Sexual dimorphism of maxillary sinus using cone beam computed tomography

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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.

KEYWORDS
Forensic science; Forensic anthropology; Radiology; Cone beam computed tomography; Sexual dimorphism; Maxillary sinus

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...
Sexual dimorphism of maxillary sinus using CBCT

Individuals 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. 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. Maxillary sinuses are air spaces, located in the maxillary bone and can be in various sizes and shapes. 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. They tend to stabilize after the second decade of life and the radiographic images could provide adequate measurements of maxillary sinus for use in morphometric forensic analysis that cannot be approached by other means.

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 (computed 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. Today there is a widespread and increasing use of CBCT for point-of-service head and neck and dentomaxillofacial imaging. 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. 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. Certain studies on 3D reconstruction, bite-mark analysis, age estimation, person identification and anthropological assessment 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. 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%).

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 × 76.5 × 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 × 768 diagonal HD Bright View LED-backlit Display. The three straight distances (height, width, and depth) were taken on the 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 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).
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 (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.

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

Right maxillary sinus: \( \text{sex} = \frac{1}{C_0} + \left( \frac{32.392}{C_2} \right) \text{right width} + \left( \frac{7.335}{C_2} \right) \text{right length} + \left( \frac{43.331}{C_2} \right) \text{right height} \).

Left maxillary sinus: \( \text{sex} = \frac{1}{C_0} + \left( \frac{1.272}{C_2} \right) \text{left width} + \left( \frac{0.0214}{C_2} \right) \text{left length} + \left( \frac{0.935}{C_2} \right) \text{left height} \).

The ROC analysis proposed the optimum cut off criterion of \( \frac{1}{C_0} = 14.3606 \) for the right sinus and \( \frac{1}{C_0} = 0.9435 \) 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 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Male</th>
<th></th>
<th>Female</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Median</td>
<td>IQR</td>
</tr>
<tr>
<td>Right width (mm)</td>
<td>29.78</td>
<td>2.25</td>
<td>30.40</td>
<td>3.10</td>
</tr>
<tr>
<td>Right length (mm)</td>
<td>40.22</td>
<td>3.02</td>
<td>39.80</td>
<td>4.25</td>
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<tr>
<td>Right height (mm)</td>
<td>39.71</td>
<td>3.79</td>
<td>39.45</td>
<td>4.85</td>
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<tr>
<td>Left width (mm)</td>
<td>29.75</td>
<td>2.39</td>
<td>29.60</td>
<td>2.55</td>
</tr>
<tr>
<td>Left length (mm)</td>
<td>39.59</td>
<td>2.97</td>
<td>39.35</td>
<td>4.20</td>
</tr>
<tr>
<td>Left height (mm)</td>
<td>39.67</td>
<td>4.17</td>
<td>39.35</td>
<td>3.80</td>
</tr>
</tbody>
</table>

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\(^{d,e} \).

<table>
<thead>
<tr>
<th>Study group</th>
<th>Predicted group membership (right width)</th>
<th>Predicted group membership (left width)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>Original</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>%</td>
<td>86.7</td>
<td>13.3</td>
</tr>
<tr>
<td>Cross-validated(^a)</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>%</td>
<td>86.7</td>
<td>13.3</td>
</tr>
</tbody>
</table>

\(^a\) 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\(^{d,e} \).

<table>
<thead>
<tr>
<th>Study group</th>
<th>Predicted group membership (right length)</th>
<th>Predicted group membership (left length)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>Original</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>%</td>
<td>80.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Cross-validated(^a)</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>%</td>
<td>80.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>

\(^a\) 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: \( \text{sex} = -2082.963 + (32.392 \times \text{right width}) + (7.335 \times \text{right length}) + (43.331 \times \text{right height}) \).

Left maxillary sinus: \( \text{sex} = -68.961 + (1.272 \times \text{left width}) + (0.0214 \times \text{left length}) + (0.935 \times \text{left height}) \).
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.1 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 side having a higher accuracy than the left side.

Table 4

<table>
<thead>
<tr>
<th>Study group</th>
<th>Predicted group membership (right height)</th>
<th>Predicted group membership (left height)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males (15)</td>
<td>Females (15)</td>
</tr>
<tr>
<td>Original</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Cross-validated</td>
<td>13</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: 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%. 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 side having a higher accuracy than the left side.
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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None.

**Conflict of interest**
No conflict of interest.

**Ethical approval**
Necessary ethical approval was obtained from the College ethics committee.

**References**