + (0.0214 \times$ left length$) + (0.935 \times$ left height$)$.

The ROC analysis proposed the optimum cut off criterion of -14.3606 for the right sinus and -0.9435 for the left sinus respectively. Subjects with values higher than the cut off criterion were classified as males and those with lower values than the cut off criterion were classified as females. The chosen cut off criteria were corresponding with the highest Youden Index.

Table 4 Classification results of discriminant functional analysis of right height[b,c] and left height.[d,e]

		Study group	Predicted group membership (right height)		Predicted group membership (left height)	
			Males	Females	Males	Females
Original	*N*	Males (15)	13	2	12	3
		Females (15)	1	14	2	13
	%	Males (100.0)	86.7	13.3	80.0	20.0
		Females (100.0)	6.7	93.3	13.3	86.7
Cross-validated[a]	*N*	Males (15)	13	2	12	3
		Females (15)	1	14	3	12
	%	Males (100.0)	86.7	13.3	80.0	20.0
		Females (100.0)	6.7	93.3	20.0	80.0

[a] Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
[b] 90.0% of original grouped cases correctly classified.
[c] 90.0% of cross-validated grouped cases correctly classified.
[d] 83.3% of original grouped cases correctly classified.
[e] 80.0% of cross-validated grouped cases correctly classified.

4. Discussion

In the field of forensic science, sexual dimorphism remains a crucial initial step toward establishment of positive identity of the deceased individual. It has been reported that the accuracy rate of sex determination is 100% from a skeleton, 98% from both the pelvis and the skull, 95% from the pelvis only or the pelvis and the long bones, 90–95% from both the skull and the long bones and 80–90% from the long bones only.[4] Next to the pelvis, the skull is the most easily sexed portion of the skeleton. Though, the determination of sex from the skull is not reliable until after puberty,[5] the craniofacial structures have the advantage of being composed largely of hard tissue, which is relatively indestructible.[17] It has been reported in previous studies that the maxillary sinuses are significantly larger in males than in females.[4]

In the present study also, comparison between male and female groups showed that the female group had statistically significant lower values for both the right and left maxillary sinuses as regards the width, length and height dimensions. In a study about sex determination from maxillary sinus dimensions in 88 patients between age group of 20–49 years by CT scan using the width, length and height of the sinuses in addition to the total distance across both sinuses showed that the maxillary sinus height was the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy of 71.6%.[18] This was in consensus with the present study which showed that the maxillary sinus height was the most reliable predictor of sex with the right sinus height able to classify with 90% accuracy and left sinus height able to classify with 83.3% accuracy. In another study of 33 hemi sectioned reconstructed CT images of maxillary sinus in a Korean population six categories of maxillary sinus were created and categorized according to their lateral aspects and shapes of the inferior walls. All measures i.e. anteroposterior length, height, width and volume of the sinus were larger in males than in females which is also in accordance to our results.[19] Fernandes performed a sex-discriminant analysis using maxillary sinus measurements in addition to nasal cavity width, total distance across the sinuses, head circumference, head width, bizygomatic width at the zygion, a glabellar/nasion/nasal bone angle and a left and right lateral canthal angle, and it was found that 79.2% of the skulls were correctly classified.[20] In a study by Teke et al.[4] the following formula was proposed for sex determination from the right maxillary sinus: sex = $-5.397 + 0.112 \times$ the width of the right maxillary sinus $+ 0.114 \times$ the height of the right maxillary sinus $- 0.045 \times$ the length of the right maxillary sinus; and from the left maxillary sinus: sex = -6.484–$0.037 \times$ the width of the left maxillary sinus $+ 0.137 \times$ the height of the left maxillary sinus $+ 0.041 \times$ the length of the left maxillary sinus. It is hypothesized that the difference in the equation derived in our study may be due to racial differences in the population in which the studies were done.

To the best of our knowledge, all the previous studies on sexual dimorphism of maxillary sinus have been performed using CT scan images, none using CBCT imaging modality has been reported till date. Currently, CBCT scans are being used for an expanding number of reasons in the dental and medical field, thus ensuring their increasing accessibility in cases demanding personal identification. With no magnification, 1:1 representation of the images and also being less severely affected by metallic artefacts than the conventional CT,[21] this imaging technology has the potential to be used as a tool for sex determination in mass disasters or when badly decomposed and incinerated bodies are available. CBCT could thus prove advantageous and serve as an accessible alternative to CT in many cases of forensics.[9]

The limitations of this study included the small sample size owing to the stringent inclusive and exclusive criteria of the study. This also emphasizes the need to conduct these analysis on a larger population. The difference in the equations generated for different populations also suggests that this study could be done for different world populations to generate such identification equation for sex determination.

5. Conclusion

In conclusion this study shows that the maxillary sinus height is the most reliable discriminant parameter that could be used for the purpose of sex discrimination. The study also for the first time proposes the reliability, usability and accuracy of

CBCT for evaluating maxillary sinus dimensions in the field of forensic science. This study thereby suggests the importance of sexual dimorphism of maxillary sinus dimensions i.e. width, length, and height when other methods and procedures used in the field of forensic science seem to be inconclusive or inadequate. This research work could thus prove vital in identifying the sex of a person in forensic anthropology. This being a preliminary research study, further studies on a larger sample size and in diverse populations are desirable.

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Conflict of interest

No conflict of interest.

Ethical approval

Necessary ethical approval was obtained from the College ethics committee.

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