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PAPER

GENERAL; ANTHROPOLOGY AND ODONTOLOGY

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Evaluation of Maxillary Sinus Dimensions in Gender Determination Using Helical CT Scanning

ABSTRACT: Gender determination is an important step in identification in forensic medicine. CT measurements of maxillary sinuses may be useful to support gender identification. This study was undertaken to study the accuracy and reliability of maxillary sinus dimensions measurement in gender classification through the use of reconstructed helical CT images. Eighty-eight patients (43 men and 45 women) with age range from 20 to 49 years were selected in this study. The width, length, and height of the maxillary sinuses in addition to the total distance across both sinuses were measured. Data were subjected to discriminant analysis for gender using multiple regression analysis. Maxillary sinus height was the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy of 71.6%. Using multivariate analysis, 74.4% of male sinuses and 73.3% of female sinuses were sexed correctly. The overall percentage for sexing maxillary sinuses correctly was 73.9%. It can be concluded that reconstructed CT image can provide valuable measurements for maxillary sinuses and could be used for sexing when other methods of sexing are not conclusive.

KEYWORDS: forensic science, maxillary sinus, CT scan, reconstructed image, dimensional accuracy, sexing

The study of anthropometric characteristics is of fundamental importance to solve problems related to identification. Craniometrical features are included among these characteristics which are closely connected to forensic dentistry, because they can be used to aid in identifying an individual from a skull found detached from its skeleton (1). Skeletal remains have been used for sexing the individual as bones of the body are last to perish after death, next to enamel of teeth (2). Radiography is used in forensic pathology for the identification of humans especially in cases where the body is decomposed, fragmented, or burned (3). The skull, pelvis, and femora are the most useful for the radiological determination of gender. Radiology can assist in giving accurate dimensions for which certain formulae can be applied to determine gender (4). It has been reported that maxillary sinuses remain intact, although the skull and other bones may be badly disfigured in victims who are incinerated, and therefore, that maxillary sinuses can be used for identification (5). Computer tomography (CT) scans are an excellent imaging modality used to evaluate the sino-nasal cavities. They provide an accurate assessment of the paranasal sinuses, craniofacial bones, as well as the extent of pneumatization of the sinuses (6). Gender determination is an important step in identification in forensic medicine. CT measurements of maxillary sinuses may be useful to support gender determination. The width, length, and height of maxillary sinus together can be used for gender determination when the whole skeleton is not available (7). This study was designed to determine the reliability and accuracy of maxillary sinus dimensions measurement as a method for gender identification of unknown persons.

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Patients and Methods

The sample consisted of 88 patients (43 men and 45 women) with age range from 20 to 49 years. They were referred to Radiology Department in Al-Najaf Teaching Hospital for the purpose of paranasal sinuses imaging. All participants were supplied with informed consent, and the study protocol was approved by Local Ethics Committee of Al-Najaf General Teaching Hospital. To determine the reliability and reproducibility of the maxillary sinus measurements, inter- and intra-examiner calibrations were carried out. These calibrations were carried out by comparing the greatest measurements of the randomly selected 10 radiographs by the same radiologist after 2 weeks from the first reading for intra-examiner calibration and by another senior general radiologist for inter-examiner calibration. The radiographs were examined on the computer in dim light room. Comparison of the two measurements showed statistical nonsignificant difference ($p > 0.05$) when paired t-test applied. Maxillary sinus measurements (width, length, height, and total distance across both sinuses) were measured from reconstructed axial and coronal sections (5-mm slice thickness) helical CT scan (Somatom Emotion; Siemens, Munich, Germany). The greatest measurements were taken after going through different

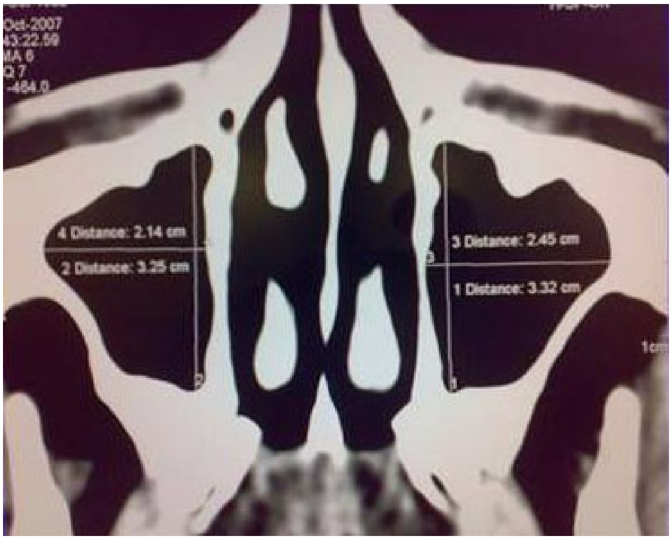

FIG. 1—*The width and length of the maxillary sinus measured from the reconstructed CT axial section.*

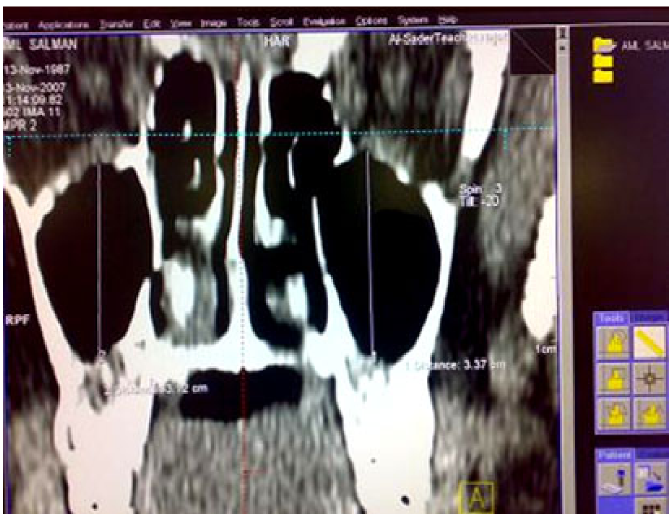

FIG. 2—*The height of the maxillary sinus measured from the reconstructed coronal CT sections.*

slices in axial and coronal sections. Edentulous patients or patients who had history of trauma, surgery, or pathological lesions in maxillofacial region were not included in this study. The maxillary sinus width was measured from axial reconstructed image section that was parallel to the hard palate as a distance from the outermost point of the lateral wall of maxillary sinus to the medial wall. The length was also measured from axial reconstructed image as the longest length antero-posteriorly (Fig. 1). The height of maxillary sinus was represented by the distance measured from the uppermost point of the superior wall of the sinus to the lowest point of the inferior wall. The measurement was obtained from reconstructed coronal section that was perpendicular to the hard palate (Fig. 2). The total distance across both sinuses was measured from reconstructed axial section as a distance from the outermost point of one maxillary sinus to the outermost point of the opposite sinus (Fig. 3). All data were subjected to descriptive and discriminate analyses using the SPSS package (version 17; SPSS Inc., Chicago, IL).

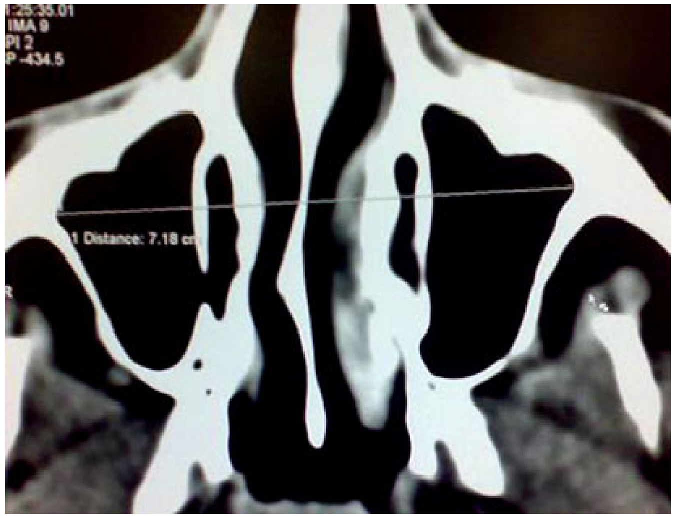

FIG. 3—*Total distance across both sinuses measured from the reconstructed axial CT section.*

Results

The total studied sample composed of 88 patients; the results were based on two study group: the male group (composed of 43 patients) and female group (composed of 45 patients).

Maxillary Sinus Width

The mean value for the maximum width of maxillary sinus for male group was (24.7 ± 4 mm) for the right side and (25.6 ± 4.4 mm) for the left side. Female group had statistically significant lower values for both right and left sides (22.7 ± 3.2 and 23 ± 4 mm), respectively ($p < 0.05$; Table 1). Right and left side differences were significant for only male group as shown in Table 2.

Maxillary Sinus Length

The mean value for maximum length of maxillary sinus for male group was (39.3 ± 3.8 mm) for the right side and (39.4 ± 3.7 mm) for the left side which was greater than that recorded for female group (36.9 ± 3.8 mm) for the right and (37 ± 4 mm) for the left side and with statistically significant difference ($p < 0.05$; Table 1). Nonstatistically significant side difference was seen for both gender as shown in Table 3.

Maxillary Sinus Height

The mean value for the maximum sinus height recorded for male group was (43.3 ± 4.8 mm) for the right side and (45.1 ± 4.1 mm) for the left side which was significantly greater than that recorded for female group which was (39.9 ± 5.2 mm) for the right side and (40 ± 4.8 mm) for the left side (Table 1). A statistically significant side difference was seen for only male group (Table 4).

Total Distance Across Both Sinuses

The mean value of this parameter was (82.4 ± 7.7 mm) for male group and (77.9 ± 6.2 mm) for female group. A significant gender difference was recorded regarding this parameter (Table 1).

Multiple regression equations have been used in this study; the variable (gender) has been given a value (0 for women and 1 for men). The classification variables were the maxillary sinus

TABLE 1—*Gender differences for maxillary sinus (MS) measurements.*

	Female				Male				
Parameters	Range	Mean	SD	SE	Range	Mean	SD	SE	*p* (*t*-test)
Right MS width (mm)	13.4–29.4	22.7	3.2	0.48	16.2–35	24.7	4	0.61	0.009
Right MS length (mm)	24.1–44.1	36.9	3.8	0.56	30.5–50.4	39.3	3.8	0.57	0.004
Right MS height (mm)	26.5–51.7	39.9	5.2	0.78	30.2–52.1	43.3	4.8	0.73	0.002
Left MS width (mm)	14.3–31.5	23	4	0.6	16.2–34	25.6	4.4	0.67	0.004
Left MS length (mm)	25.9–44.2	37	4	0.59	31.3–49.8	39.4	3.7	0.56	0.005
Left MS height (mm)	26.2–47.9	40	4.8	0.71	38.4–52.7	45.1	4.1	0.62	<0.001
Total distance across both sinuses (mm)	63.8–88.7	77.9	6.2	0.92	66–96.2	82.4	7.7	1.17	0.003

TABLE 2—*Side difference of maxillary sinus (MS) width measurements.*

	Right MS Width (mm)	Left MS Width (mm)	Right–Left MS Width (mm) Difference	*p* (paired *t*-test)
Female				
Range	13.4 to 29.4	14.3 to 31.5	−4.8 to 7.4	
Mean	22.7	23	−0.3	0.49 [NS]
SD	3.2	4	2.7	
SE	0.48	0.6	0.4	
N	45	45	45	
Male				
Range	16.2 to 35	16.2 to 34	−9.6 to 5.8	
Mean	24.7	25.6	−0.9	0.033
SD	4	4.4	2.6	
SE	0.61	0.67	0.39	
N	43	43	43	

TABLE 3—*Side difference of maxillary sinus (MS) length measurements.*

	Right MS Length (mm)	Left MS Length (mm)	Right–Left MS (mm) Difference	*p* (paired *t*-test)
Female				
Range	24.1 to 44.1	25.9 to 44.2	−7.3 to 8.7	
Mean	36.9	37	−0.1	0.79 [NS]
SD	3.8	4	3	
SE	0.56	0.59	0.44	
N	45	45	45	
Male				
Range	30.5 to 50.4	31.3 to 49.8	−8.1 to 3.8	
Mean	39.3	39.4	−0.1	0.78 [NS]
SD	3.8	3.7	2.3	
SE	0.57	0.56	0.35	
N	43	43	43	

TABLE 4—*Side difference of maxillary sinus (MS) height measurements.*

	Right MS Height (mm)	Left MS Height (mm)	Right–MS Height (mm) Difference	*p* (paired *t*-test)
Female				
Range	26.5 to 51.7	26.2 to 47.9	−6.9 to 9.4	
Mean	39.9	40	−0.1	0.88 [NS]
SD	5.2	4.8	3.3	
SE	0.78	0.71	0.49	
N	45	45	45	
Male				
Range	30.2 to 52.1	38.4 to 52.7	−10.8 to 5	
Mean	43.3	45.1	−1.8	0.002
SD	4.8	4.1	3.5	
SE	0.73	0.62	0.53	
N	43	43	43	

measurements. The equation provided by the model calculates the discriminate score "D," which aids in the prediction process of gender by substituting the value of the specific measurement(s) in the equation. The resulting value of "D" is compared with a reference value (also provided by the model). If a value of calculated "D" is greater than reference D, it indicates we are dealing with a male gender, and if "D" value is less than the reference values, this indicates dealing with female gender. The more extreme the calculated "D" from the reference value, the higher the probability that the predicted gender is really true as seen in Tables 5 and 6. Among all maxillary sinus measurements, the left maxillary sinus height was the best discriminate parameter (overall accuracy = 71.6%; Table 7). By combining the right and the left sinus measurements, the overall classification accuracy was improved to 73.9% (Table 8). Receiver operating characteristic analysis was also used to assess the validity of the tested variables. For each measurement, three cutoff values were selected. The optimum cutoff value was associated with highest accuracy rate in classifying subjects according to the gender and provides the best separation between men and women. For each cutoff value, the positive predictive value (a 50% pretest probability) was calculated to show the confidence in male determination (positive test results). Among cutoff points with highest sensitivity, the left maxillary sinus height is the best; it is associated with lowest false positive rate among all similar cutoff values of remaining parameters (Table 9).

Discussion

Identification on skeletal and decomposing human remains is one of the most difficult skills in forensic medicine. Sex determination is also an important problem in the identification. When the skeleton exists completely, sex can be determined with 100% accuracy. This estimation rate is 98% in existence of pelvis and cranium, 95% with only pelvis and long bones, and 80–90% with only long bones. However, in explosions, warfare, and other mass disasters like aircraft crashes, identification and sex determination are not easy tasks (8,9). Next to the pelvis, the skull is the most easily sexed portion of the skeleton, but the determination of the sex from the skull is not reliable well until after puberty. Sex estimation can be accomplished using either morphological or metric methodologies. Statistical methods utilizing metric traits are becoming more popular, with most of the bones having been subjected to linear discriminate classification (10). The result of the present investigation showed that the maxillary sinus exhibits anatomic variability between genders. A significant sex difference was found in relation to maxillary sinus width, length, and height. Among these parameters, the left maxillary sinus height was the best discriminate variable between genders (Wilks' lambda is 0.745 with overall

TABLE 5—*Discriminate analysis using right maxillary sinus measurements to discriminate between males and females.*

Right maxillary sinus width (RMSW)			
D = −6.535 + 0.276 × RMSW Wilks' lambda = 0.923, $p = 0.009$	Female	Male	Overall
Percent accurately predicted group membership	55.6%	60.5%	58%
			Classified as male if D>
Functions at group centroids	−0.279	0.292	0.006
Right maxillary sinus length (RMSL)			
D = −10.123 + 0.266 × RMSL Wilks' lambda = 0.908, $p = 0.004$			Overall
Percent accurately predicted group membership	53.3%	62.8%	58%
			Classified as male if D>
Functions at group centroids	−0.307	0.322	0.008
Right maxillary sinus height (RMSH)			
D = −8.256 + 0.199 × RMSH Wilks' lambda = 0.894, $p = 0.002$			Overall
Percent accurately predicted group membership	64.4%	60.5%	62.5%
			Classified as male if D>
Functions at group centroids	−0.334	0.349	0.007
Total distance across both sinuses (TDABS)			
D = −11.53 + 0.144 × TDABS Wilks' lambda = 0.905, $p = 0.003$			Overall
Percent accurately predicted group membership	62.2%	58.1%	60.2%
			Classified as male if D>
Functions at group centroids	−0.314	0.328	0.007

TABLE 6—*Discriminate analysis using left maxillary sinus measurements to discriminate between males and females.*

Left maxillary sinus width (LMSW)			
D = −5.768 + 0.238 × LMSW Wilks' lambda = 0.908, $p = 0.004$	Female	Male	Overall
Percent accurately predicted group membership	60%	62.8%	61.4%
			Classified as male if D>
Functions at group centroids	−0.308	0.323	0.008
Left maxillary sinus length (LMSL) D = −9.937 + 0.26 × LMSL Wilks' lambda = 0.913, $p = 0.005$			Overall
Percent accurately predicted group membership	64.4%	67.4%	65.9%
			Classified as male if D>
Functions at group centroids	−0.298	0.312	0.007
Left maxillary sinus height (LMSH)			
D = −9.566 + 0.225 × LMSH Wilks' lambda = 0.745, $p < 0.001$			Overall
Percent accurately predicted group membership	71.1%	72.1%	71.6%
			Classified as male if D>
Functions at group centroids	−0.566	0.592	0.013

TABLE 7—*Discriminate analysis using right and left maxillary sinus measurements to discriminate between males and females.*

	Standardized Coefficient		
RMSW	0.171		
RMSL	0.393		
RMSH	0.597		
Wilks' lambda = 0.874, $p = 0.01$			
	Female	Male	Overall
Predicted group membership	64.4%	60.5%	62.5%
D = −10.024 + (0.047 × RMSW) + (0.105 × RMSL) + (0.119 × RMSH)			
			Classified as male if D>
Functions at group centroids	−0.368	0.385	0.009
LMSW	−0.046		
LMSL	−0.156		
LMSH	1.117		
Wilks' lambda = 0.741, $p < 0.001$			
			Overall
Predicted group membership	68.9%	74.4%	71.6%
D = −8.874 + (−0.011 × LMSW) + (−0.041 × LMSL) + (0.252 × LMSH)			
			Classified as male if D>
Functions at group centroids	−0.572	0.598	0.013

TABLE 8—*Discriminate analysis using both right and left maxillary sinus measurements to discriminate between males and females.*

	Standardized coefficient		
Right maxillary sinus width (RMSW)	0.093		
Right maxillary sinus length (RMSL)	0.042		
Right maxillary sinus height (RMSH)	−0.437		
Left maxillary sinus width (LMSW)	−0.171		
Left maxillary sinus length (LMSL)	−0.178		
Left maxillary sinus height (LMSH)	1.422		
Wilks' lambda = 0.727, $p < 0.001$			
Predicted group membership	Female	Male	Overall
	73.3%	74.4%	73.9%
D = −8.271 + (0.026 × RMSW) + (0.011 × RMSL) + (−0.087 × RMSH) + (−0.041 × LMSW) + (−0.046 × LMSL) + (0.32 × LMSH)			
Functions at group centroids			Classified as male if D>
	−0.592	0.62	0.014

accuracy 71.6%). Teke et al. (7) found in their study about gender determination from CT measurements of maxillary sinus that the overall accuracy rate for left maxillary sinus height measurement was only 63.8%. On the other hand, the present study recorded the accuracy rate for both sinuses measurements to be 74.4% for men and 73.3% for women with overall accuracy of 73.9%. Teke et al. (7) reported lower accuracy rates for the same measurements, which was 69.3% for men and 69.4% for women with overall accuracy of 69.3%. This 3.9–4.6% rate difference between the two studies could be attributed to the different measurement techniques used, especially for maxillary sinus height. Teke et al. (7) measured the height by marking the first and last scene of the sinus in CT scan and the number of the sections between them was determined, then the number of sections obtained was multiplied by slice thickness (3 mm) to find out the height of the sinus. This method is considered less accurate than that used in the present study.

Multiple regression equations were applied in this study to test the accuracy rate in sex classification; if values of width, length, and height were substituted to the following formula, the accuracy rate of sex prediction will be about 74%:

D = −8.271 + (0.026 × right sinus width) + (0.011 × right sinus length) + (−0.087 × right sinus height) + (−0.041 × left sinus width) + (−0.046 × left sinus length) + (0.32 × left sinus height).

Fernandes (11) performed gender-discriminate 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, glabellar/nasion/nasal bone angle, and left and right lateral canthal angle. He found that 79.2% of the skulls were correctly classified. Another study (2) tested 16 parameter for gender assessment including maxillary sinus measurements; they found that the average accuracy reached 80–87%. In the field of forensic identification, maxillary sinus measurements can be taken with high speed and accuracy on the CT machine and standard instruments of measures. The results of the present study provided average accuracies that were comparable to those obtained using more complex techniques and parameters.

Conclusion

Maxillary sinus dimensions measurements are valuable in studying sexual dimorphism. They tend to stabilize after second decade

TABLE 9—*Validity parameters of three cutoff values for each test when used to predict male gender differentiating it from females.*

Positive if ≥ Cutoff Value	Sensitivity	Specificity	Accuracy	PPV at Pretest Probability = 50%
Right maxillary sinus width (mm)				
16.1 (highest sensitivity)	100.0	4.4	51.1	51.1
26.2 (optimum cutoff value)	34.9	91.1	63.6	79.7
29.5 (highest specificity)	18.6	100.0	60.2	100.0
Right maxillary sinus length (mm)				
30.5 (highest sensitivity)	100.0	6.7	52.3	51.7
39.5 (optimum cutoff value)	51.2	82.2	67.1	74.2
45.5 (highest specificity)	4.7	100.0	53.4	100.0
Right maxillary sinus height (mm)				
30.0 (highest sensitivity)	100.0	8.9	53.4	52.3
42.5 (optimum cutoff value)	53.5	75.6	64.8	68.7
51.9 (highest specificity)	2.3	100.0	52.3	100.0
Left maxillary sinus width (mm)				
16.2 (highest sensitivity)	100.0	6.7	52.3	51.7
24.5 (optimum cutoff value)	62.8	62.2	62.5	62.4
32.1 (highest specificity)	11.6	100.0	56.8	100.0
Left maxillary sinus length (mm)				
31.2 (highest sensitivity)	100.0	11.1	54.5	52.9
38.3 (optimum cutoff value)	67.4	64.4	65.9	65.4
44.6 (highest specificity)	7.0	100.0	54.6	100.0
Left maxillary sinus height (mm)				
38.2 (highest sensitivity)	100.0	33.3	65.9	60.0
42.0 (optimum cutoff value)	76.7	68.9	72.7	71.2
48.1 (highest specificity)	32.6	100.0	67.1	100.0
Total distance across both sinuses (mm)				
65.4 (highest sensitivity)	100.0	6.7	52.3	51.7
83.6 (optimum cutoff value)	51.2	82.2	67.1	74.2
89.2 (highest specificity)	20.9	100.0	61.3	100.0

of life, and the reconstructed CT images could provide adequate measurements for maxillary sinuses that cannot be approached by other means.

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