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Original Article

Measurements of maxillary sinus volume and dimensions by computed tomography scan for gender determination

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ABSTRACT

Introduction: Humans are sexually dimorphic. Identification of remnants of skeletal and decomposing parts of human is one of the most difficult skills in forensic medicine. Forensic anthropologists often receive an incomplete skeleton, which are recovered fragmented but some bones are often recovered intact e.g. maxilla. However, typical identification methods may be inconclusive, especially when certain extreme post-mortem changes have developed.

The aim of this study is to compare the size and volume of the maxillary sinus between males and females by CT Scan for gender determination.

Methods: 102 cases (61 males & 41 females) were studied from Gwalior region. The sinus measurements were taken from series of CT Head images on DICOM viewing software using inbuilt electronic caliper. Independent sample t-test & discriminant function analysis were done using Graph pad prism & Word Excel Sheet windows 2007 version.

Results: The dimensions & volume of the maxillary sinus of male was found to be larger than those of female & this difference was statistically significant ($p < 0.05$) for sinus AP & Volume. 65.16% of males & 68.9% of females were sexed correctly & the overall percentage for sexing maxillary sinuses correctly was 67.03% & sinus AP was the best discriminant parameter with an overall accuracy of 69.81%.

Discussion: We can conclude that CT measurements of maxillary sinus dimensions & volume may be useful for identification of gender in forensic anthropology to some extent when other methods are inconclusive.

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1. Introduction

A primary component of any skeletal analysis is determination of age and sex. Identification of the individual from skeletal remnants and decomposing parts of human is one of the most difficult skills in forensic medicine in spite of rapid progress in various diagnostic methods. Gender and age estimation is considered as an important problem in the identification of unknown skull.[1] Gender determination is an important step in identification in forensic medicine. In most of cases forensic anthropologists receive an incomplete skeleton therefore it is important for alternate areas of the skeleton to be researched for sex estimation. Because most bones that are conventionally used for sex determination (skull, pelvis and long bones etc.) are often recovered either in a fragmented or incomplete state, it has become necessary to use bones that are often recovered intact e.g. the maxilla. It has been reported that maxillary sinus remains intact although the skull and other bones may be badly disfigured in victims who are incinerated and therefore maxillary air sinus can be used for identification.

Next to the pelvis, the skull is the most easily sexed portion of the skeleton, but the determination of sex from the skull is not reliable until after puberty.[2] Skull requires the most frequent sexing in medico legal cases. It appears to be the main reliable bone exhibiting sexually dimorphic traits, because skull has a high resistance to adverse environmental conditions over time, resulting in the greater stability of dimorphic features as compared to other skeletal bony pieces.[3]

Traditionally, radiology has been limited in its applications to forensic medicine in the field of identification. Visual inspection, anatomic measurement and precise measurement of bone dimensions often exceed radiologic contribution, particularly where identification of skeletal remains is required. The most helpful area of the body for comparison radiography is the cranium.[4] Measurements of the maxillary sinuses in computerized tomography (CT) scans can be used for determination of age and gender when other methods are inconclusive.[5,6] Maxillary sinus dimensions measurements are valuable in studying sexual dimorphism. They tend to stabilize after second decade of life and the radiographic images could provide adequate measurements for maxillary sinuses that cannot be approached by other means. Hence, morphometric analysis of maxillary sinuses can assist in gender determination.[7] It has been reported that computerized tomography is a suitable imaging method in the identification of unknown human remains and presents a lot of advantages as compared with conventional radiographs.[8] CT scans are an excellent imaging modality used to evaluate the sino-nasal cavities as they provide three-dimensional information and an accurate assessment of the paranasal air sinuses.

The purpose of the present study was to determine and compare the size and volume of the maxillary sinus, between the left and right, and between the males and females of Gwalior region by CT Scan. This work has importance in identifying the sex of a person in the forensic anthropology and also for criminal investigations.

2. Materials and methods

2.1. Selection criteria

This study was an Observational study in which CT images of 102 adult individuals of Gwalior region, in the age group of 20–60 years of either sex were chosen with 61 males and 41 females, who attended the Vidya Health Imaging, Gwalior for head and paranasal sinuses CT Scan. The cases were collected from January 2012 to January 2013 who had complaints of headache or with suspicion of sinusitis but without pathological findings in maxillary sinuses and no history of trauma and in whom CT Scan was normal as diagnosed by the Radiologists.

2.2. Exclusion criteria

Any Maxillary Sinus radiography with obvious pathology or Trauma, facial asymmetry or septal deviation or who had previously undergone surgical procedures or with cleft palate or ectopic and supernumerary teeth were excluded from the study.

2.3. The materials

All the patients were examined on *Siemens Emotion 16 (16 slice) Multi Detector Spiral Computed Tomography Scanner*. All measurements of maxillary air sinus dimensions (AP, width and height) were done directly on computer on DICOM images using *Electronic Caliper* inbuilt in the DICOM viewer software. The maxillary sinus volumes were calculated manually by using a proven mathematical formula.

2.4. Methodology for measurement of maxillary sinus dimensions

The greatest measurement was taken after going through different slices in coronal and sagittal sections. Parameters measured on right and left maxillary air sinus are as follows:

1 The antero-posterior dimension was measured on Sagittal reconstructed image and was defined as the longest distance antero-posteriorly from the most anterior point to the most posterior point (Fig. 1).
2 The height of sinus was measured on coronal reconstructed image and was defined as the longest distance from the lowest point of the sinus floor to the highest point of the sinus roof (Fig. 2).
3 The transverse distance/width was measured on coronal reconstructed image and was defined as the longest distance perpendicular from the medial wall of the sinus to the outermost point of lateral wall of the lateral process of the maxillary sinus (Fig. 3).
4 Maxillary air sinus volume of each side were calculated manually using the formula: (height × width × AP diameter × 0.52) proven mathematical formula, in which maximum dimensions of maxillary air sinuses were taken which gives the approximate volume of each sinus.

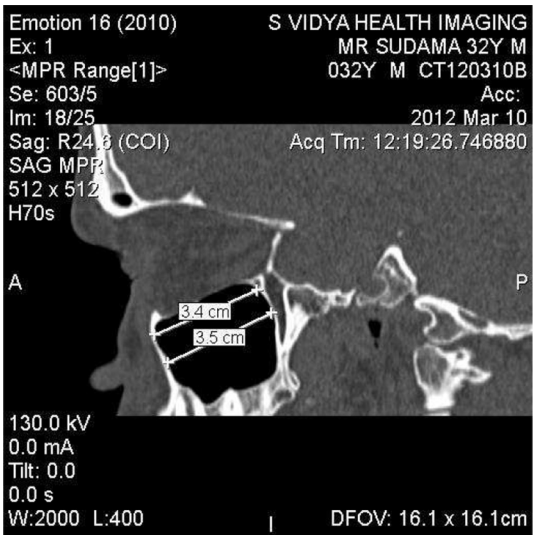

Fig. 1 – Sagittal view showing how to compare and take maximum AP diameter.

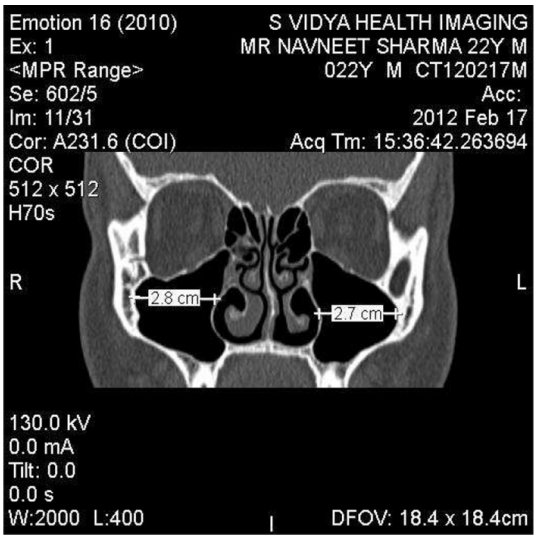

Fig. 3 – Coronal views showing maximum right and left transverse diameter (width).

2.5. *Statistical evaluation*

The statistical analysis was performed by using Graph Pad Prism and Word Excel sheet Windows 2007 version. Mean, SD and *t* value to assess the level of the parameters in males and females were determined by Independent sample *t*-test and *F*-value were calculated by *F*-test to compare variances. Differences with $p < 0.05$ were considered significant. Discriminant function analysis was also done to determine percentage of correctly sexed maxillary sinus.

3. Results

The dimensions and volume of the maxillary sinuses of both sides were significantly greater in males compared to females.

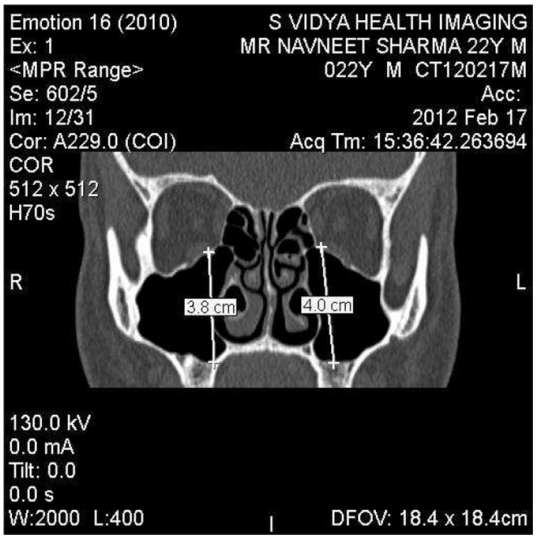

Fig. 2 – Coronal views showing maximum right and left height of maxillary sinuses.

The *p* value of right sinus AP (0.0089) and volume (0.0387) and left sided AP (0.0331) and volume (0.047) of maxillary sinuses were considered statistically significant (Table 1). Also it was noted that the dimensions of left side maxillary sinuses for both male and female were found to be insignificantly ($p > 0.05$) larger than right side, which shows that in an individual the right and left side of sinus are nearly of equal size.

The average of each sinus dimension were calculated for male and female and then analyzed statistically. The sizes of all dimensions of the maxillary sinus (AP, height, width and volume) in males were found larger than those of females, though only sinus AP and volume showed significant differences ($p < 0.05$). Whereas *F*-test to compare variances was significant for sinus width and volume (Table 2).

By discriminant function analysis it was found that maxillary sinus AP diameter was the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy of 69.81%. The final result of the analysis shows that 65.16% of males and 68.9% of females were sexed correctly and the overall percentage for sexing maxillary sinuses correctly was 67.03%.

4. Discussion

In the present study, significant differences were found in most maxillary sinus measurements between males and females, mainly because the males exhibited higher and wider maxillary sinuses than females. For this two explanations can be offered. First, according to Enlow,[9] males need to have correspondingly bigger lungs to support their relatively more massive muscles and body organs. Second, the males need a larger airway, which begins with the nose and nasopharynx. In other words, physiological changes in nasal cavity size and shape occur as a direct result of respiration-related needs, such as warming and humidifying inhaled air. As the maxillary sinus occupies the remaining space within the nasomaxillary complex, it also increases in size.

Table 1 – Descriptive statistics of right and left side of maxillary sinus in males and females.

Parameters	Males ($n = 61$)		Females ($n = 41$)		P value	t value
	Mean	SD	Mean	SD		
Right AP (in mm)	34.89	3.256	33.20	2.943	0.0089**	2.670
Right height (in mm)	36.07	6.123	34.51	4.032	0.2487	1.160
Right width (in mm)	24.33	4.265	23.39	3.801	0.2585	1.136
Right volume (in cm^3)	15.84	5.857	13.65	3.926	0.0387*	2.095
Left AP (in mm)	35.03	3.559	33.59	2.915	0.0331*	2.161
Left height (in mm)	36.72	5.651	34.63	4.414	0.1555	1.431
Left width (in mm)	24.93	4.840	23.88	3.894	0.2463	1.166
Left volume (in cm^3)	16.45	6.143	14.18	4.672	0.0470*	2.011

*Significant at $p < 0.05$; **significant at $p < 0.01$; AP = antero-posterior.

The results obtained were comparable to and consistent with the previous studies; males have larger maxillary sinus when compared with females.

4.1. *Study results of maxillary sinus AP by different authors*

In this study the mean sinus AP for male was 34.89 ± 3.26 mm for the right side and 35.03 ± 3.56 mm for the left side and average was 34.96 ± 3.4 mm which was significantly ($p < 0.05$) greater than that recorded for female i.e. 33.2 ± 2.94 mm for right side and 33.59 ± 2.92 mm for left side and average was 33.39 ± 2.929 mm. Non significant side difference was seen for both genders.

Jehan et al[10] studied 191 subjects (106 males and 85 females) and estimated the average sinus AP was 3.643 ± 0.426 cm for male and 3.493 ± 0.414 cm for female. The average sinus AP estimated by Baweja et al[11] was 34.1 ± 5.1 mm for male and 33 ± 5.6 mm for female which are close to our results because of same region study.

The mean value for maximum length of maxillary sinus by Uthman et al[6] 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 right side and 37±4 mm for left side and with statistically significant difference ($p < 0.05$). Statistically non-significant side difference was seen for both genders.

Teke et al[2] estimated the mean value for the maximum depth of maxillary sinus for male group was 42.58 ± 7.9 mm for the right side and 43.7 ± 7.78 mm for the left side which was significantly greater than that recorded for female group which was 37.8 ± 5.69 mm for right side and 37.6±6 mm for left side and with statistically significant difference ($p < 0.05$). These values are somewhat higher

Table 2 – Descriptive statistics of maxillary sinus in males and females.

Statistics	Sinus AP diameter		Sinus height		Sinus width		Sinus volume	
	Male	Female	Male	Female	Male	Female	Male	Female
N	61	41	61	41	61	41	61	41
Mean ± SD	34.96 ± 3.4	33.39 ± 2.929	36.4 ± 5.887	34.57 ± 4.223	24.63 ± 4.6	23.6 ± 3.85	16.15 ± 5.99	13.92 ± 4.299
SEM	0.4078	0.4325	0.7456	0.6581	0.5621	0.5812	0.7466	0.6506
P value (Two-tailed)	0.0117		0.1830		0.2354		0.0371	
P value summary	*		Ns		Ns		*	
Difference between means	1.569 ± 0.611		1.419 ± 0.1058		0.9970 ± 0.08352		2.231 ± 1.056	
Are means signif. different? ($P < 0.05$)	Yes		No		No		Yes	
t, df	$t = 2.568$ df = 100		$t = 1.341$ df = 100		$t = 1.194$ df = 100		$t = 2.113$ df = 100	
95% confidence interval	0.03549–0.2783		−0.068340.3521		−0.06623 to 0.2656		0.1332–4.329	
R squared	0.06184		0.01766		0.01405		0.04273	
Average (M + F) Mean ± SD	34.18 ± 3.17		35.48 ± 5.06		24.13 ± 4.2		15.031 ± 5.15	
F-test to compare variances								
F, DFn, Dfd	1.323, 60, 40		1.910, 60, 40		1.392, 60, 40		1.959, 60, 40	
P value	0.1750		0.0159		0.1346		0.0129	
P value summary	Ns		*		Ns		*	
Are variances significantly different?	No		Yes		No		Yes	

*Significant at $p < 0.05$; Ns – not significant.

than our results, may be due to ethnic and racial difference and sample size.

4.2. Study results of maxillary sinus height by different authors

In our study the mean sinus Height for male was 36.07 ± 6.12 mm and 36.72 ± 5.65 mm for the right and left side respectively and average 36.4 ± 5.887 mm which was not significantly ($p > 0.05$) greater than that of female with 34.51 ± 4.032 mm for right side and 34.63 ± 4.414 mm for left side and average 34.57 ± 4.223 mm. The average sinus AP reported by Baweja et al[11] was 37.3 ± 8.0 mm for male and 36.9 ± 7.4 mm for female which are close to our results because of same region study.

Uthman et al[6] estimated the mean value for máximum 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 right side and 40 ± 4.8 mm for left side. A statistically significant difference was seen for only male group.

Teke et al[2] reported the mean value for the maximum height of maxillary sinus for male group was 47.6 ± 6.4 mm for the right side and 47.2 ± 6.5 mm for the left side which was greater than that recorded for female group 45.1 ± 4.6 mm for right side and 43.6 ± 4.4 mm for left side and with statistically significant difference ($p < 0.05$).

4.3. Study results of maxillary sinus width by different authors

In our study the mean sinus width for male was 24.33 ± 4.26 mm and 24.93 ± 4.84 mm for the right and left side respectively and average being 24.63 ± 4.6 mm which was not significantly ($p > 0.05$) greater than that of female with 23.39 ± 3.8 mm for right side and 23.88 ± 3.89 mm for left side and average 23.6 ± 3.85 mm. The average sinus width reported by Jehan et al[10] was 2.404 ± 0.471 cm for male and 2.39 ± 0.438 cm for female. The average sinus width estimated by Baweja et al[11] was 21.8 ± 3.4 mm for male and 21.6 ± 3.7 mm for female which was lesser than our results.

Uthman et al[6] reported the mean value for máximum 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 mm and 23±4 mm respectively ($p < 0.05$). Right and left side difference was significant for only male group.

Teke et al[2] estimated the mean value for the maximum width of maxillary sinus for male group was 27.19 ± 5.46 mm for the right side and 26.89 ± 5.52 mm for the left side. Female group had statistically significant lower values for both right and left sides 24.44 ± 3.61 mm and 24.27 ± 3.98 mm respectively ($p < 0.05$).

4.4. Study results of sinus volume by different authors

In this study the mean volume in male sinus was 15.84 ± 5.86 cm^3 for right side and 16.45 ± 6.143 cm^3 for left side and average was 16.147 ± 5.99 cm^3. The mean Volume in Female sinus was 13.65 ± 3.93 cm^3 of right side and 14.18 ± 4.672 cm^3 of left side and average was 13.92 ± 4.299 cm^3. The volume of the maxillary sinuses of both sides was significantly greater in males compared to female. The total Average (M + F) mean volume of this study is 15.031 cm^3 (SD = 5.15) and it ranged from 4.731 cm^3 to 25.331 cm^3.

The range of maxillary sinus volume as described by Ariji et al[12] is 4.56 cm^3 to 35.21 cm^3 which is near the range of this study and are comparable. The total Average (M + F) mean volume by Chang-Hee et al[13] was 21.9 cm^3 which was higher than this study and this may be due to small sample size or due to anatomical variations and racial factors.

Some authors have reported differences in the volumes of maxillary sinuses between males and females.[14–16] Sahlstrand-Johnson et al[14] studied dimensions of 120 maxillary and frontal sinuses from head CT images. The mean value of the maxillary sinus volume was 15.7 + 5.3 cm^3 and significantly larger in males than in females which was same as our study. There was no statistically significant correlation between the volume of maxillary sinuses with age or side.

Emirzeoglu et al[16] examined coronal CT scan images of 77 Turkish patients (38 female and 39 male) aged between 18 and 72 years. They reported significant difference of maxillary sinus volume between males and females (Males: 19.8 ± 6.3 cm^3; Females: 16 ± 5 cm^3). This difference in maxillary sinus volume may account for the difference in the shape and morphology of the male and female face particularly around the midfacial region.

According to Karakas[17] study using CT scans of 91 Turkish individuals (47 men and 44 women) from 5 to 55 years, male patients have larger sinuses than female patients. Significant difference in the average maxillary sinus volume was noted in males' maxillary sinus volumes with 14.74 ± 5.79 cm^3 on the right and 14.55 ± 4.72 cm^3 on the left whereas in females' sinus volumes were 14.29 ± 3.42 cm^3 on the right and 13.78 ± 3.41 cm^3 on the left.

In Masri et al[18] study, maxillary sinus depth (AP) height and volume were found to be larger in males than females in 21–30 years age category ($p < 0.01$); Only height and width showed significant differences in Kawarai et al[15] study who revealed that male tended to have larger sinuses at these ages.

Ekizoglu et al[19] studied 140 subjects (70 women and 70 men) in the age group of 18–63 years. He also reported the size of the maxillary sinus is significantly small in female gender ($P < 0.001$). With discrimination analysis he detected the accuracy rate to be 80% for women and 74.3% for men with an overall rate of 77.15%.

Uthman et al[6] also conducted a study to check the accuracy and reliability of maxillary sinus dimensions measurement in gender classification through the use of reconstructed helical CT images 88 patients (43 men and 45 women, age range = 20–49 years). He found that maxillary sinus height was the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy of 71.6%, 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%. These are close to our results but somewhat higher, as in our study 65.16% of males and 68.9% of females were sexed correctly and the overall percentage for sexing maxillary sinuses correctly was 67.03% and sinus AP

was the best discriminant parameter with an overall accuracy of 69.81%.

Amusa et al[20] conducted a study on 24 dried skulls of Nigerians from which the temporal bones had earlier been dissected were studied. Endoscopy (Telescope) was utilized to visualize the paranasal sinuses and their degree of pneumatization. The height, width, depth and volume of each of the sinuses were determined. In all the paranasal sinuses, the right side was found to be larger than the left except for the maxillary sinus where the left side was found to be larger. In our study also the left side maxillary sinus dimensions were found larger than right but not significantly.

Fernandes et al[21] examined CT scans of 53 dried skulls of Zulu and Europeans, reported no sexual significant difference for the maxillary sinus width which was true in our study as well. On the other hand, maxillary sinus depth, height and volume showed significant differences between the sexes. Ethnic and gender variations were established. The discriminant analysis shows 90% ethnic prediction, while gender prediction was ultimately 79%, which was higher than our results. Slight differences between our results and those of Fernandes may be attributed to different geographical populations and differences in sample size.

Amin and Hassan[22] concluded that MDCT measurements of cephalo-caudal and size of the left maxillary sinuses are useful feature in gender determination in Egyptians by assessing in 96 Egyptians (48 males and 48 females, aged 20–70 years). Two variables showed significant differences: Cephalo-caudal and size of the left maxillary sinus. The study concluded that the correct predictive accuracy was 70.8% in males and 62.5% in females, which is nearly similar to our results.

Kim[23] studied 33 hemi sectioned Korean CT images. All dimensions and volume of the sinus were larger in males than in females. The maximum AP length of sinus was 39.3 + 4.2 mm (male − 40.7 mm, female − 37.4 mm) its maximum height was 37.1 + 5.6 mm and max width was 32.6 + 65 mm the average volume of the sinuses was 15.1 + 6.2 ml.

Vidya et al[24] study says that the volume of the maxillary sinuses of both sides was significantly greater in males compared to female skulls, which is same as our study. The p value of left width with and right-sided volume of maxillary sinuses 0.015 and 0.021 respectively were considered statistically significant.

Butaric et al[25] reported that the mean values for the maxillary sinus ranged from 18.86 cm^3 for the Peruvian sample and 36.15 cm^3 for the Australian sample.

In this study, it was found that the most important and the strongest correlated variable with the volume was the width ($r = 0.915$) of maxillary sinus and Height of sinus is the second ($r = 0.835$). Volume was least correlated with the AP diameter ($r = 0.785$). Some studies found that in edentulous patients, the maxillary sinus may expand farther in height and continue to extend into the alveolar bone,[1] this agree with this study also.

Jasim[1] reported that if both genders considered together, the correlations with the width, depth (AP) and height in dentate were ($r = 0.86$,0.52,0.64) respectively, while in edentulous group were ($r = 0.88$,0.56, 0.86) respectively. From these results one can see that the strongest correlation was with the width ($r = 0.88$, 0.86) and height ($r = 0.86$) in edentulous group, while the weakest correlation was with the depth in dentate group ($r = 0.52$).

Thus, the variations in some of the results of maxillary air sinus dimensions and volume in these study are probably due to combination of many factors like different Ethnic and Racial groups with difference in body stature, skeletal size, height and physique of an individual; sample size, Genetic and Environmental factors; Anatomical variations of sinus; difference in Osteoclastic and Osteoblastic activity and pneumatization process of sinus in different age and sex groups or past infections.

5. Conclusion

It was concluded that the dimensions and volume of the maxillary sinuses of male was found to be larger than those of female and this difference was statistically significant for AP diameter ($p < 0.0117$) and Volume ($p < 0.0371$) of sinus. By discriminant function analysis it was found that maxillary sinus AP diameter was the best discriminant parameter that could be used to study sexual dimorphism with an overall accuracy of 69.81%. The final result of the analysis shows that 65.16% of males and 68.9% of females were sexed correctly and the overall percentage for sexing maxillary sinuses correctly was 67.03%. The results obtained were comparable to the previous studies. The Craniometric points (maxillary sinus dimensions) can be precisely located and measurements can be more accurately performed using Computerized Tomography scan than on conventional radiographs and therefore CT scan of maxillary air sinus can be used as an aid in forensic anthropology and also for criminal investigations for gender determination to some extent when other methods are inconclusive.

Conflicts of interest

All authors have none to declare.

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